WAITS RIVER WATERSHED

PHASE 1 and 2
STREAM GEOMORPHIC ASSESSMENT
2007-2009

January 12, 2010

Prepared by:
Daniel Ruddell, Elisabeth McLane,
and Courtney Haynes,
Staff Scientists, and
Ben Machin, Principal
Redstart Consulting

Prepared for:
Bradford and Corinth Conservation Commissions,
Waits River Watershed Council, and
Vermont Agency of Natural Resources/
Department of Environmental Conservation
River Management Program

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1.0 EXECUTIVE SUMMARY

During 2007 and 2008, the Bradford and Corinth Conservation Commissions and the Waits River Watershed Council (the "Project Partners") engaged Redstart Forestry and Consulting to conduct fluvial geomorphic assessments within the Waits River watershed in Orange (and a small portion of Caledonia) County, VT, largely in response to concerns expressed by watershed resident about erosion and poor habitat quality. Fluvial (= flow-related) geomorphology (geo = earth, morphology = shape) helps understand the physical river forms and processes that explain many of the current conditions observed in the streams of the watershed. 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 in the last 200 years many streams in Vermont, including the Waits and some of its tributaries, have been confined to deeper, straighter channels and lost access to historic floodplains. Stream power (including flood intensity and frequency) has increased, resulting in elevated levels of erosion and lack of floodplain storage for the soil and nutrients being released. This has often resulted in elevated levels of physical damage and degraded water quality.

The assessments reported here were conducted using protocols developed by the Vermont River Management Program, which guide assessments through a series of phases that integrate information from an overarching watershed context down to project site-specific scales, with each previous stage informing the successors. Phase 1 assessment (using data from topographic and aerial maps, other historic and current sources, and limited "windshield survey" field data collection) included:

- Preliminary assessments on 470 reaches (reaches are portions of the stream with similar characteristics in terms of channel geometry, valley and floodplain settings) throughout the watershed, including baseline information needed to understand the movement of water and sediment through the stream network
- More in-depth assessment on 64 of these reaches, primarily on the Waits mainstem and the major tributaries, identifying expected reference conditions and indications of potential impacts to those conditions (e.g., flow modifications and channel straightening; floodplain restriction and changes in channel location; heightened erosion and mass failures; ice and debris jams)

Informed by the Phase 1 results and interests of the Project Partners, Phase 2 work (entailing field assessments in and along the streams) was conducted in full on 19 reaches of the Waits mainstem, Tabor Branch, South Branch, Meadow Brook, and Cookville Brook in Bradford and Corinth. Limited data was collected for the three most downstream reaches of the Waits River, which were precluded from full assessments due to the influences of wetlands and dams (in accordance with protocols). Phase 2 assessments documented the current geomorphic condition of these streams, identified departures from reference conditions, and noted a current stage of channel evolution and likely processes these streams will undergo in attempting to re-establish long-term stability (see esp. sec. 5.1.4, *Sediment regime departure, constraints to sediment transport, and attenuation*).

Assessment results are summarized in this report, and analysis and preliminary project identification is presented for reaches included in the Phase 2 assessments. The analysis informs a process designed to identify and catalogue technically feasible projects that can help reduce flood and erosion hazards along stream corridors, improve water quality and aquatic habitat, and enhance recreational opportunities.

Significant historic channel straightening (primarily for mill use and road construction/ maintenance), partial restriction of access to historic floodplains, and current elevated levels of stream power in the Waits River watershed led to two factors being given the greatest consideration when prioritizing projects:

1) Protection of, and unrestricted access to, existing floodplains as a primary means of:
    a) attenuating flood flows; and
    b) retaining fine sediments within the watershed while permitting coarser sediments to move through the watershed and rebuild a more even distribution of bed features, particularly in downstream reaches of the Waits mainstem
2) Accommodation of planform adjustments, permitting both:
    a) Rapid lateral migrations and room for mass failures and channel avulsions; and
    b) Full meander development

The particular importance of current elevated levels of stream power in the watershed means that the design and success of downstream restoration projects will be affected by discharge and sediment loads higher in the watershed. Project prioritization thus emphasizes upstream restoration of equilibrium conditions whenever feasible. The primary exception to an emphasis on upstream projects is in recommendations for ensuring that the downstream broad floodplain near the Appleton farm (by the South Main St. bridge in Bradford) is adequately protected from development encroachments. Massive embankments beneath the Interstate-91 bridge have cut off extensive portions of the former floodplain and limit access of the river to Bradford village in flood flows, likely protecting the village but also effectively turning the fields of the Appleton farm and surrounding area into a retention pond in a major flood. Some of this area appears to fall outside of the current Special Flood Hazard Area as delineated by the Federal Emergency Management Administration.

Widespread and intermittent distribution of the important stream assets needed for protection and restoration work makes parcel by parcel corridor protection efforts challenging, and municipal bodies can achieve many of the same goals more efficiently and effectively. The top priority recommendation in this report is thus for municipalities within the watershed to consider incorporation of belt-width corridors or similar measures into town-wide planning efforts. Tools to develop these corridors have been developed over the course of this assessment, but it should also be noted that 100 ft setbacks would adequately accommodate stream processes on the large majority of the smaller streams in the watershed.

Based on the results of the assessments, the following "short list" of projects, in recommended order of importance, was prioritized:

- Bradford and Corinth: Incorporation of fluvial erosion hazard (FEH) zones or other belt-width corridors into town planning processes.
- Waits River reach M04B, Appleton Farm: Review current Town of Bradford floodplain ordinance, zoning regulations and FEMA mapping to ensure that adequate protection and enforcement mechanisms are in place to ensure critical functions of this area in protecting the health and safety of the citizens of Bradford , the Waits River, and the Connecticut River into which it flows
- Meadow Brook reach T1.09, along Chelsea Rd. from downstream of Abe Jacobs Rd. to downstream of Eagle Hollow Rd.: buffer plantings and corridor protection, investigate channel management easements
- Cookville Brook reach T1.06S1.01, Devins Farm downstream of farm outbuildings: corridor protection, investigate channel management easements
- South Branch reach T1.05, South Corinth in vicinity of store: investigate channel management easements or other corridor protection, buffer plantings
- South Branch T1.01, vicinity of swimming hole off Chelsea Rd.: ensure public access and protection of private property at swimming hole, corridor protection, buffer augmentation

Highlights of results from the 2007-2008 Phase 1 and 2 geomorphic assessments in the Waits River watershed and analysis contributing to these recommendations indicate that:

- Streams included in phase 2 assessments, primarily located in the lower elevations of the watershed, are undergoing adjustments largely due to historic changes in the movement of water and sediment through the stream network, especially widespread land clearing and extensive damming and flow regulation for mill use
    - 23 of 28 segments on 19 reaches were noted in current Fair condition, indicating major adjustments ("reaches" are divided into smaller "segments" during field assessments if significant differences are observed in physical conditions or stream processes)
    - 4 segments were noted in Good condition, denoting minor adjustments: T1.08-0, T1.09A and T1.09C, all on Meadow Brook in Corinth from ~ 0.4 mi. downstream of Abe Jacobs Rd. to ~ x ft. downstream of Eagle Hollow Rd.; and Tabor Branch segment T2.02B, a section of bedrock-controlled stream behind the Historical Society on Village Rd in East Corinth
    - One segment rated Poor, indicating major to extreme adjustments: M05A on the Waits mainstem south of Bradford Center (and downstream to the major ice jam area, next to the first place west of Bradford where the Waits River is directly adjacent to Rte. 25)
- Ledge grade controls that are widely dispersed through the watershed have limited downcutting and loss of floodplain access to some degree in much of the

Phase 2 assessment area, but historic incision (downcutting) was noted in 21 of 28 segments (18 of 19 reaches)

- Straightening, which increases slope and stream power (think of a driveway going straight up a slope rather than having switchbacks) was noted on 60% of the segments assessed in Phase 2
- Having had historic floodplain access limited rather than lost, 24 of the 28 segments are now in a stage of channel evolution that primarily entails widening and planform change (especially lateral migration) as these streams try to move toward equilibrium conditions
    - ➢ 4 segments were noted in a stable or stabilizing stage of evolution following adjustments to historic or limited incision: T1.05B on the South Branch upstream of the snowmobile bridge in South Corinth (across from the store); T1.08 -0 and T1.09A on Meadow Brook; and T2.02B on the Tabor Branch (all three noted in previous item above, in Good condition)

Topography and geology strongly predispose the streams of the Waits watershed to flash flooding, particularly on smaller streams in the upstream portions of the watershed. Narrow valleys are commonly interspersed with broader valleys throughout the watershed, contributing to a high incidence of ice and debris jams and "pulse" flows that tend to move sediments intermittently, largely in flood events. Sediment discharges appear to be moving through the stream network following flash flood events but may be disrupted from setting up stable features, such as riffles and pools, by ice scouring and the heightened stream power moving through straightened channels in subsequent moderate to high flow events (especially in narrower valleys at lower elevations in the watershed). Coarse sediments that are important to setting up stable stream features (which help diffuse stream power) have been removed from stream beds in portions of the Waits mainstem (dredging to control ice jams in M05A, windrowing of sediments upstream of the Village Rd. bridge in M09A) and planebed bedforms dominate the Phase 2 assessed reaches along the Waits mainstem. These planebeds contribute to elevated stream power impacts and cycling through widening and scouring stages of channel evolution, rather than continued evolution through development of stable depositional features toward eventual narrowing of the channel and establishment of new meander patterns, and eventual stabilization.

- Intermittent patterns of sediment movement will require time (may be decades) to rebuild a more stable distribution of these features throughout the stream network; removal of sediments from the channel can significantly delay re-establishment of equilibrium
- Flash floods can quickly overtop banks on small streams and trigger erosion and mass failures along narrow valley walls, but in localized storms these flows are contained within the historically restricted floodplains of larger streams at lower elevations, thus increasing pressure on banks and valley walls in constricted areas

These factors place a premium on attenuation of high flows and sediment discharges in upstream reaches, and increase the importance of:

a) protecting and maintaining floodplain access even on small streams high in the watershed;

b) limiting development and encroachments within stream corridors and narrow valleys;

c) establishing and maintaining woody buffers in riparian corridors and

d) managing stormwater inputs to minimize direct discharges to streams.

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 with the reach descriptions in Section 6.1. Primary analysis summaries are found in the section 5.1.4 Existing Sediment Regime Summary and Section 5.2 Sensitivity Analysis.

2.0 INTRODUCTION

Beginning in early 2004, public input was sought for basin planning for water quality management in the Waits River Watershed, leading soon thereafter to formation of the Waits River Watershed Council[1]. Two Rivers-Ottauquechee Regional Commission hosted early public forums for that process, and from early stages of the process on riparian management and erosion were repeatedly noted as high priority issues for watershed residents. In 2005, the Bradford Conservation Commission, Corinth Conservation Commission, and Waits River Watershed Council identified issues of primary concern to residents and other interested parties in the Waits River watershed. The top water quality concerns as prioritized on 1/11/2005 (minutes of Waits River Watershed Council) were riparian corridors, including: stream bank erosion, lack of buffers (increasing water temperature and creating stream bank instabilities), invasive plants, impacts on fisheries, and a recreation trail along the Waits River. Additional concerns cited at the time included non point source pollution sources, lack of stream awareness, specific impairments, and forest and farm sustainability.

Over the course of evolving discussions, interest developed among participants to use fluvial geomorphic principles (discussed in brief in the next section of this report, Project Overview) to address erosion and poor habitat quality along the Waits River in particular. Fluvial geomorphology explains physical river processes and forms that occur in different landforms, geologic and climatic settings, and clarifies that stream sites should be viewed within their watershed landscapes and history of land and water use changes, rather than in isolation (VT-RMP Intro 2007). Changes to "hydrologic and sediment regimes" (i.e., the inputs and movement of water and sediment in the overall watershed) strongly influence the behavior of streams at any given point in time, and many of the heightened erosion and flood impacts being felt in Vermont today are related to such changes. These changes often unfold on a time-scale measured in decades, and many of the processes evident in the Waits watershed today are related to significant land and water use changes that occurred over the last 200 years.

The assessments reported here are based on protocols developed by the Vermont River Management Program (VT-RMP geoassesspro 2007), 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.

---

[1]The history of public involvement in the Waits River watershed planning process can be found at: http://www.vtwaterquality.org/planning/docs/pl_basin14.final_appendix.6-30-08.pdf

2.1 PROJECT OVERVIEW

In May, 2007 the Bradford and Corinth Conservation Commissions, in conjunction with the Waits River Watershed Council (henceforth the "Project Partners"), engaged Redstart Forestry and Consulting to conduct geomorphic assessments within the Waits River watershed. The Project Partners issued 2007 and 2008 requests for proposals for these assessments based on River Corridor Grant funding from the Vermont Department of Environmental Conservation, Agency of Natural Resources River Management Program (VT-RMP). These grants are a primary tool in helping communities employ a science-based approach to achieve VT-RMP's stated 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 (VT-RMP RCPG 2007; 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

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

The science of geomorphology looks at how water and sediment move within the landscape, both in space and over time. Extensive experience and observation indicate that a stream in equilibrium will erode its banks and change course to a relatively minor degree, even in flood situations. A stream can become "unbalanced", however (e.g., stream power may no longer be offset by channel roughness, room for the stream to diffuse power through meandering, and size and amount of sediment). A stream that is no longer in equilibrium will begin a series of adjustments that may include more significant changes in course, slope, depth, or width—or all four—until it becomes balanced again (VT-RMP Fact Sheet1 2003). In the Vermont protocols, Phase 1 geomorphic assessments help determine expected reference conditions for a stream (based on the physical dictates of the stream's hydrology and landscape setting). Phase 2 assessments help determine whether the stream has departed from those reference conditions, and if so, at what stage the stream is in the process of the adjustments required to regain equilibrium (VT-RMP Intro 2007). A more detailed discussion of stream departures from reference conditions and the stages of channel evolution in response to such departures can be found in section 5.1.4, *Sediment regime departure, constraints to sediment transport, and attenuation*.

In 2005, Two Rivers-Ottauquechee Regional Commission initiated Phase 1 geomorphic assessment of the Waits River watershed in Orange and (a small portion of) Caledonia Counties, VT as part of a Pre-Disaster Mitigation Planning grant from Vermont Emergency Management (phases of the geomorphic assessment process are further discussed in section 4, Methods, of this report). This stage of the Phase 1 assessment focused on preliminary data collection for the Waits River mainstem, the South Branch of the Waits, Meadow Brook - Corinth and Washington, Cookville Brook, Pike Hill Brook, the East Orange Branch, and the Tabor Branch (Fig. 1).

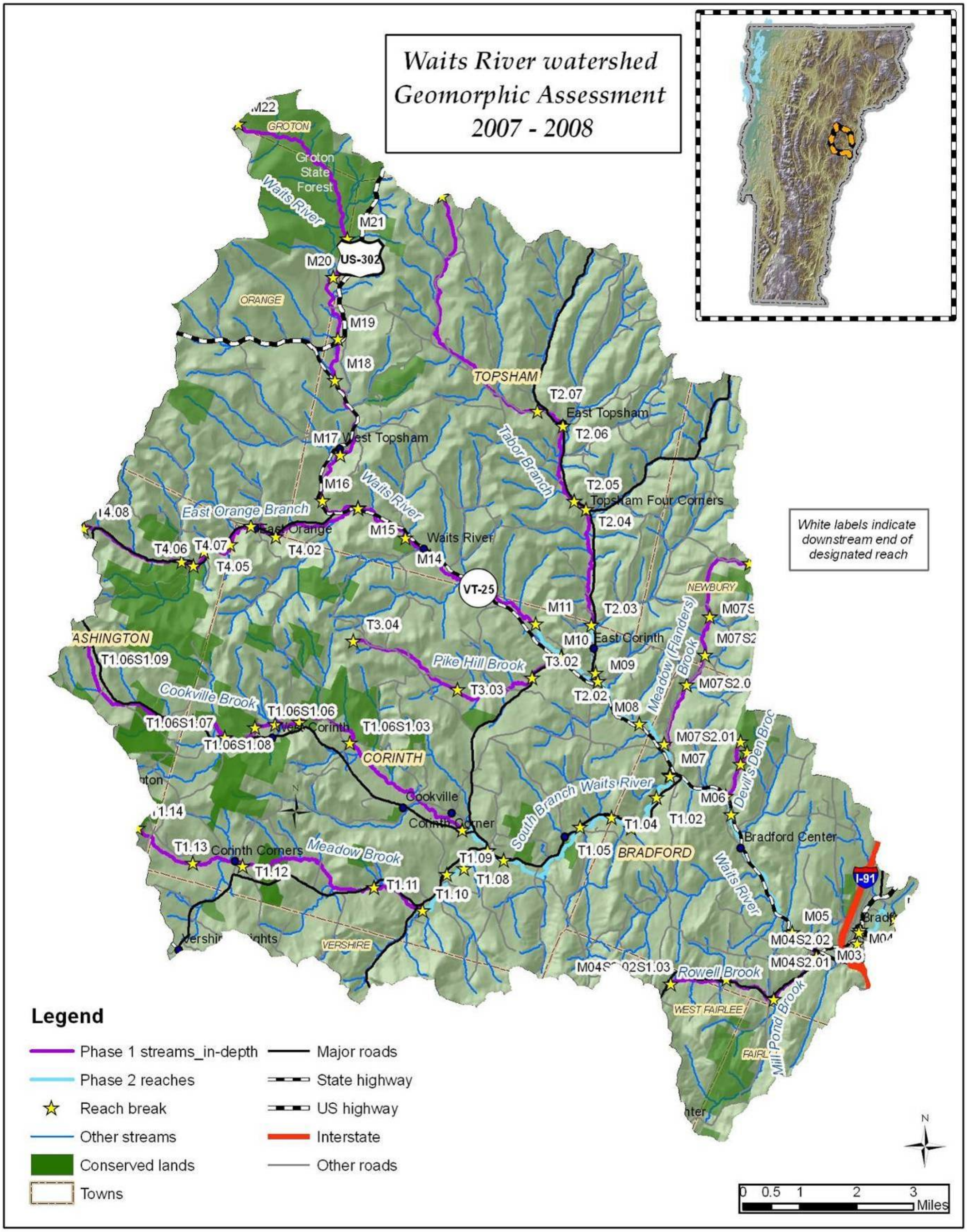


Figure 1.Overall watershed and focus reach map for 2007-2008 geomorphic assessment work in the Waits River watershed.

In May, 2007 the Bradford and Corinth Conservation Commissions, in conjunction with the Waits River Watershed Council (henceforth the "Project Partners"), engaged Redstart Forestry and Consulting to extend the Phase 1 and initiate Phase 2 geomorphic assessments within the watershed. Assessments during 2007 added further preliminary Phase 1 data for the entire watershed, and began collection of Phase 2 data for twelve reaches (reaches are portions of the stream with similar characteristics in terms of channel geometry, valley, and floodplain settings) on the Waits River mainstem and the South Branch. Partial Phase 2 assessments were conducted on the three downstream Waits mainstem reaches, which were excluded from full geomorphic assessments due to the influences of the Bradford hydroelectric dam.

In 2008 the Project Partners engaged Redstart to complete preliminary Phase 1 data collection for the entire watershed and assemble more in-depth data for the streams mentioned above, also adding Flanders Brook (aka Meadow Brook – Bradford and Newbury), Mill Pond Brook, Rowell Brook, and Devil's Den Brook to the list for more in-depth Phase 1 data collection. Phase 2 assessments in 2008 included fieldwork on ten reaches including portions of the Waits mainstem, Meadow Brook in Corinth and Washington, Cookville Brook, and the Tabor Branch.

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The Waits River Watershed lies within the larger Connecticut River drainage basin, and encompasses roughly 155.7 square miles draining an area from the highlands of Groton State Forest on the northwest edge of the watershed (elev. 3350 ft.) toward the confluence of the Waits with the Connecticut River at Bradford in the southeast portion of the drainage basin (elev. 385 ft). The area lies within the Northern Vermont Piedmont biophysical region (Thompson and Sorenson 2000).

3.1.2 Political jurisdictions

The study area includes virtually all of the town of Corinth, as well as large portions of the towns of Bradford and Topsham and smaller areas within Fairlee, West Fairlee, Vershire, Newbury, Orange, Washington, and Groton. All but the small portion of the watershed in Groton (Caledonia County) is located in Orange County, VT. Most of these towns are part of the 30-town planning area covered by Two Rivers-Ottauquechee Regional Commission; Washington and Orange are part of the Central Vermont Regional Planning Commission area, while Groton is covered by the Northeastern Vermont Development Association.

3.1.3 Land use history and current general characteristics

Bradford, Vermont, located at the mouth of the Waits River at its confluence with the Connecticut River, was first settled in 1765 and appears to have had mills located near the naturally occurring falls by the early 1800s (McKeen 1875). As was the case in much of Vermont, land clearing converted a great deal of the Waits River watershed to agricultural use by the mid-1800s. Stream power was utilized frequently to process lumber generated from clearing as well as processing other agricultural products such as grain, wool, linen, and even cotton that was processed at a brief-lived factory in Bradford (McKeen 1875). The bicentennial history of Corinth notes that, "Before the town was ever organized the first sawmill was built, to be followed by similar industries along every stream of any size that could be dammed for water power, until they totaled a baker's dozen in operation at one time or another" (Corinth 1964). By 1859, Bradford had two gristmills, three sawmills, a paper mill, and a whetstone factory taking advantage of the streams of the watershed (McKeen 1875). Phase 1 "windshield surveys" and Phase 2 fieldwork for this project found mill remains along the Waits River in West Topsham and Waits River villages as well. Gordon Kittredge, owner of an old mill site on the Tabor Branch in East Corinth that he hopes to restore for generating electricity, noted that at one time six different mills operated concurrently along the Tabor Branch between Topsham Four Corners and East Corinth, allocating the storage and release of water to run the mills in succession.

Farming appears to have been the predominant industry in the overall watershed during the 19th century (Corinth 1964, McKeen 1875). Land was quickly cleared and mined for its early post-clearing fertility, then abandoned as that fertility was depleted. "Corinth has lost steadily in its population for more than a century, from a high of 1970 people in 1840 to a low of 775 today. Soil depletion, lack of arable land to support a family, and the lure of gold…caused an exodus…." (Corinth 1964). By the year 2000 census, the population of Corinth had recovered to 1460, representative of the pattern of settlement, exodus, and resettlement throughout the watershed, which was accompanied by a transition back to forestland in much of the watershed.

In the early 21st century, much of the watershed has reverted to forest land (~75%), with agricultural use occupying a distant second place (~14%) and "urban" or developed land uses occupying ~4% of the watershed area (Fig. 2). "Urban" in this context refers to not only densely developed areas, but roads, suburbs and large-lot residential development as well. Surface waters occupy roughly 4% and wetlands an additional 3% of the overall watershed area. A more refined classification of these categories is indicated in Table 1.

Table 1. Land cover/land use data for the Waits River watershed derived from circa 2001 satellite imagery (UVM-SAL 2002). Shading indicates groupings portrayed by four-class system in Fig. 2.

BROADLEAF FOREST	35.1%
CONIFEROUS FOREST	10.4%
MIXED CONIFEROUS-BROADLEAF FOREST	28.9%
BRUSH/TRANSITIONAL	0.4%
ROW CROPS	4.7%
HAY/ROTATION/PERMANENT PASTURE	9.6%
OTHER AGRICULTURAL LAND	< 0.1%
RESIDENTIAL	0.9%
TRANSPORTATION, COMMUNICATION AND UTILITIES	3.0%
COMMERCIAL, INDUSTRIAL, BUILT-UP	< 0.1%
BARREN LAND	0.1%
WATER	4.1%
FORESTED WETLAND	2.1%
NON-FORESTED WETLAND	0.9%

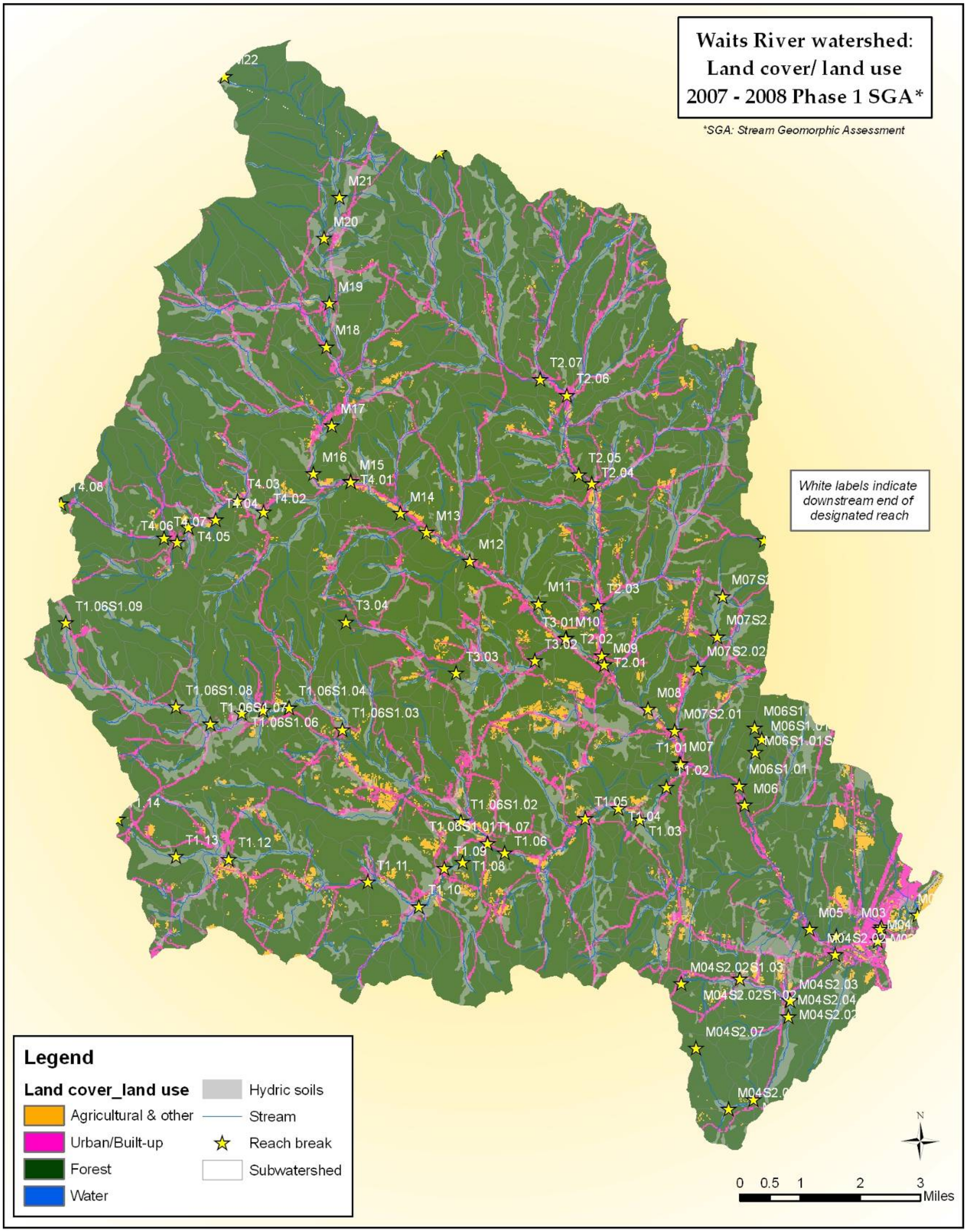


Figure 2. Land cover/ land use analysis based on satellite imagery (UVM-SAL 2002) indicates extensive forest cover in the Waits River drainage basin with agricultural and developed land uses heavily oriented to the riparian corridors. Overlaid soil maps indicate a moderate density of hydric soils; agricultural and "urban" land use conversions in these areas indicate potential impairment of wetland functions in moderating storage and release of water to streams.

Groton State Forest permanently conserves nearly 3% of the Waits River watershed in the headwaters of the mainstem of the Waits River, and this is joined by another 1.2% of the watershed conserved as part of the Groton and Washington State Forests, the Bradford, Fairlee, and Orange Town Forests, and the Washington Wildlife Management Area (VT-DEC-WQ 2008). Roughly 5% of the watershed falls within lands conserved as part of the collaborative Orange County Headwaters project, which in 2009 celebrated the conservation of more than 5000 acres located primarily in Washington and western portions of Corinth. In addition, the Bradford Conservation Commission has helped conserve land in the Wright's Mountain/Devil's Den Book area (Fig. 1). A large majority of these lands are conserved as working forest lands.

The Town of Bradford is the largest town in Orange County and in the Waits River watershed, with a population of 2,619 people according to the 2000 census (US Census Bureau 2000). The next three largest towns in the Waits River Watershed are Corinth (population 1,461 people), Topsham (population 1,142 people), which includes the villages of East Topsham, Topsham Four Corners, Waits River and West Topsham, and Washington (population 1,047) (Figure 1). Bradford is the largest commercial district within the watershed, but many residents living in Corinth, Topsham and Washington commute to other nearby commercial districts such as the Upper Valley (i.e., roughly the tri-town area of Hanover/Lebanon, NH and White River Jct., VT), Barre and Montpelier for employment. These economic centers are at a distance of at least a half-hour commute in any direction, and development pressures within the watershed are thus not as acute as in some other areas of Vermont.

3.2 GEOLOGIC SETTING

The bedrock formations underlying the Waits River watershed are dominated by the Waits River and Gile Mountain formations (Doll et al. 1961), which are generally calcareous and relatively easily weathered to fertile soils. The weathering of calcareous bedrock contributed much to the early fertility that was heavily utilized by agriculture in the watershed during the 19th century. Some granite formations, which are much harder and less disposed to weathering, have been left exposed in the very northern portions of the watershed. The mineral composition, erodibility and weathering potential of these bedrock types is an important determinant of natural communities and water quality in various areas, and has been utilized as the basis of the ecological classification of bedrock types displayed in Fig. 3 (Thompson and Sorenson 2000; VCGI 2000).

The Waits River and Gile Mountain formations originated primarily as sea sediments laid down in the eastern Iapetus Ocean during the Devonian and Silurian periods (Thompson and Sorenson 2000). These sediments were metamorphosed into mudstones (schists and phyllites dominate the Gile Mountain formation) and crystalline limestones (which dominate the Waits River formation) during a continental collision known as the Acadian Orogeny. During this orogeny (or "mountain-building event") subsurface rocks were also heated and thrust upward as domes (or "plutons"), and hardened into the granite that has been left exposed in the northern portions of the watershed as other surrounding bedrock has weathered away.

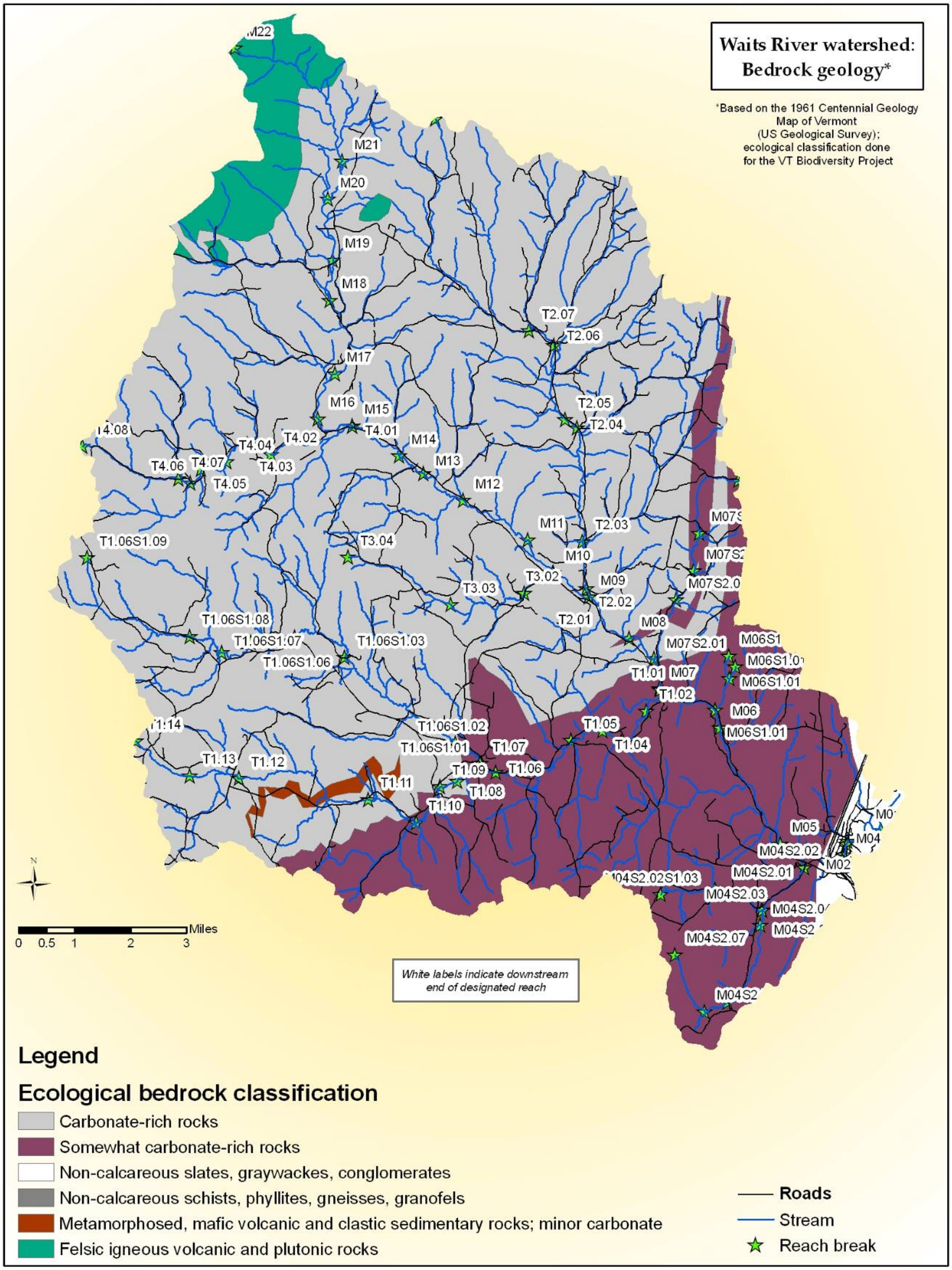


Figure 3. Bedrock geology (ecological classification) of the Waits River watershed.

The surficial geology of the watershed is heavily dominated by the influences of the Laurentide Ice Sheet, which was the last major continental-scale glacier that covered New England (Wright and Larsen 2004). Glacial advance occurred primarily from NNW to SSE, leaving an unsorted mixture of clay, sand, gravel, and boulders known as glacial till. Ice—sometimes as much as two miles thick—scraped its way across the landscape, and much of the Waits River watershed is dominated by “dense till”, sometimes referred to as “hardpan” due to its resistant nature (Fig. 5, next page). High elevations in the northern portion of the watershed are thus composed of scoured, exposed granite and other very hard rock, while mid to lower elevations contain glacial till deposits characterized by loose or compacted deposits of variant composition and moderate-high erodibility.

During the period of glacial retreat (from 15,000-12,000 years ago), a large lake formed in the Connecticut River Valley that submerged lower elevations of the Waits River watershed (Fig. 5, next page). 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 Saint Johnsbury, VT. A higher elevation glacial lake was dammed by the Shelburne ice formation off the upper arms of Lake Hitchcock, contributing to sand and fine gravel deposits found today along the South Branch and mid-portions of the Waits River mainstem (Doll et al. 1970). These deposits can be seen even in very steep valley walls along the South Branch in particular, where their presence has contributed in some instances to mass failures and gully formation over time (Fig. 4).

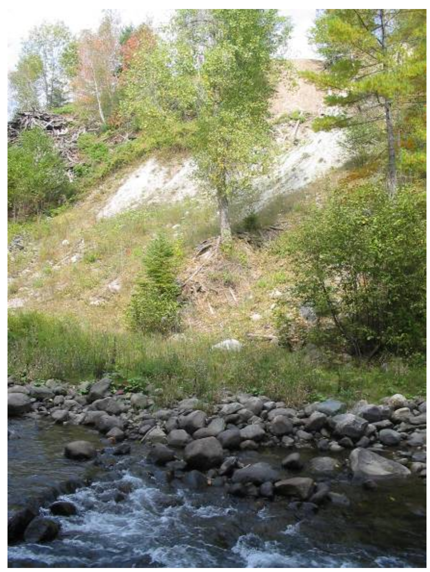



Figure 4. Sand and gravel deposits in valley walls along the South Branch of the Waits are likely related to the former presence of a high elevation glacial lake, and have been prone to mass failures and gully formation.

Fast flowing streams flowed both within and over the glacier, as well as over newly exposed bedrock and glacial till, depositing coarse-sandy material (glacial outwash or ice-contact substrates) within stream channels and the shallow waters of the lakes. Outwash deposits remain in many of the valleys of the Waits River watershed and can be highly erodible but are often somewhat resistant to erosion and movement once in the bed

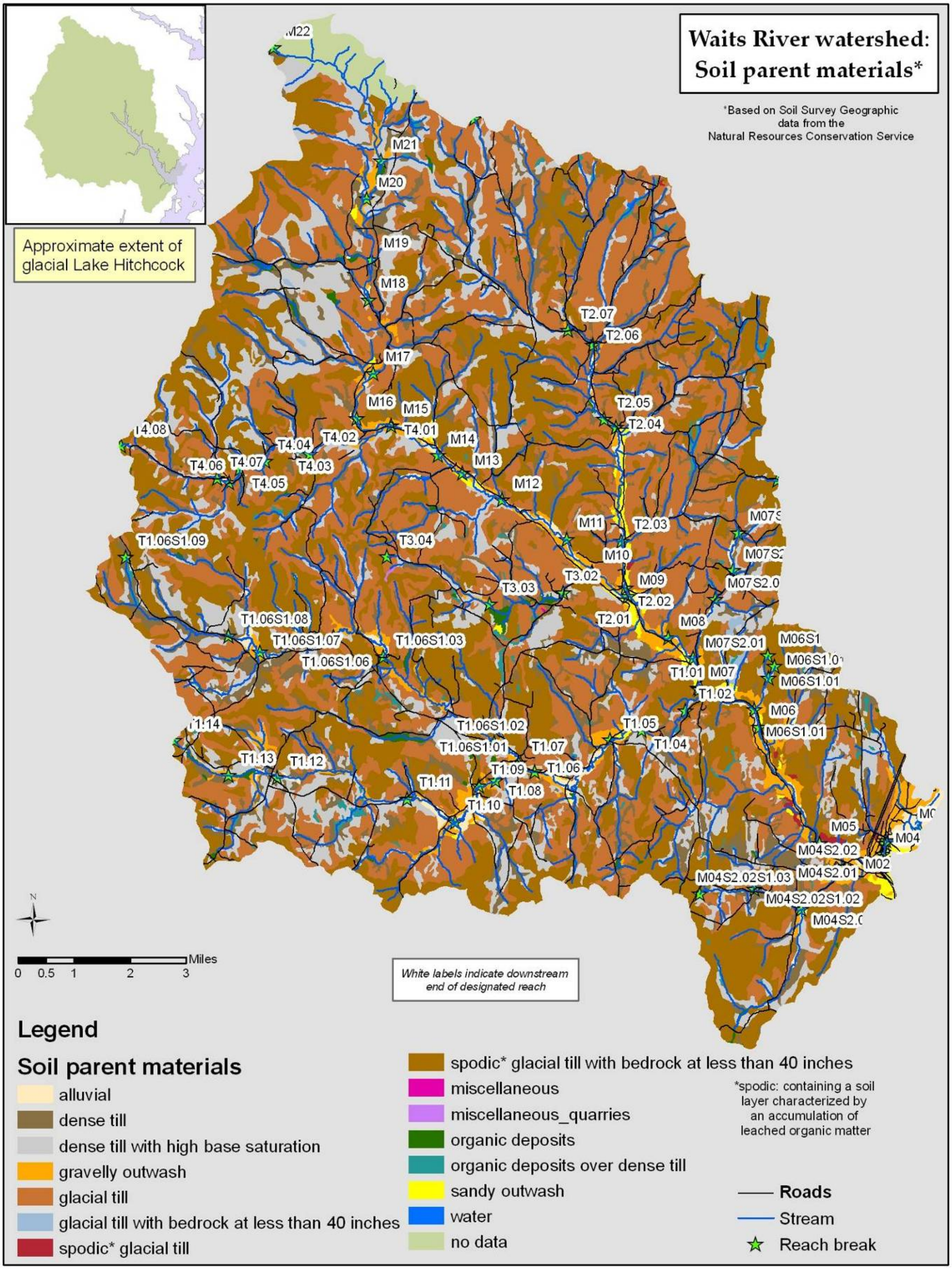


Figure 5. Soil parent materials in the Waits River watershed.

of the streams, contributing to formation of cobble "planebed" stream bed forms that characterized many of the assessed portions of the watershed (Fig. 6). Finer sand and gravel particles carried by streams settled in some of the broader valleys of the watershed and at lake margins, but fine silts and clays settled in deeper waters of Lake Hitchcock to form the type of lacustrine deposits that are largely lacking in the Waits watershed.

Figure 6. Cobble "planebeds" lacking many riffle or pool features were frequently observed in the assessed areas.

Stream processes since the last glacial period have contributed to further development of alluvial deposits, especially along the South Branch (and lowest reach of Cookville Brook, which shares the valley with the South Branch at their confluence) and the mainstem of the Waits (including the lowest reach of the Tabor Branch, which shares the Waits mainstem valley at the confluence of these two streams; Table 2). While alluvial soils are generally considered to have relatively low erosive potential due to gentle slopes, the materials are actually highly erodible and can be a significant source of sediment from unstable stream banks, particularly when well vegetated buffers are lacking. In general, however, the Waits River watershed tends to have a greater proportion of coarser "bed-load" sediments than finer grained "wash-load" sediments due to the underlying geology of the watershed.

Table 2. Waits River basin geology and soils for reaches assessed in 2007-2008 Phase 2 assessments (excerpted and combined from Phase 1, Step 3 analyses).

			Geologic Materials			Valley Side Slope		Soil Properties	
Reach ID	Alluvial Fan	Grade Controls	Dominant	%*	Sub-Dominant	Left	Right	Erodibility	%*
Waits River Main Stem									
M03	None	None	Ice-Contact	100	Alluvial	Hilly	Steep	Severe	70
M04	None	None	Alluvial	59	Ice-Contact	Hilly	Steep	Moderate	35
M05	None	Ledge	Ice-Contact	57	Till	Steep	Steep	Very Severe	87
M06	None	Ledge	Till	42	Ice-Contact	Hilly	Hilly	Severe	73
M07	None	None	Alluvial	59	Ice-Contact	Very Steep	Hilly	Moderate	37
M08	None	Ledge	Ice-Contact	84	Alluvial	Extremely Steep	Hilly	Moderate	50
M09	None	Multiple	Ice-Contact	72	Alluvial	Hilly	Flat	Slight	25
M10	None	Ledge	Ice-Contact	54	Alluvial	Hilly	Hilly	Moderate	35
Waits River South Branch									
T1.01	None	None	Till	70	Ice-Contact	Very Steep	Hilly	Very Severe	99
T1.02	None	Ledge	Till	97	Ice-Contact	Hilly	Hilly	Very Severe	88
T1.03	None	None	Till	73	Ice-Contact	Steep	Very Steep	Very Severe	98
T1.04	None	None	Ice-Contact	52	Till	Hilly	Hilly	Severe	66
T1.05	None	None	Alluvial	79	Ice-Contact	Flat	Flat	Slight	19
T1.06	None	None	Ice-Contact	88	Till	Flat	Steep	Very Severe	98
T1.07	None	None	Till	76	Ice-Contact	Extremely Steep	Very Steep	Very Severe	89
T1.08	None	Multiple	Till	40	Alluvial	Steep	Hilly	Moderate	41
T1.09	None	None	Alluvial	90	Ice-Contact	Hilly	Flat	Slight	3
Cookville Brook									
T1.06S1.01	Yes	None	Alluvial	72	Ice-Contact	Flat	Flat	Moderate	48
Tabor Branch									
T2.01	Yes	Multiple	Alluvial	58	Ice-Contact	Steep	Flat	Moderate	40
T2.02	None	Multiple	Ice-Contact	81	Alluvial	Extremely Steep	Very Steep	Very Severe	77

* ‘%’ indicates the percentage of the dominant portion in a soil complex, as well as a combination of dominant material and slope that determines the basis of the stated percentage for characteristic erodibility; percentages are rounded to the nearest whole number

3.3 GEOMORPHIC SETTING

For the purposes of geomorphic assessment and corridor planning, streams in the study area were divided into "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, as well as predicted morphology based on hydrologic characteristics and drainage basin size (methods are further discussed in Section 4.0 of this report). Classification parameters pertinent to establishing these reference stream types are listed in Table 3.

Table 3. Reference stream type summary indicating classification parameters pertinent to Waits River watershed reaches included for 2007-2008 fluvial geomorphic assessments (VT-RMP geoassesspro 2007, Phase 1 Protocols, p. 28).

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

Initial phase 1 assessment within the Waits River watershed divided the streams into 470 reaches based primarily on slope and valley confinement as delineated from United States Geologic Survey topographic maps. Sixty-four of these reaches were selected for more in-depth phase 1 analysis, as discussed in Section 2.1 (Project overview) and displayed in Fig. 1 of this report. Of these 64 reaches, slightly over half (34, or 53%) of the selected streams were lower gradient C and E type streams, with only 8 reaches (13%) selected in the highest gradient, A type classification and 22 reaches (34%) classed as B type streams (Table 4).

Table 4. Reference stream type classifications for the 64 reaches selected for in-depth Phase 1 analysis within the Waits River watershed during 2007-2008.

	Valley confinement type					
Reference stream type	**NC**	**SC**	**NW**	**BD**	**VB**	**Grand Total**
A2	5					5
A3	3					3
B3	1	16	2			19
B4		2	1			3
C3		1	8	4	5	18
C4			3	3	5	11
E4					1	1
E5					4	4
Grand Total	9	19	14	7	15	64

NC: Narrowly Confined; SC: Semi-Confined; NW: Narrow; BD: Broad; VB: Very Broad
Substrate classification types: 2: Boulder; 3: Cobble; 4: Gravel; 5: Sand

What is perhaps a bit unusual in the Waits River watershed is the frequent interspersal of stream types throughout the watershed: low gradient streams with relatively narrow valleys (some B, some C type streams) are common along the lower reaches of the Waits mainstem and major tributaries, rather than a concentration of less confined C and E streams in the lower elevations of the watershed (Fig. 7). In addition, twelve of the C type streams in the watershed are located in relatively narrow valleys (Narrow or Semi-confined; Table 4).

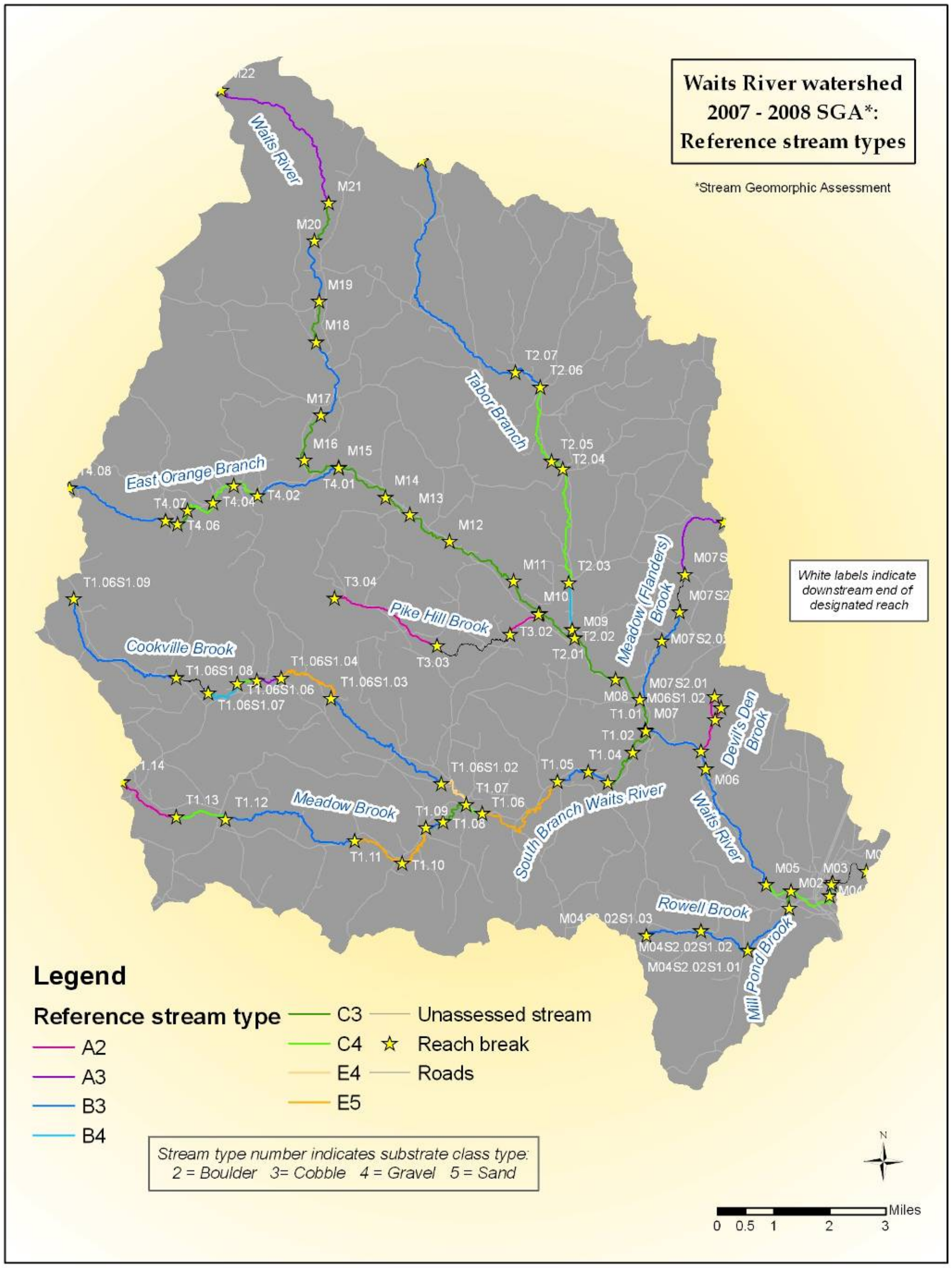


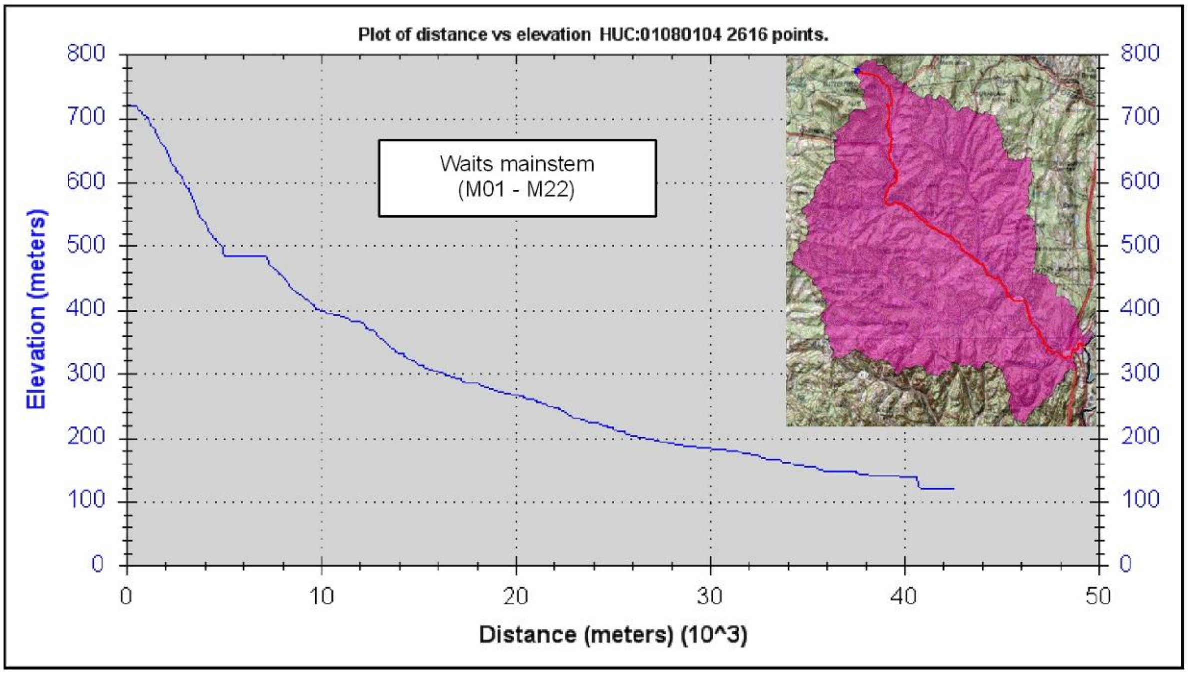
Figure 7. Reference stream types for reaches included in Phase 1 in-depth analysis in the Waits River watershed.

Complete Phase 2 field assessments included seven mainstem reaches of the Waits River (M04-M10); six reaches on the South Branch of the Waits (T1.01-T1.06); three reaches on Meadow Brook in Corinth (T1.07-T1.09); one reach on the downstream end of Cookville Brook at its confluence with Meadow Brook and the South Branch (T1.06S1.01), and two reaches on the Tabor Branch (T2.01-T2.02) (Fig. 1). Ten of these nineteen reaches were classified as C type streams under reference conditions, primarily with riffle-pool bedforms (Table 5). Three reaches (T1.05 and T1.09 on the South Branch and T1.06S1.01 on Cookville Brook) were classed as E type streams. Six reaches, dispersed throughout the assessed streams, were classed as B type streams under reference conditions.

Table 5. Reference stream types and geomorphic characteristics for Waits River basin reaches included in 2007 - 2008 Phase 2 assessments.

Reach ID	Reference Stream Type	Confinement (Valley Type)	Channel Slope (%)	Channel Length (ft)	Bedform
Waits River mainstem					
M04	C	NW	0.7	8053	Riffle-Pool
M05	B	SC	0.43	13692	Riffle-Pool
M06	B	SC	0.7	7732	Riffle-Pool
M07	C	SC	0.44	6666	Riffle-Pool
M08	C	NW	0.57	6469	Riffle-Pool
M09	C	BD	0.93	4390	Riffle-Pool
M10	C	NW	0.64	4198	Riffle-Pool
South Branch Waits River					
T1.01	C	NW	2.02	3017	Riffle-Pool
T1.02	C	NW	1.31	4718	Riffle-Pool
T1.03	B	SC	1.08	2136	Riffle-Pool
T1.04	B	SC	0.41	3623	Riffle-Pool
T1.05	E	VB	0.25	13429	Dune-Ripple
T1.06	C	NW	0.97	1852	Riffle-Pool
T1.07	C	NW	2.43	3786	Step-Pool
T1.08	B	NC	1.79	1898	Step-Pool
T1.09	E	VB	0.29	7263	Dune-Ripple
Cookville Brook					
T1.06S1.01	E	VB	0.39	5414	Riffle-Pool
Tabor Branch					
T2.01	C	BD	0.94	848	Riffle-Pool
T2.02	B	NW	0.9	4669	Riffle-Pool

Longitudinal profiles of the streams included in Phase 2 assessments (Figs. 8 and 9) indicate gentle gradient reaches alternating with steeper gradient reaches throughout the watershed, contributing to the mixture of stream types noted above. The Waits River watershed is typical of the Northern Piedmont area (as described by Thompson and Sorenson 2000), having rolling hill topography that is frequently dissected by narrow stream valleys. Relatively steep gradient ridges narrowly flank the downstream reaches of the Waits mainstem in Bradford and the South Branch in western Bradford and eastern



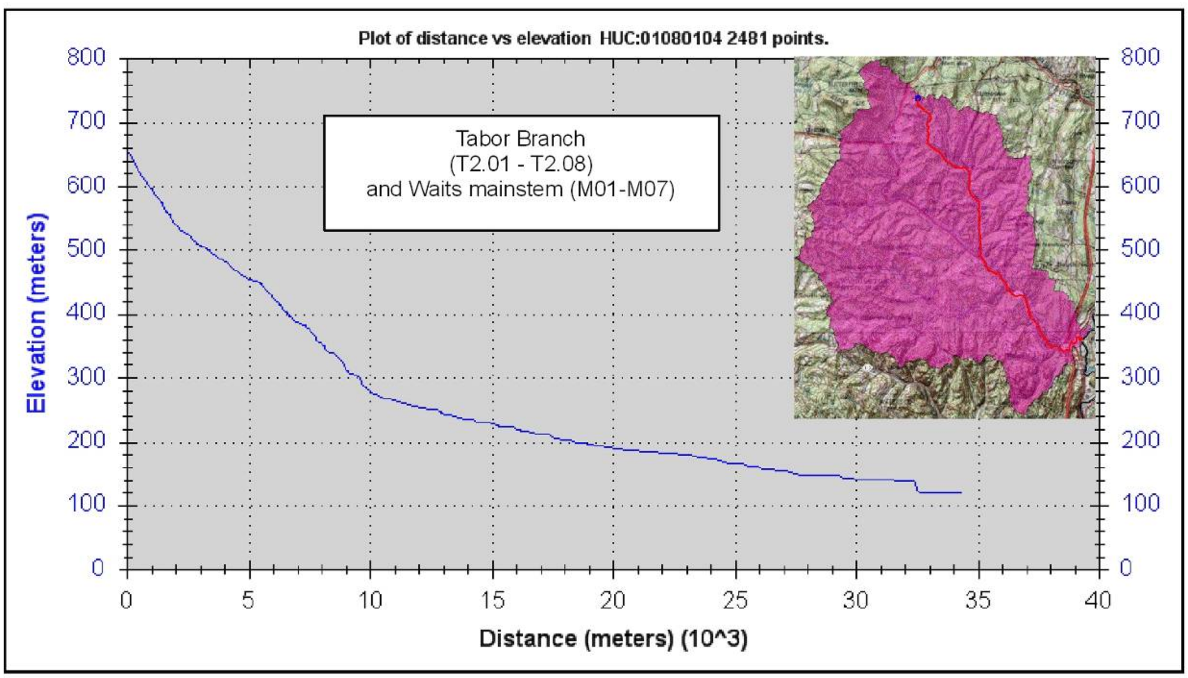
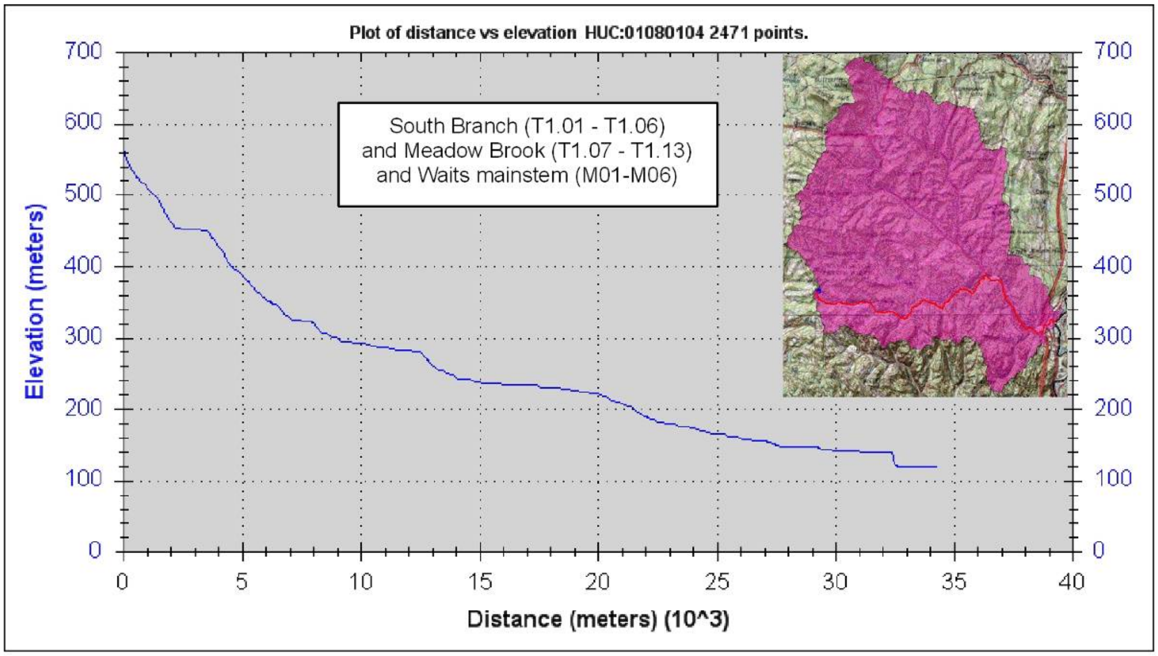


Figure 8. Longitudinal profiles for the Waits mainstem and Tabor Branch (graphics courtesy USGS streamstats website)..



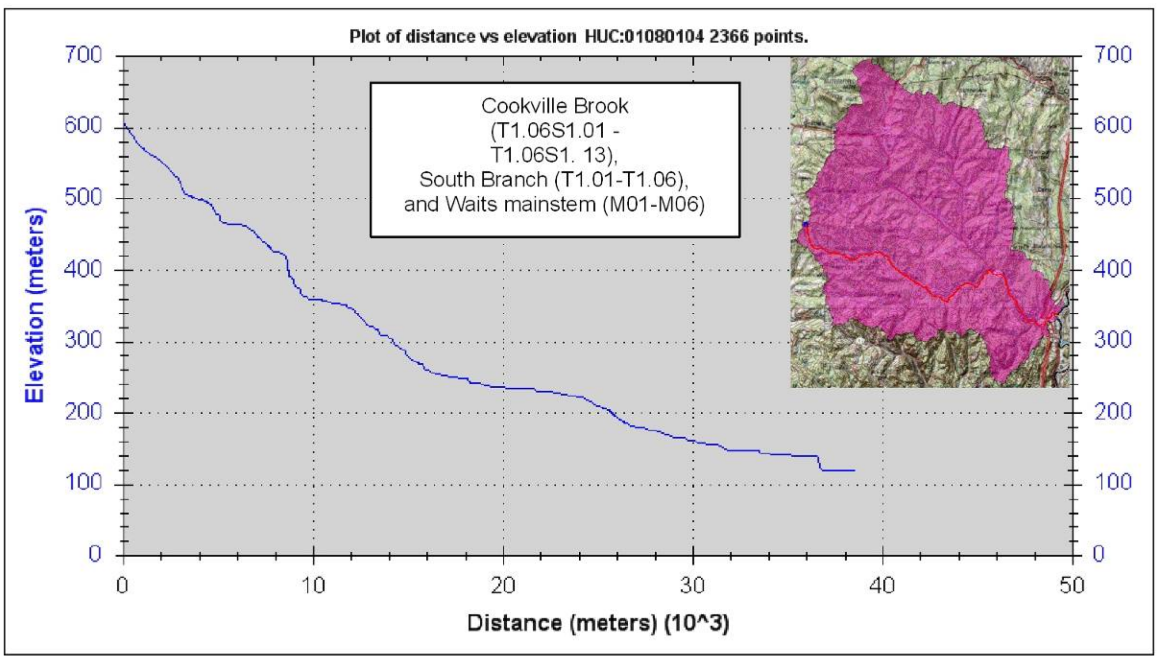


Figure 9. Longitudinal profiles for the South Branch/Meadow Brook and Cookville Brook (graphics courtesy USGS streamstats website).

Corinth, while the major tributaries (especially the Tabor Branch, Meadow Brook in Corinth, Cookville Brook, and Pike Hill Brook) as well as the upper reaches of the Waits mainstem have broader, low gradient valleys in their midstream portions (indicated by the C and E types on these streams in Fig. 7). Natural bedrock ledge grade controls are interspersed throughout the watershed also (Table 2), which has likely helped limit the degree of channel incision noted in the watershed.

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 and Leopold 1978). The information presented in this section deals very briefly with the basis of natural fluctuations, while human modifications are discussed further in section 5.1.1, *Watershed-scale hydrologic regime stressors.*

3.4.1 Waits River basin StreamStats

The United States Geological Survey (USGS) administers a *StreamStats in Vermont* website, which is designed to help compute streamflow and drainage basin characteristics for ungaged sites (http://water.usgs.gov/osw/streamstats/Vermont.html). Drainage basin characteristics for the overall Waits River basin are indicated as follows:

Waits River Basin Characteristics Report

NAD83 Latitude: 43.9945 (43 59 40)
NAD83 Longitude: -72.1163 (-72 06 58)

Parameter	**Value**
Area in square miles	156
Percent of area covered by lakes and ponds	0.15
Mean annual precipitation, in inches	40.2
High Elevation Index - Percent of area with elevation > 1200 ft	64.1

3.4.2 Waits River basin flood history

There is only one continuous-record stream gage operated by the US Geological Survey in the Waits River drainage basin that has peak streamflow records accessible via the internet. This gage is located in the upstream portions of the watershed on the East Orange Branch, with records available covering the years from 1959 – 2007. Comparable drainage basin characteristics for the East Orange Branch (excerpted from the data collection station report) are indicated as follows:

East Orange Branch Data-Collection Station Report

USGS Station Number	01139800
Station Name	EAST ORANGE BRANCH AT EAST ORANGE, VT
Area in square miles	8.95
Percent of area covered by lakes and ponds	0.05
Elevation at location of gage	1180 ft above sea level
Mean basin elevation	1780 ft above sea level

The USGS operated gages in the watershed on the South Branch of the Waits between 1940–1951 and on a small tributary of the South Branch between 1964–1974, and also has other gages on the Waits and its tributaries (http://waterdata.usgs.gov/vt/nwis/inventory). Electronically available information for these sites does not include station reports and/or peak streamflow data however, and thus does not permit a comparison of peak flows with flood-level flows for these drainage basins.

In reviewing the records at these stream gages, it is important to recognize the often localized nature of floods that can have significant impacts. While the 500-year peak streamflows of the November 1927 flood were experienced in the Waits watershed as throughout Vermont (Johnson 1928), the sometimes steep topography and often narrow valleys of the watershed predispose the Waits River basin to "flashy" flows in heavy precipitation events. The stream gage located on a small tributary of the South Branch (a limited ten year dataset) recorded its highest flows on April 3, 1967 and April 14, 1974. These dates do not even appear as annual high flows a short distance away on the East Orange Branch (Fig. 11, next page), indicating the localized nature of these events. While this is in part related to weather patterns, it is also important to recognize the impact of the topography and geology as well as changes in hydrology over time, as further discussed in Section 5.1 (Watershed hydrologic stressors) of this report. These are highly pertinent factors in the Waits watershed, as flood history related by watershed residents indicates localized flash floods as the predominant type of flooding in the watershed. Several residents noted flooding on Rowell Brook in 1998 that caused two ponds to overflow, snowballing to cause enough gullying and erosion that sufficient sediments were carried downstream to plug the mouth of Mill Pond Brook (into which Rowell Brook flows) at its confluence with the Waits mainstem in Bradford (Fig. 10).

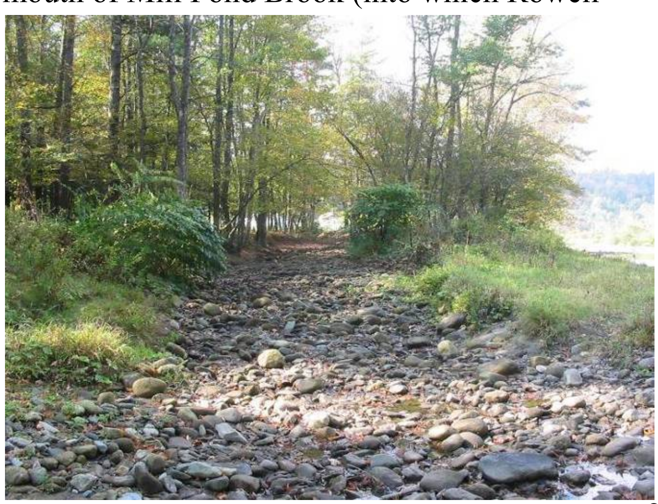


Figure 10. Sediment "slugs" from a flood on Rowell Brook in 1998 now plug the mouth of Mill Pond Brook (into which Rowell Brook flows) at low flows, as shown here. This means that Mill Pond Brook now enters the Waits mainstem further upstream if water levels are low.

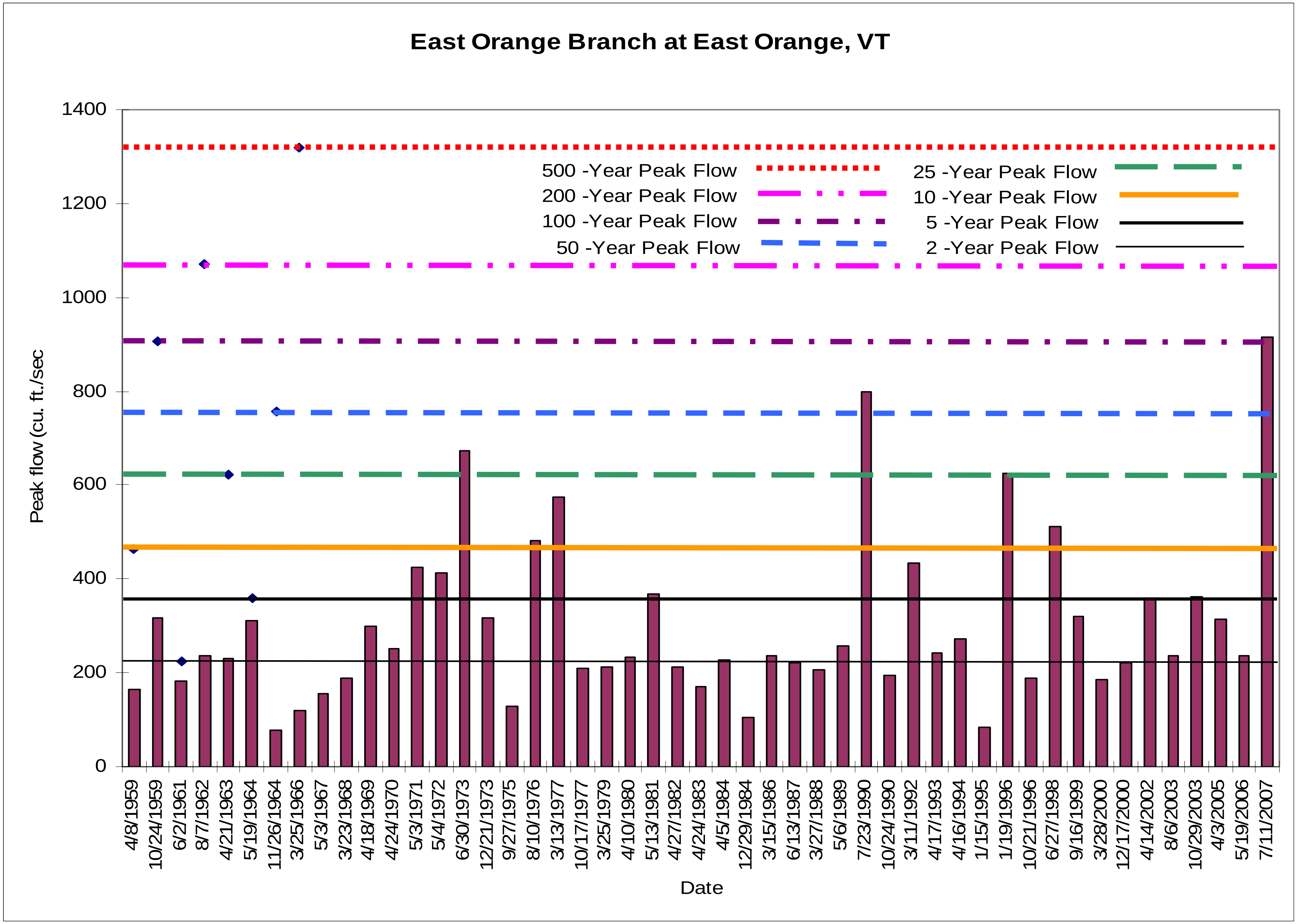


Figure 11. Channel-forming (i.e., 2-Year) and flood-level peak streamflows at the USGS continuous-record stream gage on the East Orange Branch of the Waits River.

Data from the East Orange Branch station indicate flows exceeding 100 year peak flow levels on July 11, 2007, as well as exceeding 50 year peak flows in 1990 and 25 year peak flows in 1973 and 1996 (Fig. 11). As further indication of the localized nature of flash flooding in the Waits watershed, these data also show that the 1998 flood that hit Rowell Brook (and areas along Meadow Brook and the South Branch in Corinth: pers. comm., Corinth Road Commissioner Frank Roderick, Dec. 2008), was just over the 10 year peak flow level on the East Orange Branch.

The July 11, 2007 flooding occurred when an intense series of entrained thunderstorms moved through the area in rapid succession (NOAA-BTV 2007). This event resulted in declaration of a Federal Disaster for Orange, Washington and Windsor Counties in Vermont, and resulted in eventual buyout and removal of houses in the floodplain at the base of Honey Brook in East Barre after those houses had been repeatedly damaged by flooding (NOAA-BTV 2007). According to the Burlington Weather Service's report:

> "….Spotter reports indicated rainfall amounts of 1.7" in 30 minutes, and portions of Orleans, Caledonia, Orange, and Washington Counties in Vermont received over 4 inches of rain over several hours.
>
> … The heavy rains resulted in severe flooding across the area as area streams and small rivers quickly became swollen.…It is interesting to note however that …all the flash flooding was limited to small creeks and streams that reacted quickly to the excessive rainfall and runoff. The larger rivers and streams had sufficient channel capacity to absorb the additional flows, and remained within their banks."

Although this was a widespread event, this report highlights the fact that the greatest impacts throughout the affected area were from flash flooding on small streams. Such a scenario is part of the reason that flooding is the most common and costly "natural disaster" in Vermont (VT-RMP FEH 2008). It is also notable that larger streams did not crest their banks. While this may be interpreted as "sufficient channel capacity" to absorb these flows, it also means that the force of the stream power associated with this storm was not widely dissipated on floodplains but rather experienced within the channel of the larger streams. These heightened impacts can be major contributors to elevated levels of bed and bank erosion (see further discussion in section 5.1.4 *Sediment regime departure, constraints to sediment transport, and attenuation*).

Microburst storms were also experienced in the watershed in August 2008 and again in August 2009, after completion of the Phase 2 geomorphic assessment field work included in this report. According to local reports on the August 2008 storm:

> "The microburst hit the ridge top from the top of Tullar Road to the ridge above South America Road. Two rain gauges showed six inches of rain in 45 minutes with two inches of hail accumulated on the ground on Tullar Road. The runoff collected from the open fields on Tullar and overwhelmed a 3-foot culvert and then a 2-foot culvert jumping into the road at Galt's (first house on the left) and washing out the whole road all the way to the pavement. The runoff also collected above Chelsea Road just west of the slumping area (in the dip) and ran over the pavement and washed out the bank but not the pavement on the downhill

> side. The water that did not run off Tullar ran down Chelsea Road to the east and took out two sections of pavement on the downhill lane. The Meadow Brook was running at full bank level below the bridge on Chelsea Road and over Eagle Hollow Road 6-8 inches deep for about 150 feet. No damage to Eagle Hollow Road.
>
> On South America Road, water overwhelmed successive culverts from the top of the Class III stretch and washed out half the travelled surface and gullied most of the culverts all the way to the bottom of the hill. Debris contributed to several culvert failures, but there was simply too much water overall.
>
> This event was just too much water for the drainage system. We increased the size of all the culverts on both these roads in 1998 when a similar event occurred and we have enlarged them all again after this event. We'd have to put in 3-4 foot diameter culverts in each location to handle the storm flows, but debris would probably still cause failures in such a heavy runoff." (pers. comm., Corinth Road Commissioner Frank Roderick, Dec. 2008)

The areas denoted in this communication drain into reaches T1.11 and T1.10 on Meadow Brook in Corinth (Fig. 1).

3.5 ECOLOGICAL SETTING

The Waits River watershed lies within the Northern Vermont Piedmont biophysical region (Thompson and Sorenson 2000). The area has hilly topography and abundant rivers, and is dominated by Northern Hardwoods Forests. The bedrock dictates much of the vegetation of this region, more specifically calcareous-rich bedrock supporting Northern Hardwoods on the Waits River Formation and conifer and mixed forests in higher elevation, granitic bedrock (Thompson and Sorenson 2000; the granitic bedrock is limited to the northern portions of the Waits watershed). The Northern Piedmont region has been altered by land clearing for agricultural purposes and forest/wood products, and also has a very dense network of roads and settlements. Therefore, very few large, undisturbed areas exist in this area currently (Thompson and Sorenson 2000).

Surface water is very abundant in this region, which possibly contains more lakes and ponds than any other region of Vermont and also contains many rivers and streams (Thompson and Sorenson 2000). Surface waters such as streams support many of the biological communities. Fisheries studies since the 1950's have indicated that there are abundant brook trout in the upper reaches of the watershed, and fewer populations of brook and brown trout downstream. Heightened temperature and loss of habitat and riparian vegetation are thought to be limiting factors for cold water fish population in the lower reaches of the Waits River (VT-DEC-WQ 2008, p. 52). Riparian habitat has been heavily influenced by human habitation in the last 200 years, with intensive agriculture and development largely occupying what would likely be floodplain forest habitats in much of the watershed. Although the Waits River flows into the Connecticut River, the Bradford hydroelectric dam inhibits fish passage from the Connecticut River upstream into the Waits River (USDWS 2008). Current evaluation of this barrier includes assessment of the role of the dam on protection of native brook trout populations, salmon restoration efforts and stocking practices in the watershed (VT-DEC-WQ 2008, pp. 46-47).

In addition to fisheries studies, other water quality studies of the Waits River watershed have been conducted. The Bradford Conservation Commission, Oxbow High School and Riverbend Technical Center students, and Waits River School students have (between all the groups) conducted macroinvertebrate studies on the mainstem of the Waits River and collected samples testing for E.coli, turbidity and nutrients. Results have indicated variable results and differences in collection methods that make direct comparison challenging, but the macroinvertebrate studies indicated an encouraging absence of non-native rusty crayfish (which have been found in abundance in some other watersheds in Vermont; pers. comm., Nancy Jones, Bradford Conservation Commission chair, August 2007). The Orange County Headwaters Project (OCHP) has also conducted wetland and vernal pool surveys for some portions of the Waits River watershed, with indications of generally good health of these important communities within the watershed and a limited number of occurrences of plants of special interest and significance (Peters and Haney 2007).

4.0 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 (VTANR) 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 (VTANR 2007). 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 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 Fluvial Erosion Hazard zones (VT-RMP

FEH 2008; VT-RMP RCProtect 2008). 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 are entered into the most current version of the VTANR Stream Geomorphic Assessment (SGA) Data Management System (DMS) (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm), where they are available for public review. Phase 1 data are updated, where appropriate, using the field data from Phase 2 assessments; these changes are 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 are 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) ArcView 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 (http://maps.vermont.gov/imf/sites/ANR_SGAT_RiversDMS/jsp/launch.jsp?popup_blocked=true).

4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS

VTANR-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 Two Rivers-Ottauquechee Regional Commission and Redstart personnel 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 as well. Further review by both RMP personnel and the consultants conducting the assessments were cross-checked to verify integrity of the data, and this iterative process was completed in September 2009; further documentation of that process can be found in Appendix 5. General questions about data collection methods can be answered by referencing the SGA Protocols (VTANR 2007).

It should be noted that protocols are periodically revised to increase the value of the data collected. In 2007, in the early stages of the assessment reported here, significant revisions to the scope of Phase 1 assessments were undertaken in identifying and establishing reach breaks (points where the stream exhibits significant changes in characteristics) early in the assessment of a watershed. In the Waits watershed this expanded the reaches included in Phase 1 assessment from ~65 to 470. These revisions were in part related to a series of intense, localized storms in the summer of 2007 that demonstrated how small tributary streams can suddenly become major contributors to watershed dynamics (Fig. 12; see also sec. 3.4.2, *Flood history*, of this report).

Figure 12. Sediment from a road taken out by this small tributary off of Ayers Brook in Randolph suddenly became a significant contributor to stream dynamics after an intense thunderstorm in July 2007. The woman at center right is indicating the post-flood width of the stream by her armspan.

In situations where reach breaks had not been established on such streams in initial watershed assessments, these shifts in dynamics were difficult to incorporate into analysis and planning without essentially starting the watershed assessment over again. Because these reach breaks were identified and incorporated into the Phase 1 work for this project, drainage basin size and slope assessments were made possible for 470 reaches within the watershed, providing the information for scientifically based corridor planning to accommodate stream processes and flood hazards on many of the smaller streams in the watershed. Informing river management with an overall view of watershed dynamics as well as reach-scale dynamics has been a central goal of policy shifts designed to move away from “band-aid” approaches on a case-by-case basis and make river management in Vermont more effective and sustainable (VTANR 2006).

5.0 RESULTS

The following sections summarize pertinent results of Phase 1 and 2 SGA data collection in the Waits River watershed. Stressor, departure, and sensitivity maps are presented as a means to integrate the data that have been collected and show the interplay of watershed and reach-scale dynamics. These maps should assist in identifying practical restoration and protection actions that can move the river toward a healthy equilibrium (VT-RMP RCPG 2007). Single page 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 (VT-RMP RCPG 2007). 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 those shown in sec. 5.1.4, which specifically look at the reaches assessed in Phase 2) 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, these "bigger picture" relationships are critical to understanding how upstream processes (either historic or current) affect what may be happening further 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 Waits River 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 and an indication of the potential rate of subsequent channel evolution (VT-RMP geoassesspro 2007, Phase 2, Step 7.7; VT-RMP RCPG 2007, 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 select analysis (Chapter 5 maps).

5.1 DEPARTURE ANALYSIS

5.1.1 Watershed-scale 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 (VT-RMP RCPG 2007).). In the Waits River watershed, hydrologic changes including intermittent increased stream power appear to have contributed to historic downcutting on all but one reach fully assessed in Phase 2.

As noted in section 3.1.3 of this report, *Land use and general characteristics*, the Waits River watershed is roughly 75% forested today. Historical photos of the general area (Corinth 1964; Fig. 13) and forest species and age distributions throughout the watershed (pers. comm., Virginia Barlow, co-editor Northern Woodlands Magazine and Corinth Tree Warden) indicate that the watershed was likely heavily deforested during the 19th century, particularly in the areas surrounding village centers. These village centers were (and still are, though they are not the centers of industry and economic activity that they were in the 19th century) concentrated along the Waits mainstem and major tributaries of the watershed.

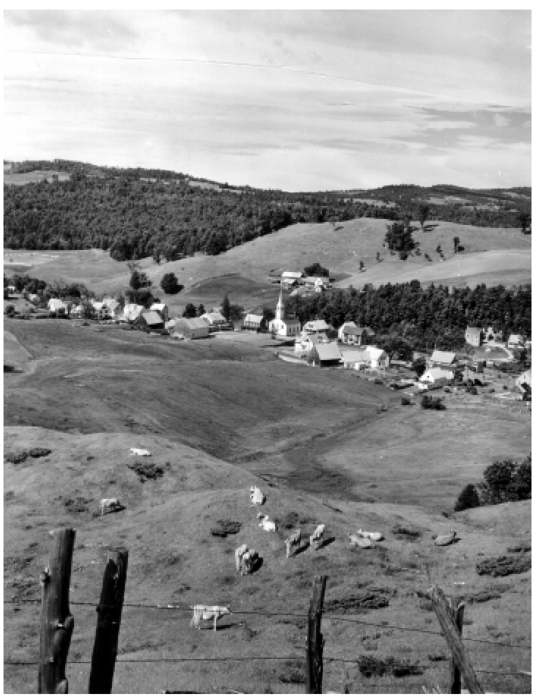


Figure 13. Historical photos of East Corinth (~1960, left) and Corinth Center (~1909, right) indicate significant clearing within the watershed in the areas surrounding village centers (photos from University of Vermont Landscape Change Program, http://www.uvm.edu/landscape/menu.php.)

Trees play a large role in attenuating and slowing water inputs to the stream, both through the interception of water during precipitation events but also through large amounts of water that are taken up and cycled through transpiration. This can most easily be observed by the length of time that water levels remain high after a storm when leaves are off of deciduous trees (commonly 2 or 3 days after a moderate to heavy rain) in comparison with a summer storm, when water levels might recede within four to eight hours after the same type of storm. A simple experiment on a stream with well-forested buffers illustrates similar dynamics: a stick placed in a sand bar close to water level during the day will often be submerged first thing in the morning, after the period of time that trees have not been actively cycling water as rapidly as when they are exposed to sunlight. These observations help clarify the types of changes that occur in hydrologic dynamics when trees are removed from a larger landscape: water reaches the stream more quickly and in higher quantities than in areas that have trees present.

Subwatersheds draining these cleared portions of the watershed have thus experienced significant changes in land cover and land use that are likely still contributing to channel adjustments (Fig. 14). Preliminary research has indicated that "urban" land use conversions approaching 10% of a subwatershed can be sufficient to be reflected in stream dynamics (Booth and Jackson 1997), and agricultural (cropland in particular) land use can strongly affect hydrology as well (Schilling and Wolter 2005). "Urban" land use (including densely developed areas, roads, suburban areas and large-lot residential development) fell within a range of 10-20% in 37 of the 64 subwatersheds (58%) selected for in-depth Phase 1 analysis in the Waits River watershed, and an additional 4 subwatersheds (6%, all around Bradford village at the downstream end of the overall watershed) exceeded a 20% threshold of "urban" land use. In the Waits watershed, only one of the 64 subwatersheds selected for in-depth phase 1 analysis had greater than 5% agricultural use, and none exceeded a 10% threshold.

Historical clearing during the late 18th and 19th centuries initially contributed to higher runoff of both water and sediment (USDA-FS 2001). While this situation tended to diminish with reforestation of the watershed, further contributing factors to hydrologic changes in the Waits River watershed are notable in two particular areas: road encroachments and flow regulation. A relatively high density of roads laid out in close proximity to the streams of the watershed helped alter the rainfall-runoff regime in such a way that water inputs intensified, and the watershed's hydrologic regime became more "flashy". Road density is a significant contribution to the "urban" land uses noted in the subwatersheds, and 14 of the 64 reaches (22%) receiving in-depth phase 1 analysis indicate 10-20% of the river corridor land use as "urban"; an additional 34 of the 64 reaches (53%) exceed a 20% threshold of "urban" land use in the river corridor. With the advent of heavy equipment, it has also become far more cost-effective to expand road ditching rather than have to continually repair roads from the damages of heavy frost heaving and washouts. Careful attention to directing these surface water inputs to well vegetated surfaces can help mitigate the effects of direct surface water inputs to streams, but in many instances it is difficult to reduce the amount of water that now enters these streams without percolating through soil first.

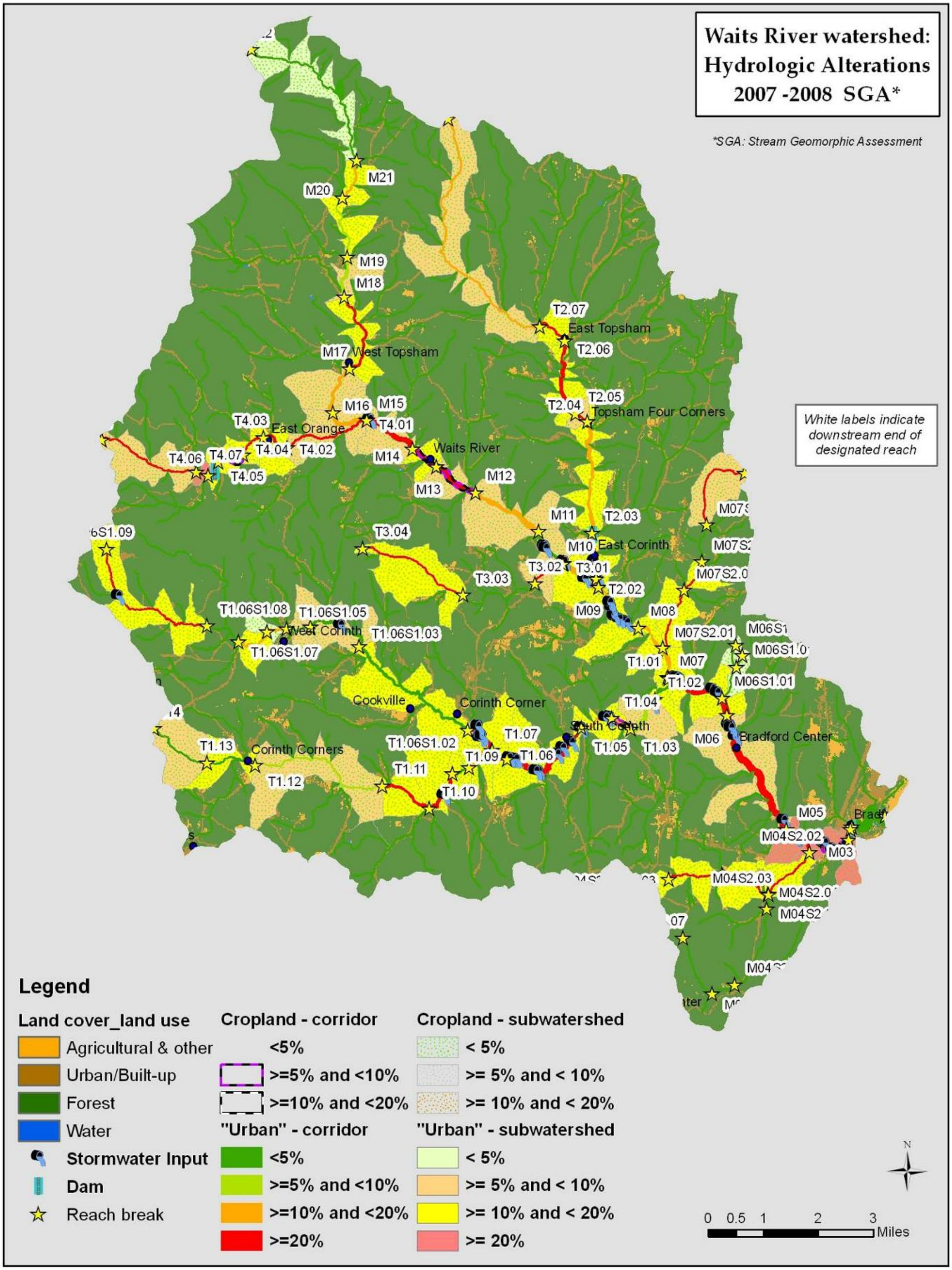


Figure 14. Watershed-scale hydrologic alterations map for the Waits River watershed.

Surface water inputs to the stream noted in field assessments were concentrated to some degree near village centers (Fig. 14).Although not frequently observed in the Waits watershed, ditching of agricultural fields can similarly increase water inputs to streams and are included with documented surface water inputs; old field ditches were evident in reach M07 on the Waits mainstem and T1.05 on the South Branch, and given the relatively low degree of intensive agricultural use may have become less evident over time in other portions of the watershed. In addition, it should be noted that field swales (as opposed to ditches) often behave very differently than wooded areas in heavy precipitation events, and this type of overland flow (included as documented surface water inputs in phase 2 field assessments) can quickly overwhelm drainage systems in these types of events (Fig. 15; see also the notes on 2008 flash flooding at the end of section 3.4.2, *Waits River watershed flood history*, in this report).

Figure 15. The field swale at left contributed sufficient water in a heavy downpour to initiate gullying along the road (right), eventually combining with a tributary downhill to wash out a 6 ft. culvert and a section of the road.

As discussed in section 3.1.3 of this report, *Land use and general characteristics,* mills (and the dams to help power them) were an extensive presence within the watershed. Thirteen mills were located in various portions of Corinth (Corinth 1964), and at one time six mills were operating concurrently on the Tabor Branch between East Corinth and Topsham Four Corners, with flows allocated through the course of the day to power the mills successively (pers. comm., current mill dam owner Gordon Kittredge of East Corinth) . Water storage and release for mill use contributed to “pulse” flows. The combination of an intermittent increase in stream power and “sediment starving” at the dams has likely contributed to “hungry water”, a phenomenon that helps explain a significant degree of channel incision (also referred to as downcutting or degradation of the channel). These factors serve to increase stream power and degradational processes, which has likely contributed to some of the historic downcutting that has occurred on all but one reach (18 of 19 reaches; 21 of 28 segments) fully assessed in Phase 2. (Incision is a field-assessed parameter and thus is not evaluated in Phase 1 assessments). There were indicators of historic channel incision even in areas where ledge and bedrock grade controls are presently evident in the stream channel, and the only reach that showed no signs of downcutting over time was reach T1.09 on Meadow Brook in Corinth, where beaver activity is common and the banks of the stream appear more prone to erosion than the bed. In the large majority of these cases, this has meant a reduction in floodplain access rather than full loss of access to historical floodplains (see further discussion in Sec. 5.1.4, Sediment regime departure).

It should also be noted that mill use of these streams often entailed removal of large woody debris from stream channels to prevent damage to infrastructure. Large woody debris can be an important component of stream power diffusion, pool formation, and fine sediment retention, and frequently plays a large role in smaller headwater streams in particular (USDA-FS 2001).

5.1.2 Watershed-scale sediment regime stressors

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 2007):

> 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. Generally, these patterns 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.

At a watershed scale the Waits River basin does not appear to be a particularly high bed or wash load system at the current point in time, although islands, flood chutes, and indications of historic channel migration common throughout the watershed indicate that more significant sediment deposition likely occurred historically in the watershed (Fig. 16). Depositional features were distributed relatively evenly throughout the reaches included in Phase 2 assessments, with high levels of depositional features (>5 features/mi.) noted on 17 of 19 reaches (21 of 28 segments). The large majority of these depositional features were not large however, with the most significant deposits noted in the upstream segment of reach T1.06S1.01 (an alluvial fan) and in reaches T1.01 on the South Branch (near the confluence with the Waits mainstem) and M05 on the Waits mainstem. In fact, much of the riffle and pool formation in the stream beds of the

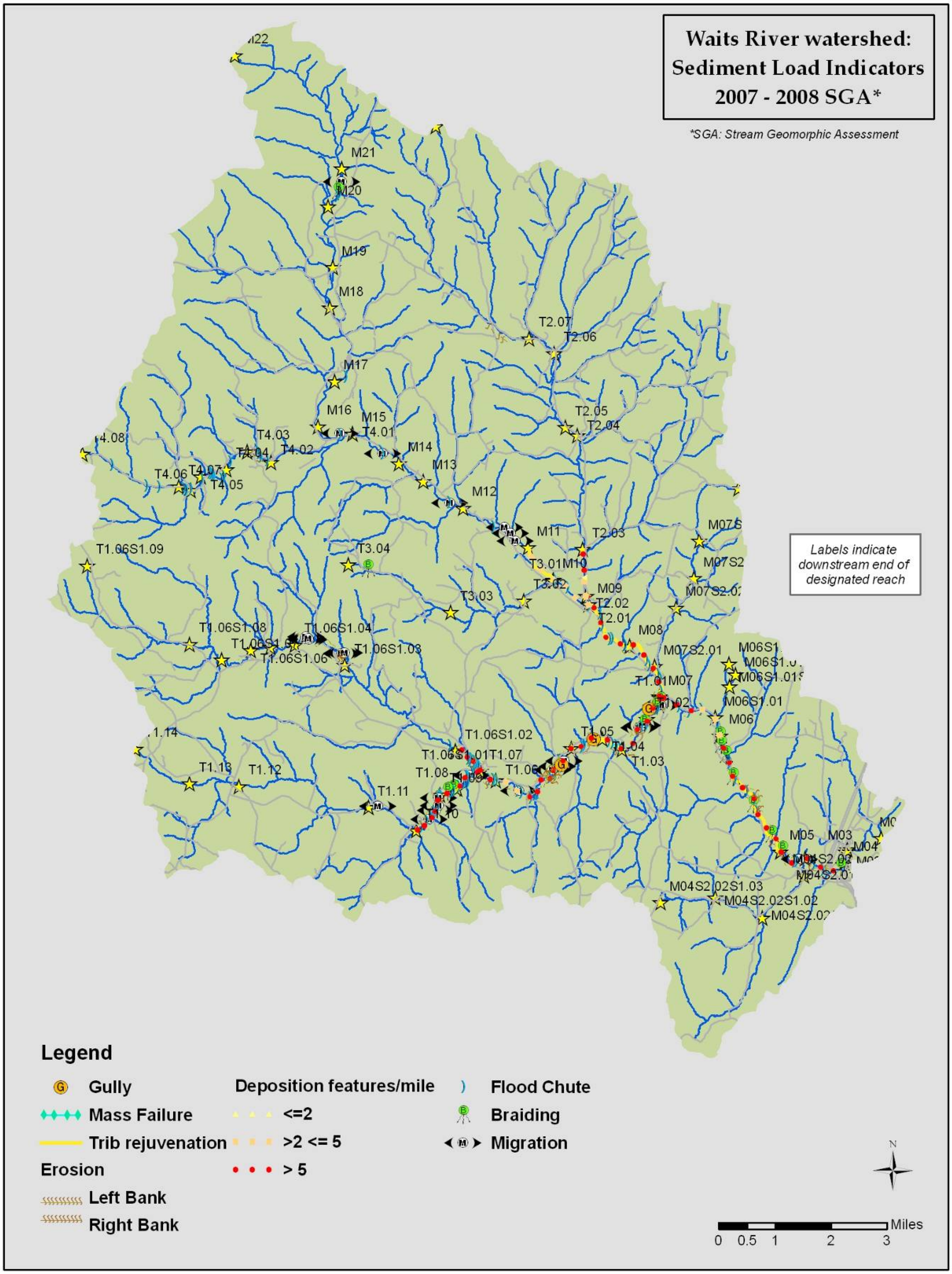


Figure 16. Watershed-scale sediment load indicators for the Waits River watershed.

assessed reaches was noted as being relatively weak, and planebed bed forms were noted in at least a portion of all but the most downstream of the Waits mainstem reaches receiving full Phase 2 assessments.M04, the most downstream reach and the sole exception to a dominant planebed form, only had its upstream segment assessed fully; the downstream segment would most likely have a planebed as well, but was excluded from full assessment due to the fact that it is heavily influenced (essentially impounded) by the Bradford hydroelectric dam a short distance downstream. This area was noted as having heavy layers of detritus accrued on the bed of this relatively deep and slow moving portion of the Waits River in this area.

Island formation (included with braiding indicated in Fig. 16) is common along the lower reaches of the Waits River mainstem; most of these islands have trees and/or significant perennial vegetation growing on them. Some of these may have formed when the stream channel split around an existing piece of land (carving a flood chute that was later captured by the stream outside the former, narrower channel) rather than depositional features that later became vegetated, but it is likely that sediment deposition and/or alterations in stream power would have at least contributed to initiation of these types of channel migrations. "Pulse flows" associated with damming at mill sites would encourage sediments to drop out and accumulate when low flows became insufficient to move existing sediment loads, and the high percentage of cobble sized materials observed in the streams of the watershed (indicative of the common underlying glacial till geology) may have led to large "sediment slugs" stored behind dams that were released when the dams were breached by floods or otherwise removed.

Sediment removal appeared to have occurred in Waits mainstem reach M09 just upstream of the Village Rd. bridge near the confluence of the Tabor Branch in East Corinth, where a good deal of cobble and boulder sediments were windrowed along the banks. It appears likely that some of this activity occurred in conjunction with bridge replacement and/or sediment removal upstream of the bridge following flooding, possibly after the same storm that hit Rowell Brook in 1998 or perhaps in another localized flash flooding event. Such activities are not uncommon in the aftermath of floods, and are frequently undocumented (Fig. 17).

Figure 17. Windrowing of sediments following flash flooding, particularly upstream of undersized bridges and culverts and similar constrictions, is not uncommon and is frequently undocumented. This can complicate understanding channel evolution and the movement of sediment in a stream system.

Waits mainstem reach M05 has also had sediments removed in the past, as part of efforts to mitigate ice jams in the area of Bradford Center (pers. comm., Barry Cahoon, VT Stream Alteration Engineer), and some gravel was removed commercially from this portion of the Waits mainstem during the 1970s (pers. comm., Corinth Road Commissioner Frank Roderick). Lacking any further documentation or history of gravel removals in the watershed, it is difficult to determine how widespread these practices have been historically and what role they have played in channel evolution. Given the geologic history of the area, particularly the amount of relatively dense till present in the watershed, it appears that channel evolution subsequent to these removals has been relatively slow as new sediments are recruited into these areas. These sediments appear to be contributing first to planebed formation and then evolving toward more defined depositional features, with the primary indications of heavier sediment deposition (islands in particular) being more historic in nature.

New sediment recruitment at this point in time is occurring from such factors as erosion, mass failures and gullies, and tributary rejuvenation. Tributary rejuvenation occurs when the mainstem of a stream has undergone sufficient downcutting that the tributaries adjoining it are forced to lower their elevation to meet that of the mainstem. This process is usually accompanied by headcuts and nick points migrating back up the stream bed of the tributary, thereby recruiting sediments into the main stream as the headcutting advances upstream along the trib (Fig. 18). Tributary rejuvenation was observed during Phase 2 field assessments in Waits mainstem reaches M05, M07, M08, and M10, as well as South Branch reach T1.03, but did not appear extensive and is likely more historic in nature as well.

Figure 18. Tributary rejuvenation contributes sediments to a stream when nick points or headcuts move back up a tributary, as the adjoining trib (such as the small one pictured here) begins to lower its elevation to meet the new elevation of a receiving stream that had previously cut down into its bed.

Similar dynamics are sometimes triggered by flash flooding that creates large gullies along small streams (or sometimes just drainage swales) that can contribute large amounts of sediments to the receiving stream. Mass failures can be triggered by flooding in narrow valleys with highly erodible side slopes, and frequently are more common after a stream has cut down into its bed in these types of settings. Mass failures and gullies were observed on Waits mainstem reach M08 and each of reaches T1.01 – T1.07 on the South Branch (with the exception of reach T1.06), areas that were associated with geologic materials deposited along the edges of glacial Lake Hitchcock or a higher elevation glacial lake dammed by ice along the upper arms of that Lake (Fig. 19).

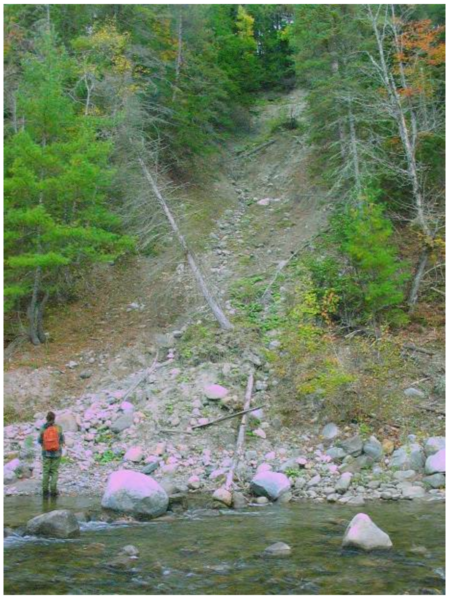


Figure 19. Sediment contributions from mass failures and gullies were relatively common along the South Branch of the Waits. Pink cast to rocks is just an artifact of poor photo quality.

Although mass failures and gullies were noted on 10 different reaches in Phase 1 and Phase 2 assessments, only two reaches were noted with moderate (reach T1.01, 2-5/mi.) or high (reach T1.03, >5/mi.) levels of mass failures and gullies. Large mass failures are noted in Phase 1 when they are visible during "windshield" surveys, which occurred on Waits mainstem reach M14, South Branch reach T1.11, and East Orange Branch reach T4.01.

Intermittent bedrock grade controls along the Waits mainstem (reaches M10, M09, M08, M06, M05) appear to act in conjunction with windrowing of coarser bed materials in reaches M10, M09 and M06 to contribute to planebed formation that has amplified stream power in flash floods and disrupted features that would store, sort and distribute sediments more equally under reference conditions. This dynamic is likely augmented by some ongoing "sediment starving" below the partially intact dam at the upstream end of reach T2.02 on the Tabor Branch (at the site of one of the old bobbin mills), as coarse sediments were noted in significant deposits upstream of the dam (Fig. 20). (The Tabor Branch enters the mainstem of the Waits downstream of reach M09.) The apparent result is a process of delayed channel evolution, or possibly a cycling between aggradation that is building new depositional features at bankfull and moderate flood flows, but then being scoured back out in higher flash flood events that appear to occur at relatively frequent intervals in differing, localized portions of the watershed.

Figure 20. Aggradation upstream (left) of a partially breached dam (right) on the Tabor Branch indicates likely ongoing "sediment starving" downstream.

Cobble-dominated sediments appear to be currently aggrading at the downstream end of the South Branch in reach T1.01 and downstream of the iron bridge at Chelsea Rd. (and the South Branch confluence) in reach M06, establishing new depositional features in a process of channel evolution, as well as near a braided section of river upstream of Johnson Drive in reach M05. Bar and pool formation in the narrow valleys of the watershed otherwise appear to occur as high flows "pulse" through alternating areas of bedrock constrictions and overwidened sections of stream, a dynamic resulting in deep scour pools at bedrock outcrops along the valley walls and weak depositional features that are frequently being reconfigured in high flows. Sandy and fine grained gravel materials were found widely dispersed in the planebed formations along the Waits mainstem, and are believed to be present in significant quantities upstream of the Bradford hydroelectric dam (this was difficult to confirm during fieldwork due to the depth of the water in this area).

Alluvial sediments are more common along upstream portions of the South Branch and Meadow Brook in Corinth, as well as in the apparent alluvial fan on Cookville Brook in the upstream portion of reach T1.06S1.01, and beaver activity in this portion of the watershed appears to coincide with a preponderance of these deposits in reaches T1.05, T1.08 and T1.09. Beaver dams appeared heavily impacted by flash flooding in both 2007 and 2008, with several areas of broken dams observed and only two intact dams assessed in the Phase 2 reaches (in reach T1.09). Despite the ephemeral nature of these dams, the combination of impoundments and low slope gradients in these areas serves to slow the transfer of both sediments and water to downstream reaches. Due to the types of soils present, sediments that do get moved are dominated by fines and are augmented by significant erosion along portions of the stream with sandy banks where woody buffers are lacking (common in reaches T1.05 and T1.09). These fine sediments are being transported long distances and are contributing to infilling of planebeds and relatively unstable depositional features in downstream reaches. Significant amounts of large woody debris present in reach T1.07 (and to a lesser degree in the downstream portion of T1.08) help to retain some of these sediments.

5.1.3 Reach-scale stressors

Watershed-scale stressors form a hierarchical pretext for understanding the timing and degree to which reach-scale modifications are contributing to field-observed channel adjustments (VT ANR 2007). 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 6). 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.

Table 6. Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (VT-RMP-RCPG 2007).

		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, • River corridor encroachments, • Localized reduction of sediment supply below grade controls or channel constrictions	• Upstream of dams, weirs, • Upstream of channel/floodplain constrictions, such as bridges and culverts
Energy Grade	**Depth**	• Dredging and berming, • Localized flow increases below stormwater and other outfalls	• Gravel mining, bar scalping, • 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)

Channel Slope and Depth Modifier Maps (Sections 5.1.4 and 5.1.5, respectively) can be used to determine whether stream power has been significantly increased or decreased. A Channel Boundary and Riparian Modifiers Map (Section 5.1.6) can help explain whether the resistance to stream power has been increased or decreased.

5.1.3a Channel slope modifiers

Analysis of channel slope modifiers in the Waits River watershed indicates that channel straightening is likely the predominant stressor in the basin, with indications of straightening observed in nearly 61% of the reaches assessed in Phase 2 and 37% of the total (in-depth Phase 1 and Phase 2) assessed reaches (Fig. 21). Channel straightening occurred historically through direct channel manipulation to supply mills on the Waits mainstem, the South Branch, both Meadow Brooks (Corinth and Bradford/Newbury, the latter aka Flanders Brook), Tabor Branch, Cookville Brook, the East Orange Branch, and possibly some of the other smaller tributaries of the watershed as well. In addition, straightening has occurred through a combination of incremental impacts including: road and development encroachments; structural measures such as riprap and bank toe stabilization; less direct maintenance of the channel "in its place" through field cultivation and ditching; 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.

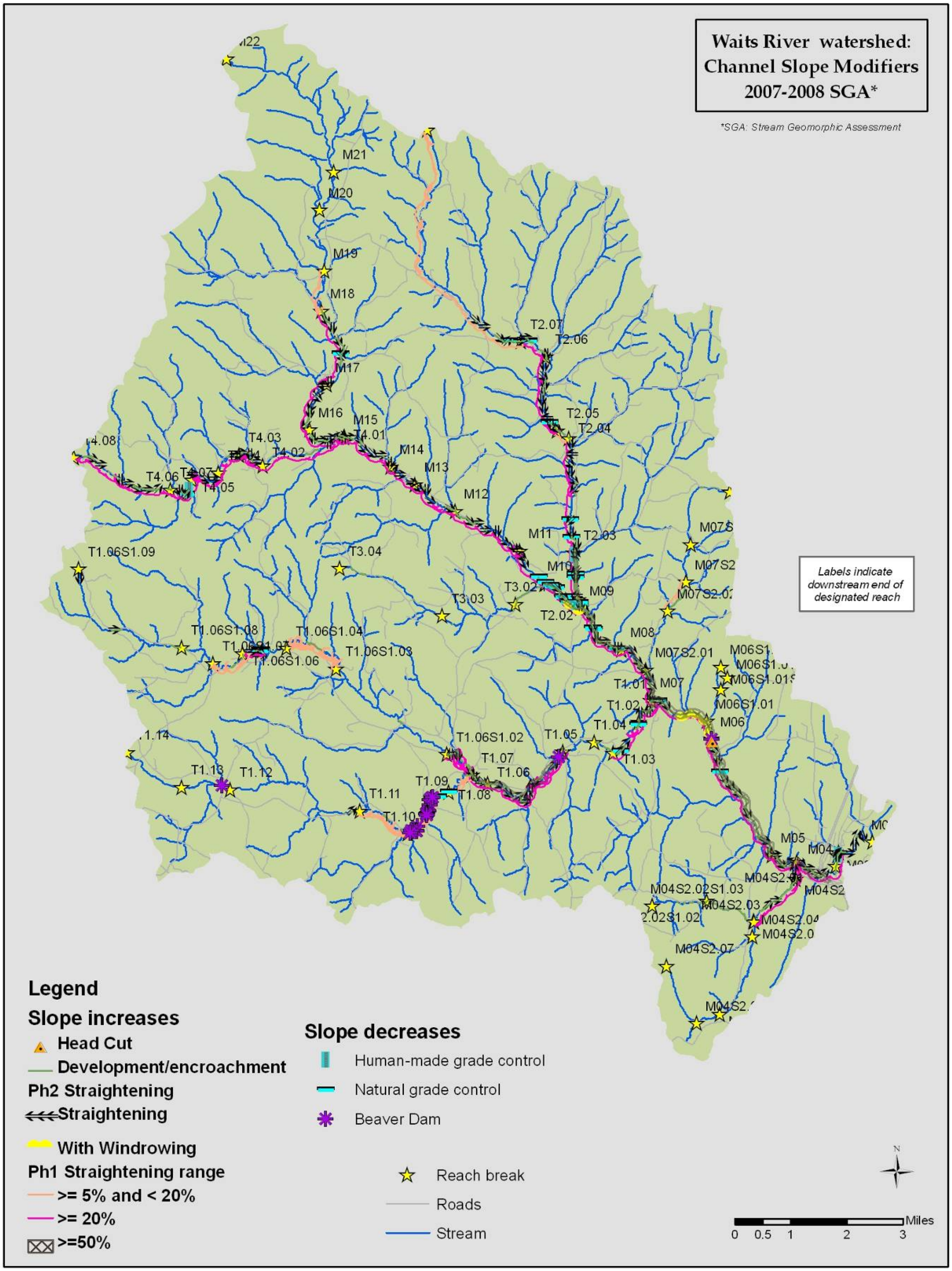


Figure 21. Channel slope modifiers map for the Waits River watershed.

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. Widespread ledge and bedrock outcrops and grade controls (Fig. 21) appear to have limited the vertical extent of stream bed downcutting in the Waits watershed overall, although all but one reach assessed in Phase 2 showed indications of historical incision.

Slope increases also appear to be limited by an interspersing of low slope gradients at higher elevations of the watershed, sometimes in combination with beaver activity (e.g., along Meadow Brook (Corinth) tributary T1, reaches T1.07 up; Meadow (aka Flanders) Brook (Bradford/Newbury), tributary M07S2; and upstream portions of Cookville Brook, T1.06S1 and Tabor Branch, T2, and Pike Hill Brook, T3; actual beaver dam locations indicated in Fig. 21 are generally collected as Phase 2 field data and may not appear on Phase 1 reaches if they are not visible in aerial photographs or during "windshield surveys"). Beaver activity often amplifies slope decreases in these low gradient areas through dam building and meander development along flooded side channels. Meander development decreases slope (and stream power) when the stream moves across slope gradients rather than dropping more directly. Channel straightening and development/encroachment in these areas thus negatively impacts an important mechanism for upstream diffusion of stream power and heightened sediment transport capacity. It should be noted that much of the historical incision (downcutting) within the Waits watershed likely occurred during the 19th century, a period when beavers were virtually extirpated in the state (Thompson and Sorenson 2000, p. 241).

5.1.3b Channel depth modifiers

Phase 1 and 2 data collection in the Waits River watershed indicates extensive amounts of road encroachment, with 23 of 28 stream segments assessed in Phase 2 (82%) indicating >=20%, 2 segments 5-20%, and 3 segments <5% encroachment within the segment (Fig. 22). Although there are rare instances where roads are at the same grade as the surrounding terrain, elevated roads within the river corridor increase the depth of flood flows, and thus also increase stream power. Stormwater inputs such as road and field ditches can contribute to these effects as well. Old field ditches were observed in Waits mainstem reach M08 (just downstream of East Corinth), and more recently active field ditches and drains are located in South Branch reach T1.05 (South Corinth near the store) and reach M04 (downstream of the South Main St. bridge). These field ditches augment the more frequent and extensive road ditches in the watershed in delivering water to the stream system more quickly, particularly in heavy downpours. These inputs work in conjunction with the extensive road encroachments, frequent intermittent ledge grade controls, and moderately erosion-resistant planebed substrates to elevate flow impacts throughout the majority of the reaches assessed in Phase 2 fieldwork on the Waits.

The relatively narrow valleys of the watershed can further heighten these impacts, particularly in areas where bedrock or human constructed constrictions narrow the valley significantly. Alternating areas of narrow constrictions and overwidened, “blown-out” sections of stream, with evidence of flows “pulsing” through the watershed, were common along the field-assessed portions of the Waits mainstem, the South Branch, and reach T2.02 on the Tabor Branch in East Corinth. Ice jams, sometimes with attendant flooding, are common along the Waits mainstem from the vicinity of reach M04 near the South Main St. bridge upstream to Bradford Center, approaching reach M06, as well as on the Tabor Branch in East Corinth. Ice damage was also frequently observed on the upstream side of trees along the banks of narrow portions of the South Branch (T1.01-T1.04) and the downstream reaches of Meadow Brook in Corinth (T1.07, T1.08). Fresh alluvial soils observed high along the banks of the Tabor Branch evidenced the wide extent of flows travelling above the ice, highlighting the potential impacts of these increased depths on streamside features and corridor encroachments and the importance of unrestricted floodplains in accommodating these stream processes.

Depth decreases in the Waits watershed were generally denoted by, and frequently augmented by, increased deposition occurring in: a) widened (or actively widening) portions of the stream and b) upstream of constrictions. Notable areas in the first regard include the decreases in stream power and attendant deposition associated with beaver activity and widening (more erodible banks than stream beds) along Meadow Brook in Corinth (T1.05, T1.09); an alluvial fan in the upstream portion of reach T1.06S1.01 on Cookville Brook; significant deposition at the base of the South Branch in reach T1.01; and a braided section of the Waits mainstem upstream of Johnson Dr. in reach M05, where the river has been dredged in the past to attempt control of ice jams. Significant deposition, particularly delta and backwater deposits, create the potential for more shallow depths during moderate flows due to the sediment build-up and the wider channel that results from the backwater conditions. Stream power is often reduced in these areas, leading to further deposition.

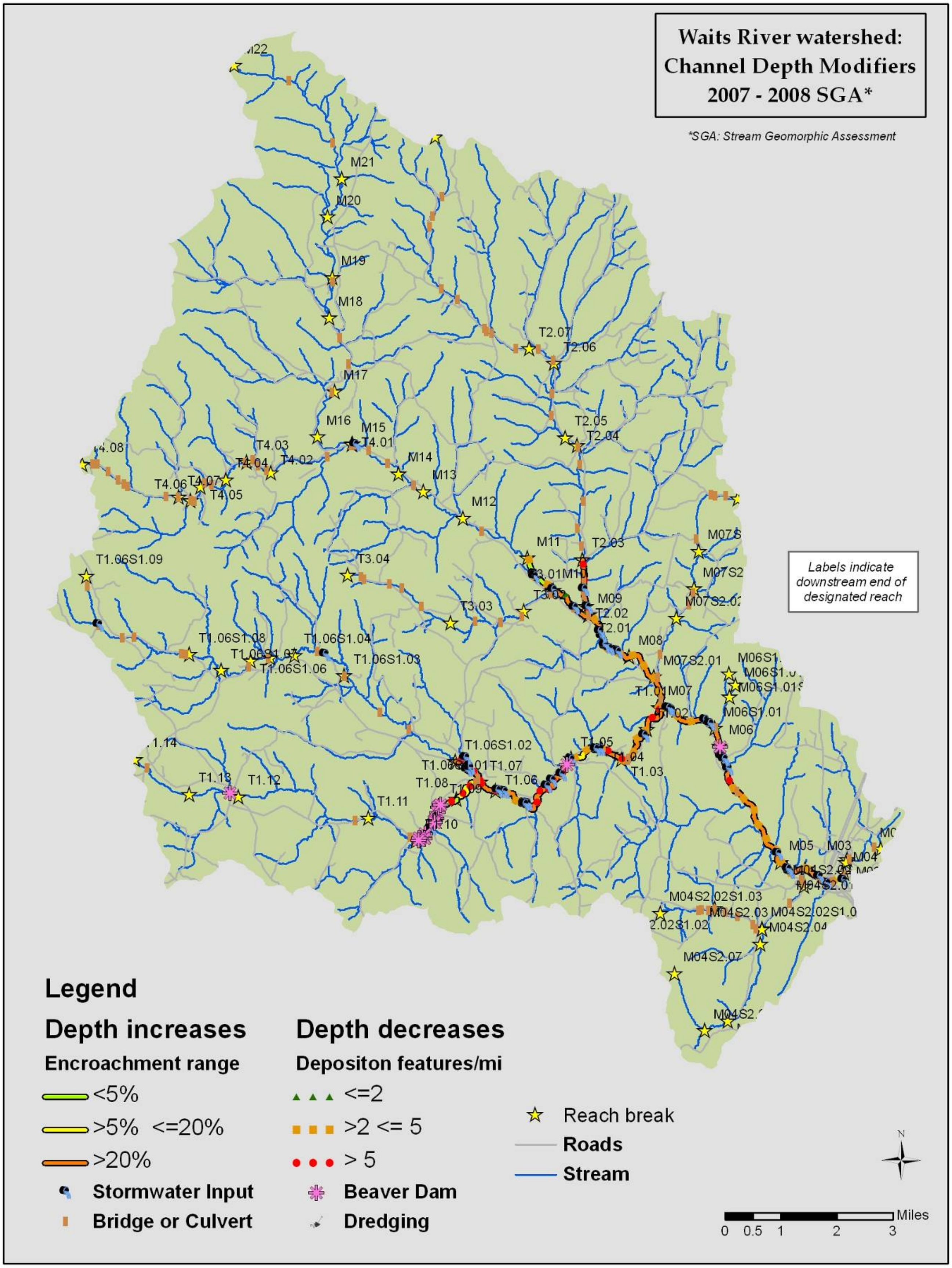


Figure 22. Channel depth modifiers map for the Waits River watershed.

The combination of ice scouring and "pulsing" of flows through the frequently interspersed narrow valleys of the basin (the frequent alternation of these valleys in downstream areas is a distinctive characteristic of the Waits watershed) may be limiting significant build-up of sediment deposits. A dominance of planebed forms with only moderate levels of depositional features (2-5 features/mi., with few areas of significant aggradation) along much of the Waits mainstem is likely related to these dynamics. Field observations indicated a cycling through channel evolution stages, with depositional features beginning to set up in moderately high flows or widened areas but subsequently being scoured out, rather than continuing to accrue in these areas (Fig. 23).

Figure 23. Frequent alternation of narrow and wide valleys along the Waits mainstem appears to contribute to cycles of channel evolution, with depositional features setting up in moderate flows and at widened areas upstream of constrictions (left, looking downstream) and subsequently being scoured back out in high flows and downstream of constrictions (right, looking upstream).

5.1.3c 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.

Only 3 of 28 segments assessed in 2007-2008 Phase 2 fieldwork on the Waits lacked a coarse bed substrate, all located in reach T1.09 on Meadow Brook in Corinth. Despite the lack of a coarse bed in these segments, bank conditions are even more highly erodible in reach T1.09 and channel evolution, and adjustment processes in that reach occur primarily through widening rather than downcutting.

Bank conditions in the other assessed reaches are not as erodible as in T1.09, but cohesive banks were only noted in 7 of the 28 segments assessed in Phase 2, mostly dispersed in upstream portions of the assessment area (Waits mainstem reaches M08 and M10, Tabor Branch reaches T2.01 and T2.02, South Branch reaches T1.03, T1.07, and T1.08). Given the combination of coarse bed substrates, dominantly non-cohesive banks, and elevated stream power in high flows currently characteristic of the watershed, elevated levels of erosion would be anticipated and in fact were encountered in field assessments. Moderate (5-20%) to high (>20%) levels of erosion were noted on 13 of the 19 reaches (17 of 28 segments) assessed in Phase 2 field work, and were most notable on the South Branch (Fig. 24; Table 7).

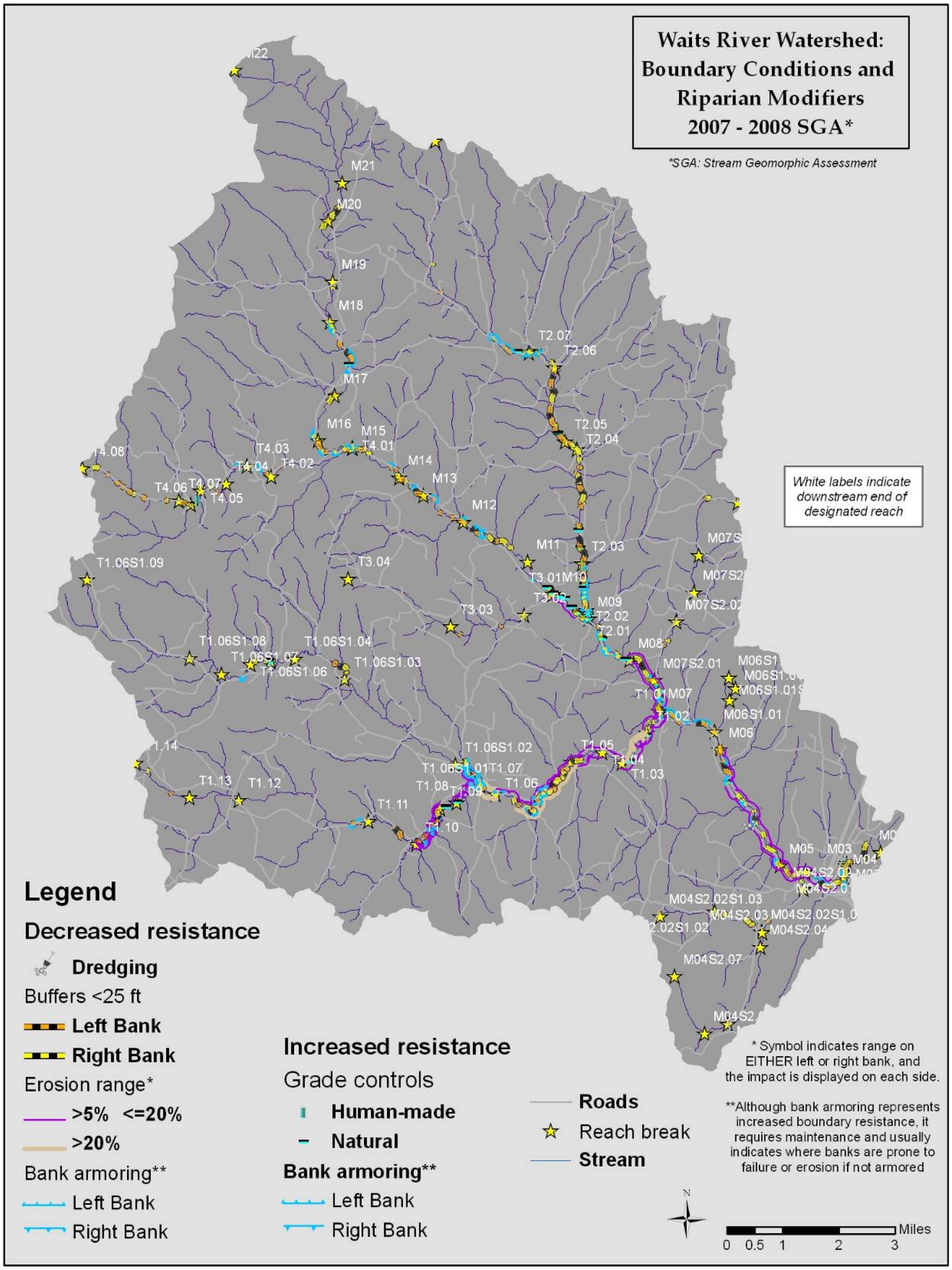


Figure 24. Boundary conditions and riparian modifiers map for the Waits River watershed.

Table 7. Waits River watershed segments noted with moderate to high levels of erosion during 2007 - 2008 Phase 2 assessments. A segment suffix of "-0" indicates the reach was not segmented.

	Left bank erosion		Right bank erosion	
Reach	>20%	>5% <=20%	>20%	>5% <=20%
Waits River mainstem				
M04		M04B		M04B
M05		M05A		M05A, M05B
M06				
M07		M07-0		M07-0
M08				
M09		M09B		
M10				
South Branch Waits River				
T1.01		T1.01-0		T1.01-0
T1.02		T1.02-0	T1.02-0	
T1.03				T1.03-0
T1.04		T1.04-0		T1.04-0
T1.05	T1.05A			T1.05A, T1.05B
T1.06	T1.06-0		T1.06-0	
T1.07				T1.07-0
T1.08				
T1.09		T1.09B, T1.09C		T1.09A
Cookville Brook				
T1.06S1.01		T1.06S1.01A		
Tabor Branch				
T2.01				
T2.02				

At first glance these levels of erosion do not appear particularly high, but a slightly different picture begins to emerge when bank armoring is also taken into account. Moderate (5-20%) to high (>20%) levels of erosion were noted on 13 of the 19 reaches (20 of 28 segments) assessed in Phase 2 field work as well (Table 8). Although bank armoring represents temporarily increased boundary resistance, it requires maintenance and usually indicates where banks are prone to failure or erosion if not armored. In addition, bank armoring frequently represents a hindering of channel evolution processes and a transfer of impacts (notably elevated stream power) to areas further downstream.

Table 8. Waits River watershed segments noted with moderate to high levels of bank armoring during 2007 -2008 Phase 2 assessments. A segment suffix of “-0” indicates the reach was not segmented.

	Left bank armoring		Right bank armoring	
Reach	>20%	>5% <=20%	>20%	>5% <=20%
Waits River mainstem				
M04		M04B		
M05		M05B		M05A, M05B
M06	M06A, M06B			M06B
M07		M07-0		M07-0
M08		M08-0		M08-0
M09		M09A		M09A
M10				
South Branch Waits River				
T1.01		T1.01-0		T1.01-0
T1.02		T1.02-0	T1.02-0	
T1.03				T1.03-0
T1.04		T1.04-0		T1.04-0
T1.05		T1.05A, T1.05B		T1.05A
T1.06		T1.06-0		
T1.07		T1.07-0		T1.07-0
T1.08				
T1.09		T1.09C		T1.09B
Cookville Brook				
T1.06S1.01	T1.06S1.01A	T1.06S1.01B	T1.06S1.01A	T1.06S1.01B
Tabor Branch				
T2.01		T2.01-0	T2.01-0	
T2.02	T2.02B, T2.02C	T2.02A	T2.02A	

There is a general overlap between areas with elevated levels of erosion and bank armoring and areas lacking buffers along the reaches assessed in 2007-2008 Phase 2 field work, with notable exceptions along the narrower reaches in the downstream portions of Meadow Brook (Corinth) and the South Branch and along the Waits mainstem (Fig. 24). Moderate to high levels of erosion in spite of well vegetated woody buffers suggest that the banks of these areas would be subject to high rates of erosion if buffers were removed or negatively impacted. It should be noted that trees that toppled into the streams from these buffers along Meadow Brook and the South Branch in particular were doing a great deal of work in slowing the movement of sediments downstream, in addition to substantially limiting soils losses on steep banks with mass failures.

5.1.4 Sediment regime departure, constraints to sediment transport, and attenuation

Within a reach, the principals of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (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. 25). 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 (VT-RMP RCPG 2007).

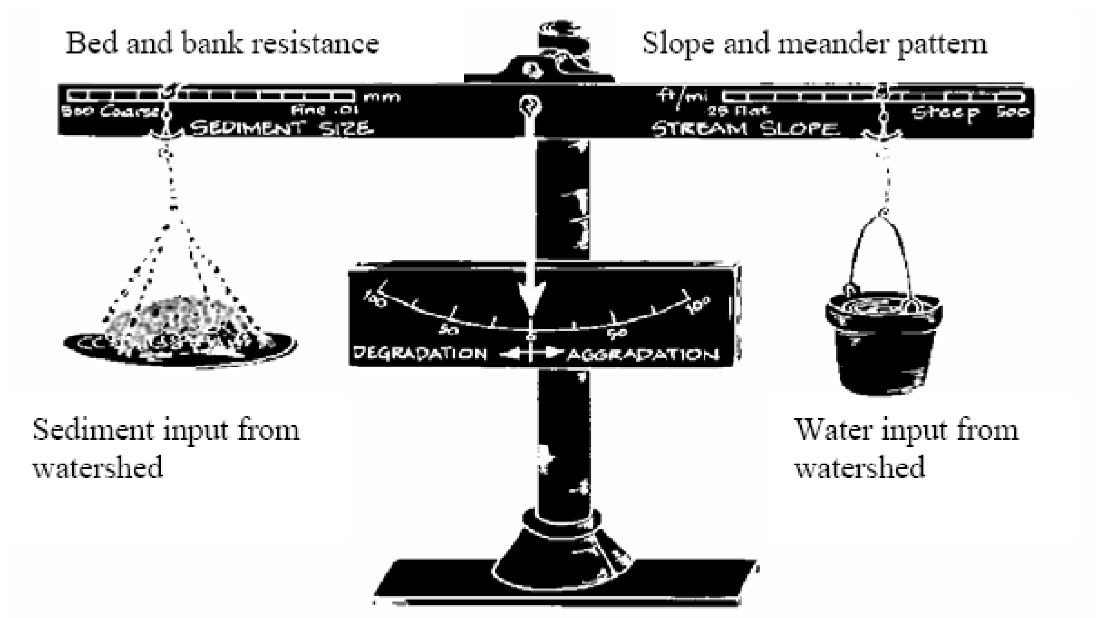


Figure 25. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955).

When stream power and sediment are relatively balanced, the 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 9; VT-RMP RCPG 2007, pp. 34–36).

Table 9. Pertinent Phase 1 reference sediment regime parameters for Waits River watershed reaches included in 2007- 2008 Phase 2 assessments.

Sediment regime	Natural valley types	Pertinent reference stream types	Applicable Waits River watershed reaches
Transport	NW Valley slope >2%	B4	T2.02
	NC Valley slope <2% (uncommon)	Bc3	T1.08
Coarse equilibrium (in = out) & fine deposition	SC	C3 (SC uncommon) Cb3 (SC a bit uncommon)	M07 M05, M06
	NW Valley slope >2% (a bit less common)	Bc3	T1.01, T1.07
	NW Valley slope <2%	Bc3, Bc4, C3, C4	M04, M08, M10, T1.02, T1.03, T1.04, T1.06
	BD, VB Valley slope <2%	C3, E4, E5	M09, T1.05, T1.06S1.01, T1.09, T2.01

Valley confinement type: NC, Narrowly confined; SC, Semiconfined; NW, Narrow; BD, Broad; VB, Very Broad

Substrate type: 3 = Cobble; 4 = Gravel; 5 = Sand Subslope: 'c' = <2%, 'b' = 2-4%

Based primarily on valley slope and confinement, 10 of the 19 reaches included in Phase 2 assessments in the Waits River watershed are considered C-type streams under reference conditions, with 3 additional E-type streams. The C-type stream is typically found in unconfined valleys, displays a meandering nature, and uses floodplains for sediment storage and dissipation of stream power. E-type streams display similar characteristics but also have a very low width to depth ratio and a more sinuous nature, generally flowing through fine-grained alluvial materials in very low gradient settings.

The six remaining reaches included in Phase 2 assessments in the Waits watershed would be considered B-type streams under reference conditions. B-type streams are usually in more confined valley settings with higher slope gradients, and often demonstrate a Transport sediment regime. In the Waits watershed, however, many B-type streams also have relatively low slope gradients (so-called "c" subslopes of <2%) and would be expected to store more sediments in their narrow floodplains than would higher gradient streams. In this scenario, the reference sediment regime for these streams would thus be Coarse Equilibrium and Fine Deposition as well, and the only B-type stream included in 2007-2008 Phase 2 assessments that would be a Transport reach under reference conditions would be Tabor Branch reach T2.02 in East Corinth. A somewhat uncommon occurrence also appears in the watershed in reach T1.08 on Meadow Brook in Corinth, where a valley slope of <2% occurs in a Narrowly Confined valley type. Due to increased stream power in high flows in such a confined valley, a reach such as this could reasonably be expected to function as a Transport reach under reference conditions.

Further natural anomalies exist in the Waits watershed as well, primarily due to the relatively narrow valleys of the watershed. These anomalies occur in the C-type streams of Waits mainstem reaches M05, M06, and M07; South Branch reaches T1.01, T1.02, T1.03 and T1.04; and Meadow Brook reach T.107, where some unusually narrow valley confinements and higher slope gradients affect sediment storage and transport on these streams. Although a Coarse Equilibrium and Fine Deposition reference sediment regime could reasonably be expected on these reaches, sediment storage capacity is significantly reduced by the width of the valleys, and higher gradients are likely to encourage greater transfer of sediments in high flows (such as flash floods). It should be noted, however, that reach T1.01 on the South Branch flattens out significantly near the confluence with the Waits mainstem and was storing substantial amounts of sediment of various sizes. T1.07 on Meadow Brook in Corinth was also observed storing significant amounts sediment (including fines) due to the amount of large woody debris in the stream. This is a particularly important function in headwaters streams that is less often observed in lower elevation streams.

The reduced sediment storage capacity and elevated turnover rates (in high flows) of so many reaches in the Waits watershed place a premium on the broader floodplains of the watershed for storing sediment and high flows. These valuable "attenuation assets" play a particularly valuable role in this watershed in alleviating flood hazards and impacts for downstream reaches as well as preventing excessive loss of nutrients through export out of the watershed. Waits reach M09 (just upstream of the Tabor Branch confluence) was the only Broad valley included in Phase 2 assessments, while reaches T1.05 (South Branch), T1.06S1.01 (Cookville Brook at confluence with South Branch), T1.09 (Meadow Brook) and T2.01 (Tabor Branch confluence with Waits mainstem) all have Very Broad valley confinement types.

The Coarse Equilibrium and Fine Deposition (CEFD) and Transport sediment regimes noted in Table 9 are generally observed on streams exhibiting equilibrium between stream power and sediment transport. Streams that are in a state of disequilibrium (and hence are adjusting to try to reestablish a balance between these factors) may exhibit additional sediment regimes (paraphrased from VT-RMP RCPG 2007, pp. 34–36):

> Confined Source and Transport (Yellow in Table 10): Steep gradients and narrow, confining valley walls; mass wasting and landslides common; storage of coarse or fine sediment is limited, so both are transported downstream due to high transport capacity derived from both the gradient and entrenchment of the channel
>
> Unconfined Source and Transport (gold in Table 10): Sand, gravel, or cobble plane bed streams; at least one side unconfined by valley walls; not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure leads to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from deep incision (downcutting) and little or no floodplain access
>
> Fine source & transport, coarse deposition (Red in Table 10): Sand, gravel, or cobble streams with variable bed forms; at least one side unconfined by valley walls; these

streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; increase in coarse sediment storage occurs due to a high coarse sediment load coupled with lower transport capacity that results from a lower gradient and/or channel depth.

These types of sediment regime departures, as observed in the Waits watershed, are further discussed in the next section.

Sediment regime departure

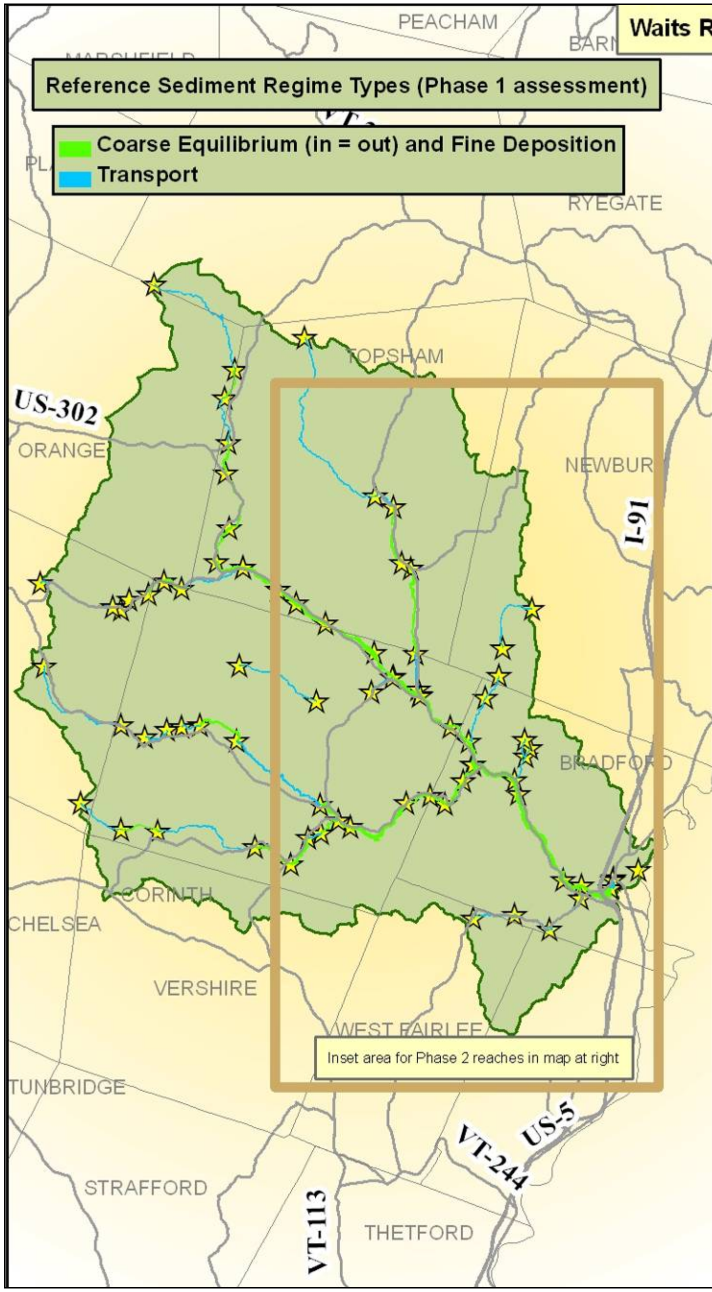
Phase 2 sediment regimes (which help identify current departures from reference conditions) are determined based on a number of parameters measured in rapid field assessments (VT-RMP RCPG 2007, pp. 34–36), as summarized in Table 10. These include field signs of active adjustment processes indicating that streams are in a state of disequilibrium, including a likely stage of channel evolution.

Table 10. Pertinent data for characterizing existing sediment regime using Phase 2 data (VT ANR RCPG 2007).

<table>
<tr><td rowspan="2">Transport</td><td rowspan="4">Incision <1.3</td><td colspan="3">Valley type = NC, SC, or bedrock gorge</td></tr>
<tr><td rowspan="2">Valley type = NW</td><td colspan="2">Stream type = A, B, or F</td></tr>
<tr><td rowspan="2">Coarse equilibrium & fine deposition</td><td colspan="2">Stream type = Bc, C, or E</td></tr>
<tr><td colspan="3">Valley type = BD or VB</td></tr>
<tr><td>Confined source & transport</td><td rowspan="4">Incision ≥1.3</td><td colspan="3">Valley type = NC or SC</td></tr>
<tr><td>Unconfined source & transport</td><td rowspan="3">Valley type = NW, BD, VB</td><td rowspan="2">Channel evolution stage = I/II/III/V</td><td>Bank armoring and straightening ≥50%</td></tr>
<tr><td rowspan="2">Fine source & transport, coarse deposition</td><td>Bank armoring or straightening <50%</td></tr>
<tr><td colspan="2">Channel evolution stage = IV</td></tr>
</table>

Phase 2 assessments in the Waits watershed indicated that, in contrast to seventeen Phase 1 reaches that would function as Coarse Equilibrium and Fine Deposition (CEFD) areas under reference conditions, only nine segments (smaller portions of reaches) in six Phase 2 reaches currently function with CEFD sediment regimes (Waits mainstem reaches M04 and M07, South Branch reach T1.01, Cookville Brook reach T1.06S1.01, and Meadow Brook reaches T1.07 and T1.09). Most currently function as Transport streams, with heightened erosion and elevated stream power contributing to conversion (or augmentation) of nine segments to Fine Source & Transport and Coarse Deposition, six segments to Confined Source and Transport, and four segments to Transport sediment regimes (Fig. 26). These alterations appear to be largely driven by the narrow valleys of the watershed and changes in hydrology, with patterns of sediment transport and storage strongly affected by (but also affecting, particularly in the case of planebed formation) increased stream power.

Waits River Watershed Sediment Regime Departure



Map at left indicates reference sediment regimes for 60 reaches within the Waits watershed, based primarily on valley type and slope. This Phase 1 assessment shows 26 reaches of the watershed with reference Transport sediment regimes, and 34 reaches with "Coarse equilibrium and Fine Deposition" (CEFD) sediment regimes. CEFD streams utilize access to their floodplains as a primary means to store sediment and nutrients within the watershed. 19 reaches were included in 2007-2008 Phase 2 assessments (inset); 17 of these have CEFD reference sediment regimes. Only two tributary reaches in upstream portions of the Phase 2 assessment area have Transport sediment regimes under reference conditions.

Due primarily to changes in hydrology and attendant changes in sediment storage and transport within the narrow valleys of the watershed, existing stream types and dynamics identified in Phase 2 field work (map at right) indicate that only nine segments (smaller portions of reaches) in six Phase 2 reaches currently function with CEFD sediment regimes; most have been converted to some type of transport regime. This means that most sediment entering the stream is either:
a) transported long distances (fines) and frequently contributing to infilling of planebeds;
b) is being dropped out when the load reaches a point the stream cannot carry (particularly at channel constrictions).

Ledge grade controls have helped limit downcutting in both downstream and upstream portions of the watershed. Current stream adjustments thus primarily include widening and appear strongly related to elevated stream power, with a strong predisposition to flash flooding and ice jams in the watershed. These impacts are augmented by:
a) extensive encroachment in conjunction with naturally narrow valleys in the watershed; and
b) extensive straightening and changes in hydrology (esp. a reduction of the time it takes water to reach the streams), further increasing stream power in floods.

Corridor protection to allow unrestricted access to remaining floodplains and the important role of beaver activity, plus establishment and maintenance of woody buffers that slow the rate of water inputs to the stream and contribute large woody debris that plays a critical role in slowing the movement of water and sediments in narrow valleys, are high priorities for helping attenuate stream power and flood impacts in the Waits River watershed.

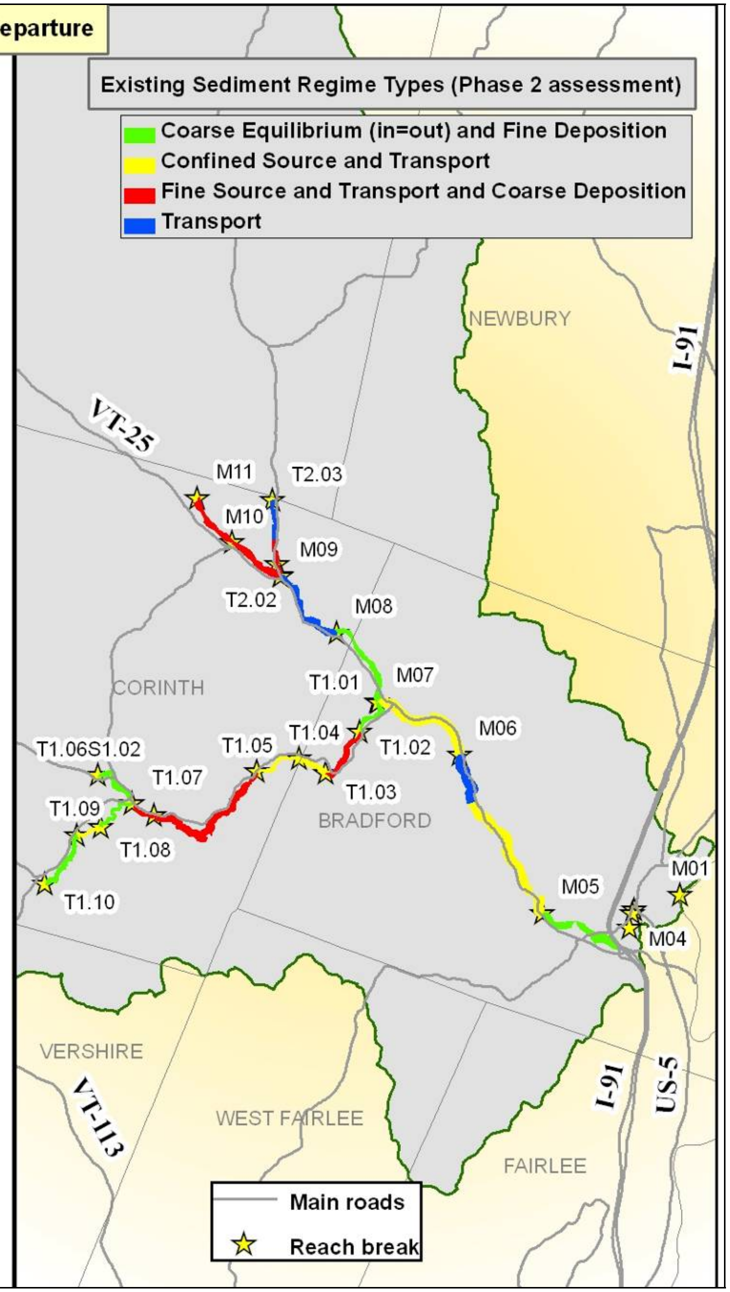


Figure 26. Sediment regime departure map for the Waits River watershed.

Due to the conversion of a large majority (11 of 17 reaches) of Coarse Equilibrium and Fine Deposition sediment regimes to various transport sediment regimes in Phase 2 reaches, fine grained "washload" materials are often being transported long distances through the watershed, dropping out only when low velocity conditions are encountered and frequently contributing to infilling of planebeds in downstream reaches. Channel widening and elevated levels of erosion plus concentrated deposition at channel constrictions, tributary mouths, and overwidened sections of the stream characterize a Fine Source & Transport and Coarse Deposition sediment regime in segments M09A and B and M10 on the Waits mainstem; T1.02, T1.05A and B, and T1.06 on the South Branch; and T2.01 and T2.02A on the Tabor Branch. Given flash floods that have occurred in various portions of the watershed in the last two decades, this current sediment regime appears related to the movement of flood-related sediment discharges through the stream network. Although Mill Pond Brook and Rowell Brook were not included in 2007-2008 Phase 2 assessments, a similar "coarse deposition" sediment plug (likely related to a 1998 flash flood) was observed at the base of those streams where they reach the Waits mainstem in reach M04 (Fig. 8). In addition, it should be noted that reach T1.09 on Meadow Brook currently functions with a Coarse Equilibrium and Fine Deposition sediment regime but is extremely sensitive to changes in watershed inputs and has experienced two significant flash flood events, cumulatively significant land clearing, and some significant straightening in upstream reaches during and since the completion of 2007-2008 assessments that will likely be contributing flood-related sediment discharges to this area in the relatively near future.

Historic incision has contributed to imposition of a Confined Source and Transport regime on Waits mainstem segments M05A, M06A and B; South Branch reaches T1.03 and T1.04; and Meadow Brook reach T1.08. Reach T1.08 would be a Transport reach under reference conditions, but channel adjustment processes following historic downcutting currently include elevated sediment discharges from this reach, increasing the importance of large woody debris in reach T1.07 in attenuating these discharges.

Tabor Branch reach T2.02 was the only Phase 2-assessed reach besides T1.08 that would be characterized by a Transport sediment regime under reference conditions. Transport streams assessed in Phase 2 included Waits mainstem segments M05B and M08 and Tabor Branch segments T2.02B and C. Although there have been significant historic impacts on the Tabor Branch, bedrock controls in the upstream portions of reach T2.02 appear to have limited historic incision and current adjustment processes, and the reach currently retains a Transport sediment regime (unlike segment T2.02A, which is characterized by a Fine Source & Transport and Coarse Deposition sediment regime). The current Transport regimes of Waits mainstem segments M05B and M08 represent a sediment regime departure from reference conditions (Coarse Equilibrium and Fine Deposition), and the impacts that are thus being transferred downstream increase the importance of unrestricted access to even the small amounts of floodplain available in these narrow valleys for attenuating flow and sediment discharges.

Channel evolution

Once 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. Schumm (1977 and 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. 27). The five stages of channel evolution for F-model evolution are paraphrased from the SGA protocols (VT-RMP geoassesspro 2007, Appendix C) 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.

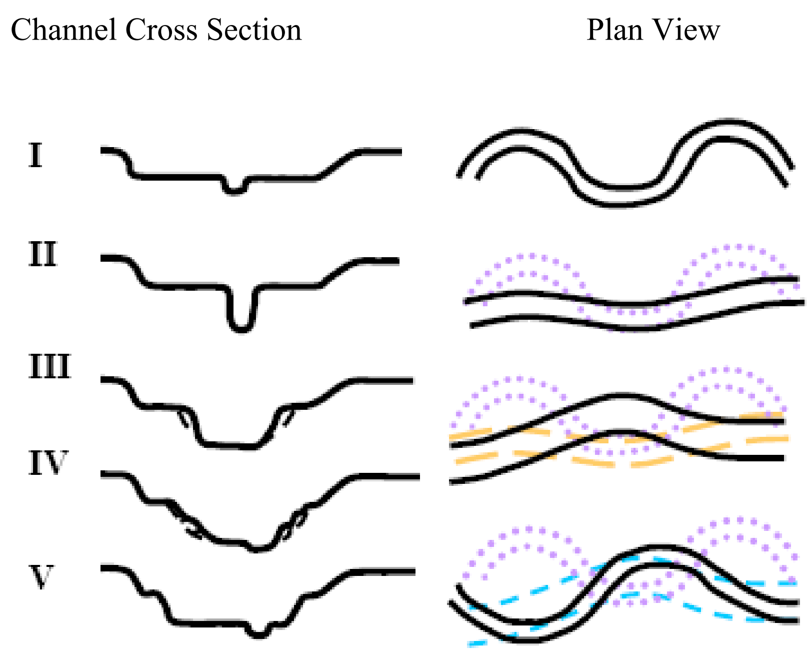


Figure 27. Channel evolution process showing channel downcutting or incision in Stage II (cross section), widening through Stages III and IV, and floodplain reestablishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a primarily flood-driven process often taking place over decades (VT-RMP RCPG 2007).

A number of Phase 2-assessed streams in the Waits River watershed also exhibited a second model of channel evolution ("D-model" evolution) that is more typical in areas where stream banks are more erodible than the bed. Under these conditions the stream does not significantly incise and instead evolves primarily through widening and/or lateral movement. The three stages for D-model channel evolution are paraphrased from the SGA protocols (VT-RMP geoassesspro 2007, Appendix C) as follows:

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

Then either of the following Stage II scenarios may occur:

> **Stage IIc. Widening/Migration** — Widening and migrating laterally through bank erosion caused by increased stream power. The balance between stream power and boundary materials is re-established when the slope flattens after a process of channel lengthening and increased sinuosity.
>
> **Stage IId. Braiding** — Extreme deposition and braiding, with water flowing in multiple channels at low flow stage ("D" stream type). Channel width narrows through aggradation and the development of bar features. Main channel may shift back and forth through different channels and chute cut-offs, continuing to erode banks or terraces.
>
> **Stage III. Stable** — Channel adjustment process is complete (back to a B, C or E stream type).

Phase 2 work assessed 25 of 28 stream segments in the Waits River watershed corridor at a stage of evolution featuring widening and planform adjustments. Stage III in F-model channel evolution was noted on 21 of these segments, with widening and planform adjustments following historical incision (Fig. 28). Four segments were noted in stage IIc, an equivalent widening stage in D-model channel evolution: T1.06S1.01A and B at the base of Cookville Brook and T1.09B and C on Meadow Brook. The only stream segments noted in a stable or stabilizing stage of channel evolution during 2007-2008 assessments were T1.05B on the South Branch and T1.08 and T1.09A on Meadow Brook.

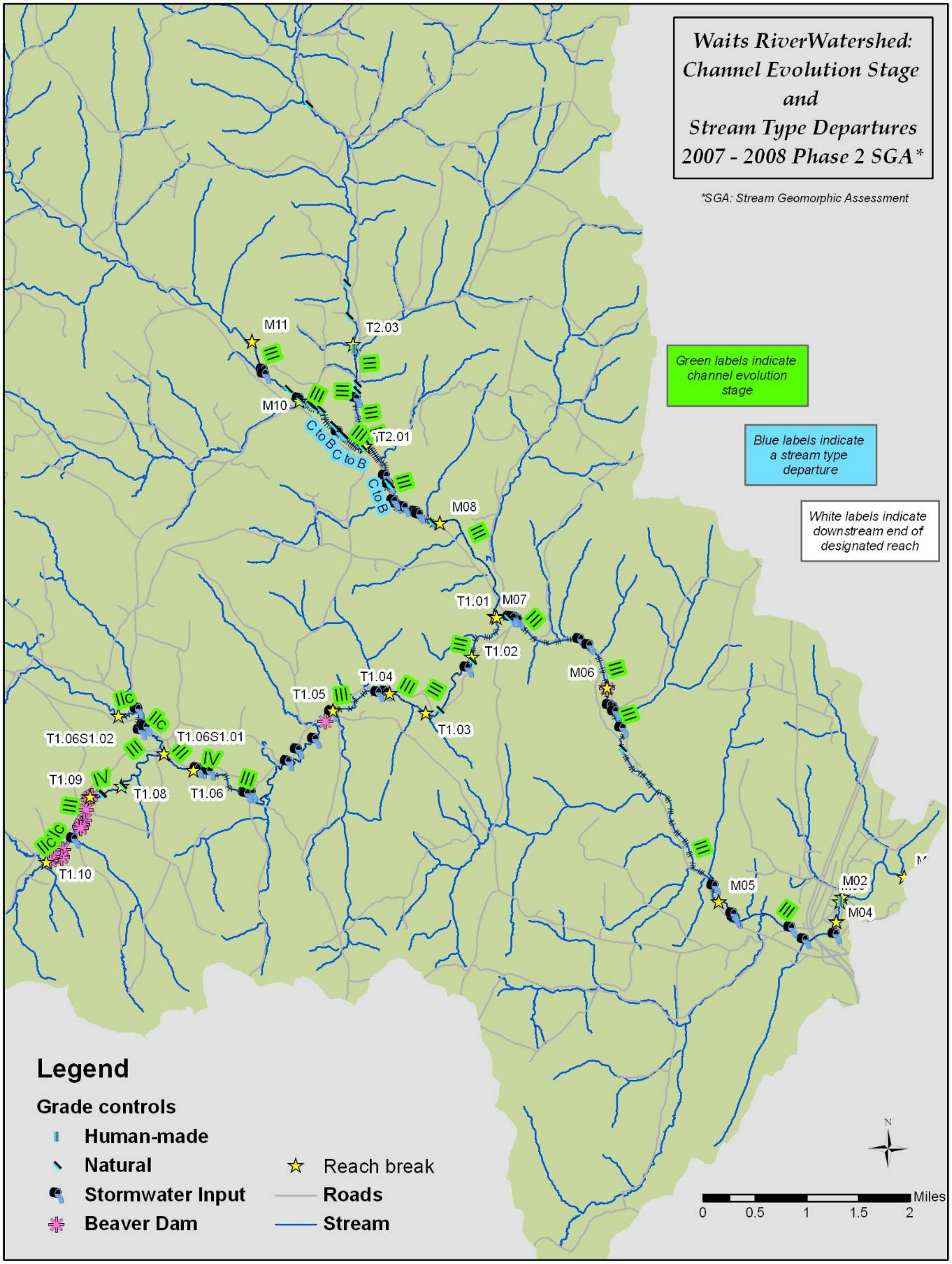


Figure 28. Channel evolution stage and stream type departures map for the Waits River watershed.

Loss of access to historic floodplains, represented by departure from C-type streams to B- or F-type streams (entrenched in narrower valleys), was indicated in three segments on two reaches assessed in 2007-2008, M08 and M09A and B, and was likely in Tabor Branch segment T2.02B. The term "likely" is used here because T2.02B is bedrock-controlled at this point in time and there were no discernible indications of the historic incision that is strongly suspected in this area due to the impacts of historic concurrent operation of six mills along the Tabor Branch between East Corinth and Topsham Four Corners. Most of the other segments along this stretch showed clearer indications of historic downcutting resulting from sediment starving and pulse flows engendered by the extensive flow regulation in this area (see section 5.1.1, *Watershed-scale hydrologic stressors*, for more on these dynamics). Because of the lack of indicators of incision this segment was noted as a reference F type stream, and it is possible that downcutting did not occur here because of the extensive bedrock, but signs of incision both upstream and downstream make it far more likely that this segment departed from a B to an F type stream historically and there are no indications of this process left due to subsequent scouring of the channel.

Wide dispersal of coarse bed substrates and ledge or bedrock grade controls in the Waits River watershed has helped to limit the vertical extent of channel incision and loss of floodplain, but some impairment of floodplain function was indicated in Phase 2 assessments in all reaches except T1.09 on Meadow Brook and M08 on the Waits mainstem. This partial reduction in floodplain capacity entails loss of floodplain access in moderate to high flow events but not high flow events exceeding twice the maximum depth of the channel. An apparent consequence of this dynamic is that sufficient (though reduced) floodplain capacity is distributed throughout the watershed to absorb the impacts of the largest flash floods by the time those inputs accumulate in the larger downstream reaches of the watershed. Elevated flows at more moderate levels, however, are being contained within a much narrower area than the floodplains that were available historically. The cumulative impacts of impairment of floodplain access and elevated stream power heighten pressure on banks and narrow valley walls, and contribute substantially to the predominance of stage III (widening) channel evolution in the majority of the Phase 2-assessed reaches in the Waits watershed.

Sediment discharges appear to be moving through the stream network following flash flood events but may be disrupted from setting up stable features, such as riffles and pools, by the heightened stream power moving through the channel in subsequent moderate to high flow events (especially in narrower valleys). Channel migration and bifurcation (i.e., splitting of flows around deposits or islands) is common in the narrow valleys of the watershed. Heightened hydrologic inputs in "urban" areas, combining increases in impervious surfaces in conjunction with increased numbers of stormwater inputs, can keep pushing downstream reaches into adjustments. (Although the Waits watershed does not appear on its face to be an "urban" environment, see section 5.1.1, *Watershed-scale hydrologic stressors*, for further discussion of the applicability of this terminology). Further incision is largely limited, and channel adjustments and evolution appear to be cycling, or have high potential to continue cycling, through stages III and IV in much of the watershed.

Channel adjustments due to increased flows can be difficult to remediate in downstream reaches (Booth and Jackson 1997), potentially prolonging the stages of disequilibrium in these streams and leaving them open to heightened flood impacts in future events. This places a premium on attenuation of high flows and sediment discharges in upstream reaches, and increases the importance of:

a) protecting and maintaining floodplain access even on small streams high in the watershed;

b) limiting development and encroachments within stream corridors and narrow valleys;

c) establishing and maintaining woody buffers in riparian corridors and

d) managing stormwater inputs to minimize direct discharges to streams.

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 curtail the rate of channel evolution and exacerbate the impacts of increased stream power on downstream reaches.

Constraints to channel evolution

Ledge outcrops interspersed throughout the 2007-2008 Phase 2 assessment areas in the Waits River watershed represent significant constraints to vertical channel evolution, and have likely limited loss of valuable floodplain access through channel downcutting. As noted in the previous discussion of channel evolution, the widespread interspersal of these grade controls strongly orients channel evolution in the Waits watershed to widening and lateral migration as the primary means of re-establishing equilibrium.

It is notable that recurrent interspersal of narrow valleys (with frequent bedrock outcrops in valley sidewalls and streambanks commonly observed) adds significant natural constraints to lateral channel evolution in the Waits watershed as well. Settlement patterns in the watershed have featured extensive road encroachment and concentrated development in a number of villages situated in close proximity to the stream. Human-built lateral constraints are concentrated along the Waits River mainstem due to the Waits River Rd./Rte. 25 that runs alongside the river through much of its length (Fig. 29), especially in the vicinity of Bradford Center along Waits mainstem reach M05. A similar high density of lateral constraints exists along the Village Rd. in East Corinth village along reaches T2.01 and T2.02 on the Tabor Branch. Less concentrated constraints exist on virtually every reach assessed in Phase 2 except T1.08 on Meadow Brook. The combination of natural and human-constructed lateral constraints places a premium on minimizing imposition of further lateral constraints to channel evolution along the streams of the Waits River watershed. It should be noted that because of the frequent alternation of these constraints in narrow and wide valleys within the Waits watershed, stream equilibrium (and reduction of flood hazards) may depend to an unusually high degree on protection of even limited opportunities for floodplain access and lateral migration.

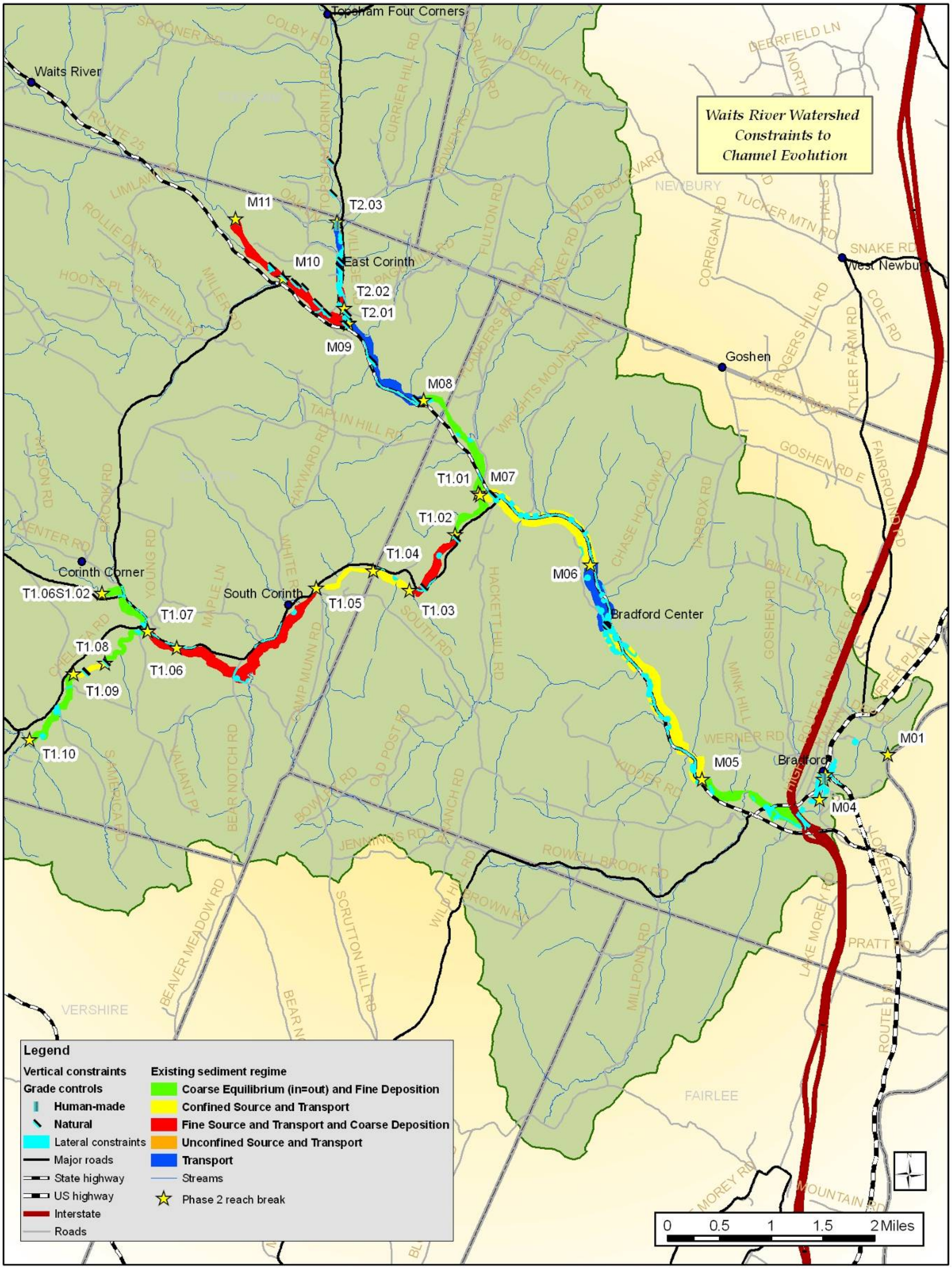


Figure 29. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution in the Waits River watershed 2007-2008 Phase 2 assessment area.

Attenuation assets

Given the significant number and degree of lateral constraints along the Waits River Rd. in particular, and the frequent road encroachment throughout the area (and hence significant investments in maintenance of infrastructure for both municipal and state organizations), protection of attenuation assets in upstream reaches of the assessment area will play an especially important role in storing fine sediment discharges and mitigating flood impacts on downstream reaches by accommodating and diffusing high flows. Key assets include:

- Meadow Brook reach T1.09 (Chelsea – Goose Green Rd. hayfields from downstream of Abe Jacobs Rd. to downstream of Eagle Hollow Rd.)
- South Branch reach T1.05 (Chelsea – Goose Green Rd. in South Corinth in vicinity of the store)

With re-establishment of equilibrium conditions in downstream reaches largely dependent on flow and sediment discharges in upstream reaches, further emphasis (and priority) is placed on protection of these upstream assets. A singular exception to this emphasis on protection of upstream attenuation assets exists in the vicinity of the Apppleton farm in downstream segment M04B. Massive berms installed during the construction of Interstate-91 cut off nearly half of the historic Waits River mainstem floodplain in this area, dramatically increasing the importance of the remaining available floodplain for storing flood flows in particular. With the Bradford dam located a short distance downstream, heavy deposition of fines on the bed of the stream observed in reaches M03 and M04 indicate that this area also play an important role in storing sediment from upstream discharges.

Upstream tributary confluences are usually of particularly high value in fulfilling these same functions (attenuating flow and sediment discharges and mitigating flood impacts), but the 2007-2008 Phase 2-assessed portions of the Waits watershed found none of these assets undeveloped at this point in time. While these constraints place a higher value on protecting the undeveloped (or less developed) wide floodplains mentioned above, the tributary confluences (despite some restriction) still play a vital role meriting protection of remaining assets. Key assets in this category include:

- Cookville Brook reach T1.06S1.01 (Devins Farm); there are some moderate development constraints in the upstream portions of the reach where the farm buildings are located
- South Branch reach T1.01, especially in the downstream portion of the reach approaching the Waits mainstem confluence(near Fisk's); there are some moderate development constraints in this area
- Tabor Branch T2.01 and Waits mainstem reach M09 (downstream end) in the vicinity of the Tillotson farm. Stream access of this floodplain by the Tabor Branch appears unlikely along much of Village Rd., and the Waits mainstem has access restricted to some degree by windrowed stone on the left bank. The floodplain slopes up from the Waits mainstem and determination of the amount of floodplain that could be accessed through removal of some of this stone would need higher resolution survey details than are collected in phase 2 assessments.

With broader floodplains at tributary confluences restricted to some extent by lateral constraints some of the narrower floodplains of the watershed play an important, if less, extensive, role in attenuating flow and sediment loads in the Waits watershed. Of particular note in the 2007-2008 Phase 2 assessment area were:

- Waits mainstem reaches M07 and M08, a somewhat unusual section of stream in that these low gradient reaches are located in relatively narrow valleys (M07 Semi-confined, M08 Narrow). The narrow floodplains do fulfill some important functions, and the current lateral constraints in this area are primarily from extensive road encroachment rather than other development constraints.
- Waits mainstem segment M05B, which is a B type stream but is a low gradient stream ('c' subslope) and as such has some capacity to store sediments and high flows. This reach has experienced sufficient changes (primarily road encroachment) to convert the sediment regime from Coarse Equilibrium and Fine Deposition to a Transport regime, and is located downstream of a reach (M06) that has been converted to a Confined Source and Transport regime due to significant straightening and some windrowing of sediments from the stream. Although there are development constraints in addition to the road encroachment from Rte. 25, there are pockets of available floodplain, particularly in the vicinity of Kenyon Rd., that can play an important role in helping the stream move back toward equilibrium conditions, particularly through sediment storage.

Existing sediment regime summary

To summarize, the existing sediment regime in the 2007-2008 Phase 2-assessed portions of the Waits River watershed features:

- Increased stream power largely driven by changes in hydrology (land clearing, significant straightening and encroachment, increased stormwater inputs), heightened by the effects of restricted access to historic floodplains, has converted the large majority of reaches in the assessed areas to various types of sediment transport (rather than storage) regimes
- Historic incision (downcutting of streambeds) was widely noted and likely related to "sediment starving" and pulse flows due to extensive historic mill dam presence in the watershed
- Incision has been limited to some extent by the presence of ledge grade controls that are widely dispersed throughout the watershed, and appears to be a current adjustment only in limited portions of the watershed
- Sediments are now being recruited primarily through mass failures along steep valley walls and bank erosion as streams try to re-establish a new equilibrium in response to elevated stream power, and widening is the dominant current adjustment observed in the watershed
- Riffle, pool, and other feature formation is weak along the assessed portions of the Waits mainstem in particular, and planebeds are the current dominant bedform; dominant cobble substrates were frequently observed with significant infilling by fine sediments that are depositing primarily in overwidened portions

of the stream channel because there are only small areas of floodplain being accessed in all but the highest flood flows in downstream reaches

- While flash flooding events appear somewhat common in the smaller streams in upper portions of the watershed, these flows are often absorbed by the time they reach the larger streams in lower elevations of the watershed and are not commonly accessing historic floodplains
- Dominant planebeds lacking many of the features that help diffuse stream power thus combine with limited access to former floodplains to further elevate the effects of stream power on erodible banks and valley walls in the intermittent narrow valleys that are common in the Waits watershed
- Although valuable attenuation assets are provided by some of the broadest floodplains, located in upstream portions of the watershed (T1.05 on the South Branch and T1.09 on Meadow Brook were the most prominent examples in the 2007-2008 assessments), the streams in these areas are dominated by highly erodible former glacial lake deposits; these areas are extremely sensitive to changes in watershed inputs such as increased flows that can be caused by straightening, encroachments and bank armoring, and localized microbursts and similar intense storms
- Ice jams are common in the watershed due to the frequent alternation of narrow and wide valleys, even in the downstream portions of the watershed; jams have been particularly common on the Waits mainstem in the vicinity of Bradford Center but evidence was also observed during Phase 2 assessment ins the narrow valleys of the South Branch and Tabor Branch
- Dredging to attempt control of ice jams has occurred historically in reach M05 on the Waits mainstem, and windrowed materials appear to have been pulled out of the stream bed in reach T2.02 on the Tabor Branch in East Corinth and upstream of the Village Rd. bridge in Waits mainstem reach M09, likely in response to sediment plugs occurring at bridges that were not adequately sized to transport both water and sediment in flood flows
- Extensive encroachment from the Waits River Rd./Rte. 25 has resulted in further constriction of naturally narrow valleys in many areas, as well as significant bank armoring and additional windrowing (e.g., reach M06 downstream of the iron bridge and M07 near the old bridge abutments near Flanders Brook Rd.)
- The combination of ice scour, straightening, windrowing and bank armoring is contributing to maintenance of elevated levels of stream power along the mainstem of the Waits in particular, and it is not clear if these factors are prolonging disequilibrium through a cycling of channel evolution between widening, deposition, and subsequent scouring and disruption of feature formation by ice and elevated stream power, or whether these impacts have significantly disrupted stream equilibrium and the Waits mainstem in particular has not had sufficient time to move toward a new equilibrium following these impacts

The combination of increased stream power and sediment discontinuities raise the following issues on the portions of the Waits mainstem and Tabor Branch assessed in 2007-2008:

1. Heightened stream power is difficult to remediate downstream, increasing the importance of opportunities for attenuating flow in upstream reaches
2. Intermittent naturally narrow valleys and extensive encroachment and lateral constraints to channel evolution limit opportunities for attenuating high flows and increase the importance of accommodating lateral movement of the stream and protecting remaining undeveloped floodplains
3. The widely dispersed nature of these limited areas of floodplain and the erosion hazards posed by lateral movement of streams make it likely that municipal actions to protect these areas will be more effective and efficient than parcel by parcel conservation efforts
4. Sediment windrowing and bank armoring can significantly retard the process of channel evolution and further increases the impacts of elevated stream power on downstream reaches
5. Adequate sizing of bridges and culverts to transport both sediment and flow discharges (including an accounting of the role that piers and alignment play in effective functional width of the structure) can help reduce the need for windrowing and bank armoring as remediation for flood impacts, lowering long-term maintenance costs and transfer of impacts to downstream reaches
6. Stormwater inputs further increase streampower and potential flood impacts, and should be directed onto well-vegetated surfaces and managed to avoid direct inputs to the stream as much as possible
7. Well vegetated woody buffers play a large role in mitigating the impacts of elevated stream power by decreasing the rate at which water enters the stream and physically diffusing stream power in floods

Portions of the South Branch, Meadow Brook, and Cookville Brook included in 2007-2008 Phase 2 assessments include extensive areas of former glacial lake deposits with fine-grained and/or highly erodible geologic materials, as well as some of the broadest floodplains in the watershed. These factors raise the following issues in this portion of the watershed:

1. The presence of important, relatively undeveloped floodplains in larger parcels make parcel by parcel conservation practices more feasible in this portion of the watershed
2. Low-gradient, beaver-impacted areas play an important role in attenuating flow and sediment loads and are highly to extremely sensitive to imposition of lateral constraints including development encroachments, stream crossing (i.e., bridges and culverts), and structural measures designed to maintain the stream in a straightened or fixed location
3. Sandy banks along extensive portions of the streams in this area are extremely erodible and contribute fine-grained sediments that do little to contribute to

formation of stable stream features, instead often being transported long distances and contributing to infilling of planebeds in downstream reaches

4. Maintenance of undisturbed native vegetation in buffers along low-gradient streams in these areas helps reduce erosion and store fine sediments on floodplains more effectively
5. Well vegetated woody buffers in narrower, steeper gradient valleys help decrease the rate at which water enters the stream, stabilize erodible materials on valley sideslopes, and play a large role in meander development, formation of depositional features, and sediment retention through contributions of large woody debris; the latter fact is particularly important in slowing and reducing the transfer of fine-grained sediments
6. The extreme sensitivity of some of the streams in this area to changes in watershed inputs mean that changes in hydrology including increased land clearing or direct stormwater inputs upstream may result in rapid stream adjustments, particularly heightened erosion in areas lacking well vegetated woody buffers

5.2 SENSITIVITY ANALYSIS

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain current sediment regime departure in the 2007-2008 Phase 2 assessment area of the Waits River watershed. 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 geoassesspro 2007, Phase 2, Step 7.7; VT ANR RCPG 2007, Section 5.2). 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.

The large majority of Phase 2-assessed reaches in the Waits River watershed are 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 (Fig. 30). This is in part due to the selection of mostly C-, Bc-, and E-type streams for Phase 2 assessment, which are by nature relatively sensitive and capable of recovery to equilibrium conditions in response to restoration efforts (Rosgen 1994). In general, the high sensitivity of a majority of reaches throughout the Phase 2 –assessed area indicates good possibilities for success of passive geomorphic projects, which would 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.

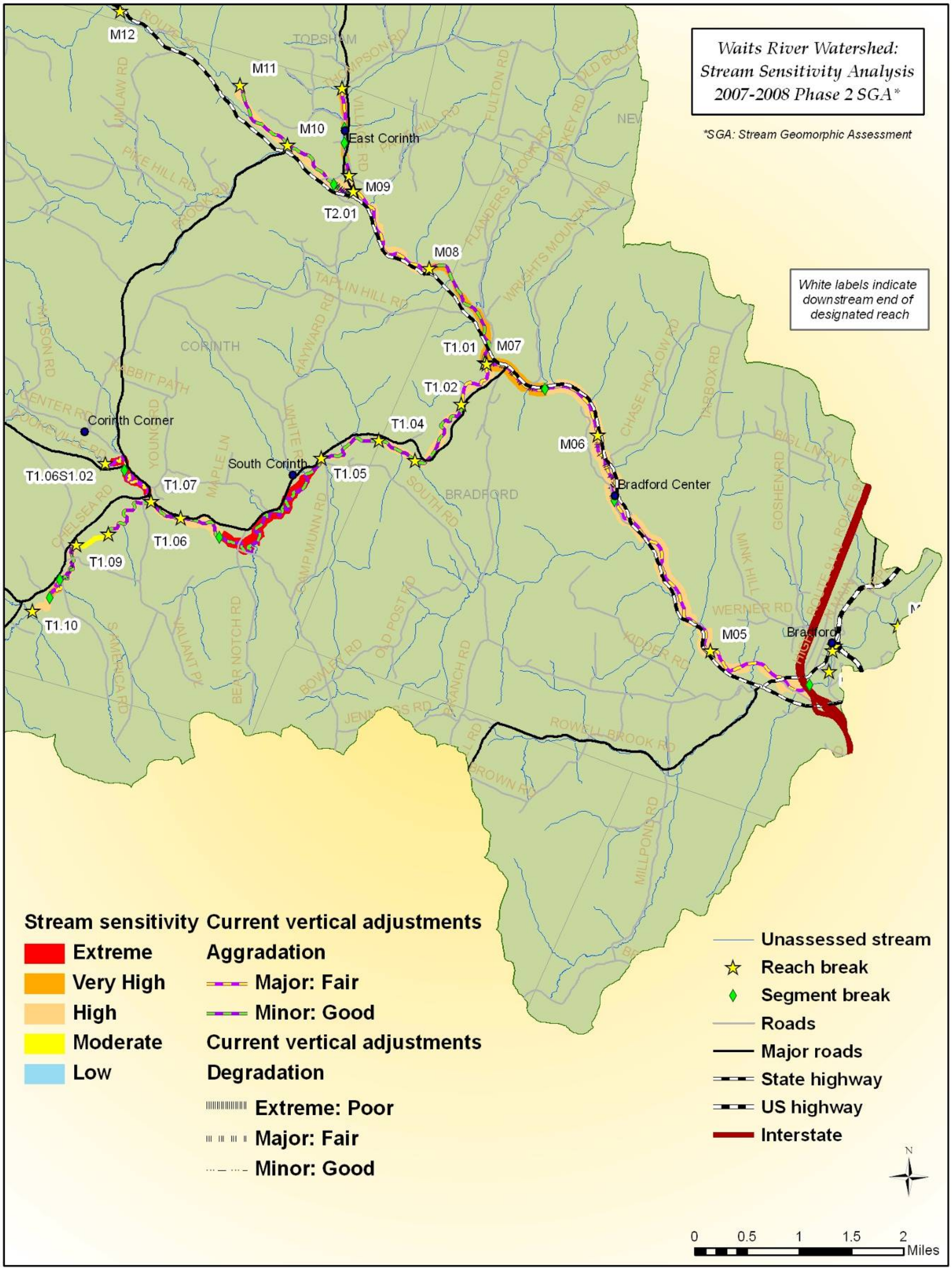


Figure 30. Sensitivity analysis for the 2007-2008 Phase 2 assessment area within the Waits River watershed.

- Low sensitivity was indicated on only one segment in the 2007-2008 Phase 2 assessment area: the bedrock-controlled T2.02B on the Tabor branch in East Corinth village
- Moderate sensitivity was also indicated on only one reach: T1.08 on Meadow Brook in Corinth
- High sensitivity was noted on 18 of 28 segments dispersed throughout the Phase 2 assessment area
- Very High sensitivity was noted in 5 out of the 28 assessed segments: Waits mainstem segments M06B and M07, Tabor Branch segments T2.02A and C, and Meadow Brook T1.09 B.
- Extreme sensitivity was noted on 3 of 28 segments: T1.05A on the South Branch in South Corinth and both segments of Cookville Brook reach T1.06S1.01

It should be noted that the geologic materials in Meadow Brook reach T1.09 are very similar to those of South Branch reach T1.05, and the primary reason these reaches were indicated with only High sensitivity (rather than the Extreme sensitivity of T1.05A) is because there are current indications of only minor active vertical adjustments in this area.

Current vertical adjustments within the 2007-2008 Phase 2-assessed streams of the Waits watershed are primarily aggradational, with 11 segments (out of a total of 28 assessed segments) in eight reaches indicating major adjustments, widely dispersed in the watershed (Waits mainstem M04B, M05A and B, M06A and B, M08; Tabor Branch T2.02C; South Branch T1.01; Cookville Brook T1.06S1.01A and B; Meadow Brook T1.09B). An additional 16 segments indicated minor aggradational adjustments, leaving only one assessed segment with no indications of current aggradational adjustments: Meadow Brook T1.08.

Only three segments indicated major (Waits mainstem M05B and M06B) to extreme (Waits mainstem M09A) current degradational adjustments, which appeared primarily related to dredging, windrowing and riprapping within the last 20-35 years in these areas. All three of these segments also indicated current major (M09A) to minor aggradational adjustments.

The Extreme sensitivity of segment T1.05A is in part due to current active vertical adjustments including aggradation that appears largely due to conversion of upstream reaches to transport sediment regimes (Fig. 24 in sec. 5.1.4, Sediment regime departure), with coarse deposition dropping out in this area primarily when the load exceeds the capacity of the stream to transport it. With an alluvial fan located further upstream at the base of Cookville Brook (T1.06S1.01), a natural transport reach in T1.08 and extensive deposits of fine sediments in reach T1.09, channel evolution in T1.05 will be strongly linked to processes and impacts in upstream reaches. T1.05 itself, with Extreme sensitivity and highly erodible materials, will in turn be a substantial driver of downstream dynamics as well. T1.05 may: a) continue to contribute fine sediments from stream banks in areas lacking buffers, adding these sediments to those already contributing to infilling of planebeds in downstream reaches; or b) it may be able (particularly with the establishment of better buffers) to utilize stream power to rebuild floodplain access and further distribute coarse sediments. If these coarse sediments are not distributed more evenly over time, resulting “slugs” of accruing sediments are likely to encourage further lateral migration and heightened bank erosion. These configurations of current sensitivity ratings along the South Branch and Meadow Brook lend a strong emphasis to prioritization of project implementation in upstream reaches when feasible.

There have been some very recent changes in watershed inputs in reach T1.09 and upstream, with microburst storms in July 2008 (washed out much of Tullar Rd. and increased sediment inputs to reach T1.11) and August 2009, significant riprapping and installation of a grade control at the Eagle Hollow Rd. bridge at the downstream end of reach T1.10, and substantial land clearing and recent road ditching in the subwatersheds of reaches T1.12 and T1.13. These impacts occurred during and after the time period in which phase 2 assessments were done, and hold high potential for causing further adjustments in this portion of the watershed.

Low sensitivity for segment T2.02B on the Tabor Branch is due to the extensive bedrock in both bed and banks along this portion of the stream, and virtually ensures its status as a transport reach. With current conversion of sediment regimes in M08, M09 and M10 to various transport regimes as well, the Very High sensitivity noted in Waits mainstem reach M07 and segment M06B (up and downstream of the Chelsea Rd. bridge) highlights an increased role these areas are playing in sediment storage. This suggests that minimizing lateral constraints and protecting vital floodplain functions even in these relatively narrow valleys will contribute largely to encouraging a more rapid return to equilibrium conditions along the Waits mainstem.

6.0 PROJECT IDENTIFICATION

6.1 REACH DESCRIPTIONS—PRELIMINARY PROJECT IDENTIFICATION

Within the context of the overarching considerations discussed in previous sections of this report, preliminary project identification for reaches included in the Waits River watershed 2007-2008 Phase 2 assessment is presented on a reach-by-reach basis in the following pages. The first three reaches on the downstream end of the Waits River mainstem were excluded from full geomorphic assessments due to heavy influences from the damming of the Connecticut River and the Waits River at the Bradford dam, and do not include project identification. Features that were assessed are briefly discussed for these reaches. As is the case with most streams and rivers, these reaches would benefit from the establishment of wooded buffers along the stream (primarily for a limited amount of stream shading and bank stabilization), but this practice would not be likely to significantly influence stream dynamics in this area at this time.

"Left bank" and "right bank" in the reach descriptions are referenced looking downstream. Reach maps include a "belt width corridor" 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 ANR 2007 Protocols, Appendix H). "Human investments within the belt width inevitably result in structural constraints placed on the channel adjustment process to protect those investments and address associated threats to public safety. These threats will be largely avoided by recognizing the hazards created by development, incompatible with channel adjustments, within the critical belt width" (VT ANR 2007 Phase 2 Protocols, p.17). Background imagery for the reach maps is from the National Agricultural Imagery Program (NAIP), dated 2003.

6.1.1 Reach M01 – Waits River mainstem from Connecticut River confluence to the Bradford hydroelectric dam.

Reach M01 extends 5100 ft (~ 0.95 mi) from the confluence of the Waits River with the Connecticut River, just downstream of a trestle on the Boston & Maine railroad, upstream to the Bradford hydroelectric dam. The reach includes extensive wetlands and oxbows and represents high value wildlife habitat and an important stopover point on the Connecticut River flyway, a major migratory route for birds. The Bugbee Boat Landing and campsite is located on the right bank of the river, and the area includes numerous inlets and dead-ends for boaters wishing to explore (CRWC 2007). This section of the Waits is also heavily influenced by significant shifts in water levels due to operation of a major store and release hydroelectric dam downstream on the Connecticut at Wilder, VT. Due to these fluctuations and the extensive wetlands, the reach was excluded from full rapid geomorphic assessment, in accordance with SGA protocols. Features that were assessed included:

- Left bank riparian corridor is largely occupied by recreational playing fields, the Bradford Country Club golf course, and a public boat launch on the left bank; buffers generally exceed 100 ft in width, with a subdominant 50-100 ft width.

- Right bank corridor is dominated by intensive agricultural use (corn/rotations) and wetlands, and buffers are predominantly 50-100 ft in width near the wetlands with a subdominant class of <25 ft in the agricultural areas

6.1.2 Reach M02 – Waits River mainstem, the Bradford hydroelectric dam.

Reach M02 is a very short reach (~275 ft) delineated to include the run of the river hydroelectric dam currently operated by Central Vermont Public Service. The reach was excluded from further Phase 2 assessment, in accordance with SGA protocols. The dam currently operates under a Federal Energy Regulatory Commission exemption (FERC 2008), and lack of a fish ladder or similar structures effectively isolates the Waits River from the Connecticut River in terms of fish passage (USFWS 2008). Fisheries management of the Waits River watershed has worked with this fact for evaluation of watershed possibilities for salmon restoration efforts, as well as the role the dam plays in protection of native brook trout populations in upstream portions of the watershed and the implications for stocking practices throughout the watershed (VT-DEC-WQ 2008, pp. 46-47).

6.1.3 Reach M03 – Waits River mainstem from Bradford CVPS hydroelectric dam to Old Creamery Rd. bridge.

Reach M03 extends 1065 ft (~ 0.2 mi.) from the hydroelectric dam upstream to the Old Creamery Rd. bridge, which was being replaced at the time of Phase 2 assessment. The reach is channelized and influenced heavily by the dam and was thus excluded from rapid geomorphic assessment. Although the dam is run of the river, the water in the channel of this reach was more than 5 ft deep up to the edge of the right bank. Features that were assessed included:

- Right bank largely bedrock-controlled and/or undercut
- Left bank corridor has extensive encroachment, with development (both commercial and residential, including an old mill building that is still occupied) nearly to the water's edge along virtually the entire reach. Dominant buffer width <5 ft, with a subdominant 5-25 ft buffer.
- Right bank corridor largely wooded, predominantly by hemlock; one house 150 ft from the stream on downstream end of the reach, with private drive to access it; electric power substation, two residences and a commercial garage on upstream end of the reach, leaving a predominant right bank buffer of 50-100 ft with a subdominant 5-25 ft class.
- Evidence of beaver activity in the reach, with a good number of chewed stems on the downstream end.

Figure 31. Reach M03, hydro dam head gate, commercial and residential development along left bank.

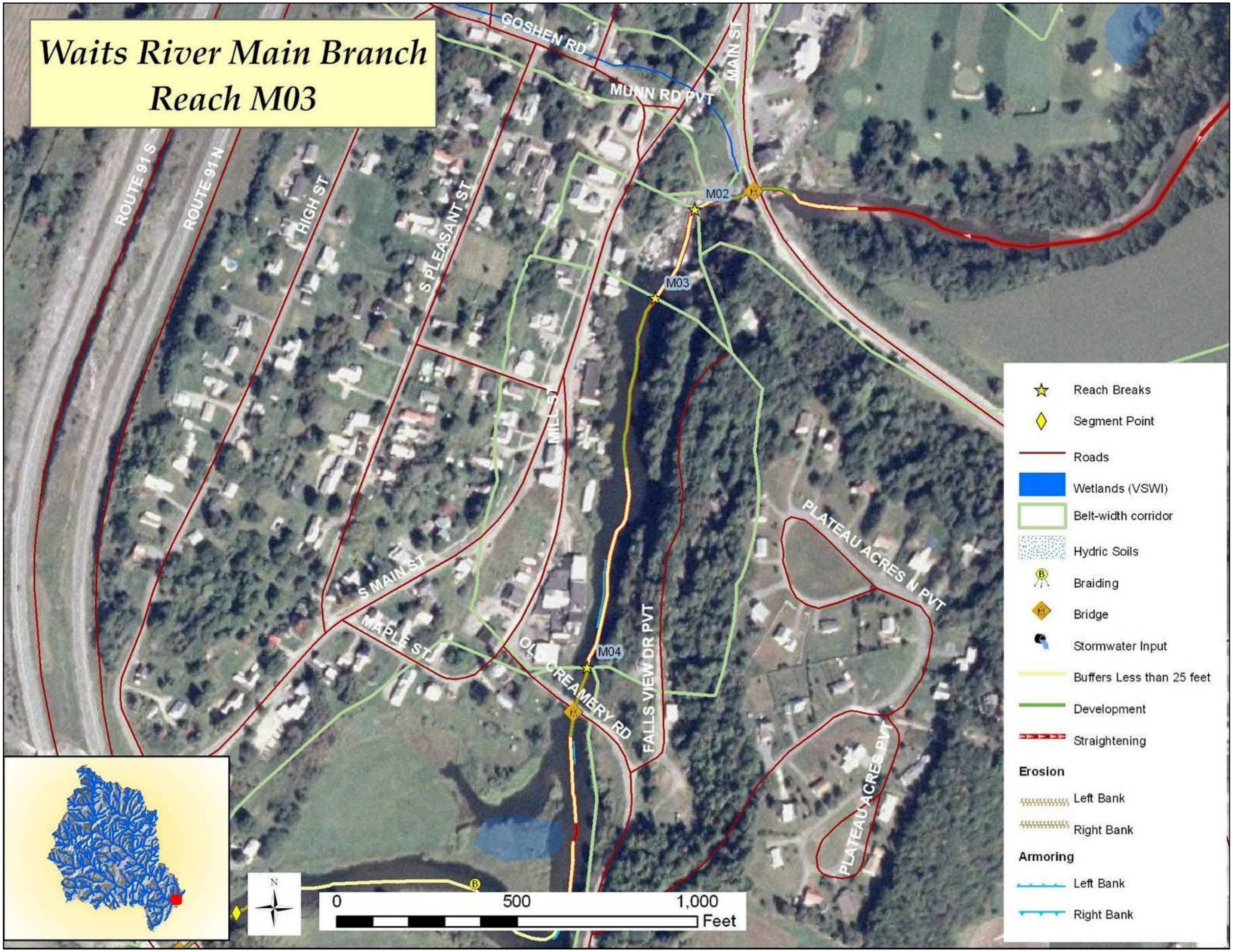


Figure 32. Waits River mainstem Reach M03.

6.1.4 Reach M04 – Waits River mainstem from Old Creamery Rd. bridge to the point where Waits River Rd. (Rte. 25) is directly adjacent to the Waits River.

Reach M04 extends roughly 8053 ft (~ 1.5 mi) upstream of the Old Creamery Road bridge (which was being replaced at the time of assessment) to a road pull-off just downstream of the first point west of Interstate-91 where the Waits River Road (Rte. 25) is directly adjacent to the Waits River (this is near a house at 2315 Waits River Rd., and the downstream end of a bedrock outcrop that is the terminal point of a long stretch of riprap on the north side of Rte. 25). Reach M04 was assessed as 2 segments of roughly 1721 ft and 6332 ft in length, divided just downstream of the interstate (I-91) bridge due to changes in planform and slope and channel dimensions.

Segment M04A, the downstream segment, includes significant oxbow wetlands and is heavily influenced by the Bradford dam (which is located ~1100 ft. downstream). It appears to be virtually impounded by bedrock at the base of the reach, which funnels the river toward the waterfalls at the dam, and the bed of the river below the interstate bridge has a thick layer of silt and detritus above the cobbles beneath. Due to these influences and the wetlands, this segment was excluded from rapid geomorphic assessment, in accordance with SGA protocols. Features that were assessed included:

- Riparian corridor dominated by intensive agricultural use on both banks; buffers essentially non-existent in segment M04A
- Erosion was extensive on the left bank and more limited along the right bank (100 ft, 5 ft high on right bank)
- Rip rap has been placed along both banks; on the left bank rip rap extended more than half the segment, and much of it had failed over time; limited extent on the right bank
- The old abutment and new bridge at Old Creamery Rd. both present a floodplain and minor channel constriction
- Japanese knotweed evident in patches within the wetlands and more extensively along the banks underneath the interstate bridge

Figure 33. Bank toe armoring and riprap are common in segment M04A, as are patches of Japanese knotweed as visible left of the Interstate-91 bridge in this photo.

Segment M04B comprises approximately 6332 ft (~ 1.2 mi) on the upstream end of the reach. Massive embankments beneath the interstate bridge have cut off extensive portions of the former floodplain and limit access of the river to Bradford village in flood flows at the downstream end of the segment, likely protecting the village but also effectively turning the fields of the Appleton farm and surrounding area into a retention pond in a major flood. Key features included:

- M04B is classed a C type stream, dominant riffle-pool (subdominant planebed) with a cobble substrate, but significant encroachments throughout change the Narrow valley type to Semi-confined
- Extensively straightened, with very close encroachment from Appleton Rd. on the downstream end and less severe encroachment from the Waits River Rd. (Rte. 25) along much of the remainder of the segment
- Left bank valley walls very steep; buffer widths generally >100 ft, but <25 ft anywhere the stream moves away from the valley wall
- Right bank buffer generally <25 ft, increased to 50-100 ft in limited areas of steeper valley walls dominated by bedrock outcrops
- Characteristically cobble bed exhibited a planebed form through much of the reach, with only weak riffles evident and primary features being scour pools forming near the numerous bedrock outcrops
- Limited incision ratio likely related to downcutting being primarily historic in M04B, with stream able to access what remains of available floodplain
- Two bridges at the I-91 overpass and one at South Main St. all present floodplain and channel constrictions primarily due to the presence of piers in all of the structures; deposition was noted above each of these structures, and the left bank abutment of each of these structures also exhibited some scour

Figure 34. Segment M04B showing eroded banks and steep riffle at Kenison property near Masonic hall

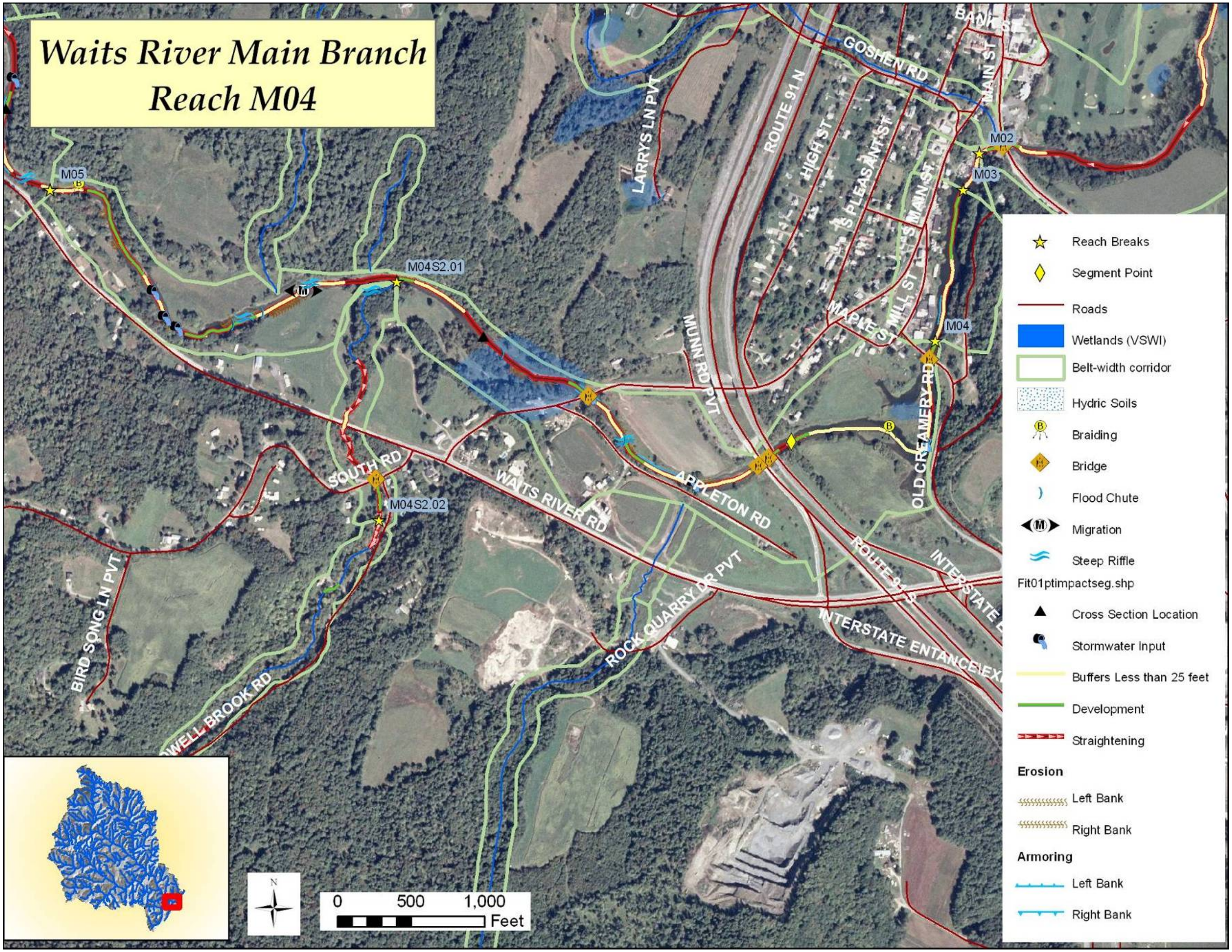


Figure 35. Waits River mainstem Reach M04.

Table 11. Waits River mainstem Reach M04 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M04A	Protect River Corridor	Medium	Low	Y	Portions within FEMA Special Flood Hazard Area probably less important than floodplain upstream o I-91 abutments
M04 A	Plant buffers	Low	Low	Y	Low-cost; banks erodible, would likely need to tolerate periodic inundation
M04 B	Protect River Corridor	High	Medium	Y	Check current protection and ordinances; much of it may lie outside FEMA Special Flood Hazard Area; essentially retention pond in major flood
M04 B	Re-establish buffers	Medium	Low	Y	Buffers on right bank are <25 ft
M04 B	Replace existing bridge structures	Medium	Low		3 bridges, all present floodplain constrictions, S. Main St. bridge also presents channel constriction; when bridge is due to be replaced consider structure that allows for more sediment transport to reduce flood hazards

6.1.5 Reach M05 – Waits River mainstem from first point west of Bradford where Waits River Rd./ Rte. 25 is directly adjacent to the Waits River to ~ 0.3 mi. north (upstream) of Chase Hollow Rd.

Reach M05 comprises 13,692 (~ 2.6 mi) ft of the Waits River mainstem extending from a pullout near 2315 Waits River Rd. (the first point west of Bradford where the Waits River Rd./Rte. 25 is directly adjacent to the Waits River) to ~ 0.3 mi. north of Chase Hollow Rd. The reach was assessed as two segments of 9903 ft and 3789 ft, divided just upstream of the braided section of stream near Johnsons' small engine shop (downstream of mid-reach cross section location in Fig. 36). The reach was segmented due to planform and slope changes that are related to the presence of ledge grade controls in the upstream (M05B) segment.

Segment M05A, the downstream segment, spans roughly 9903 ft (~ 1.9 mi) from the downstream terminus of the reach, upstream to Bradford Center, where the first set of channel-spanning ledge grade controls occur roughly 1200 ft upstream of a Waits River Rd (Rte. 25) bridge over the Waits mainstem. The downstream portion of M05A appears historically incised and is a frequent ice jam location, but narrow floodplain access is available in much of the segment. The Waits River may be cycling between stage II and III channel evolution in this area; it is not clear how much of an impact dredging and gravel removal have played in this dynamic, as opposed to how much sediment is being scoured out and subsequently replaced in ice scouring and high flows of varying intensity. Key features included:

- M05A is dominant plane bed (habitat type departure) with cobble substrate in a semi-confined valley
- Under reference conditions, the segment is a borderline C/B-type riffle-pool and was designated a subreach; although this C-type portion of the stream is longer in length than upstream segment M05B, M05A alternates between B and C type characteristics in short sections through the segment and the B-type was designated the reference type for the overall reach
- The entire reach is straightened, flowing in close proximity to the highway along most of its extent.
- Bedrock outcrops common along the left bank steep valley walls; low (~1.4) entrenchment ratio in areas where right bank encroachments are significantly raised above river elevations but the C portions of the stream retain floodplain access and are much less entrenched

Figure 36. Segment M05A showing stream entrenchment in areas where the left valley wall and elevation of the road bed off the right bank work in tandem to create a significantly narrower valley.

- Generally planebed with weak riffles; some depositional bed features in wider floodplain areas; scour pools near bedrock outcrops
- Islands, mid-channel bars, side bars and steep riffles all present
- Channel is braided upstream of Johnson's small engine shop (Johnson Drive), where gravel was removed commercially during 1970's and channel was periodically dredged for ice jam control up until the mid 1970s (pers. comm, Barry Cahoon, VT stream alteration engineer)
- Left bank buffers >100 ft; right bank buffers dominant 50-100 ft and subdominant < 25 ft
- Bridge just north of Kenyon Rd and south of Bradford Center village is 207 ft wide, but effective width is reduced to 162 feet by angle of alignment and presence of bedrock on LB DS that effectively constricts floodplain access in this area. old bridge abutment is narrower than bankfull flow width
- Extensive portions of the segment are prone to ice jams

Segment M05B extends roughly 3789 ft (~ 0.7 mi) upstream from Bradford Center to an island upstream of the Chase Brook confluence with the Waits River. Key Features include:

- Bc-type stream ('c' subslope <2%), riffle-pool with a cobble substrate, in a semi-confined valley
- River in M05B appears to be 'pulsing' through constricted areas between bedrock and bank armoring, alternating with wider floodplain areas
- Grade controls consist of three sets of ledge located shortly upstream of the Rte. 25 bridge and are channel spanning by virtue of overlapping sets of ledge
- Three sets of bedrock constrictions noted as channel constrictions within the segment, but not floodprone constrictions;
- Deposition common upstream of constrictions as well as in eddies downstream of outcrops; scour pools also found along bedrock outcrops
- Extensive straightening primarily due to encroachments, especially from Waits River Rd. /Rte. 25

Figure 37. Segment M05B: Rip rap and Rte 25 road encroachment in background, sidebar downstream of bedrock outcrop in foreground

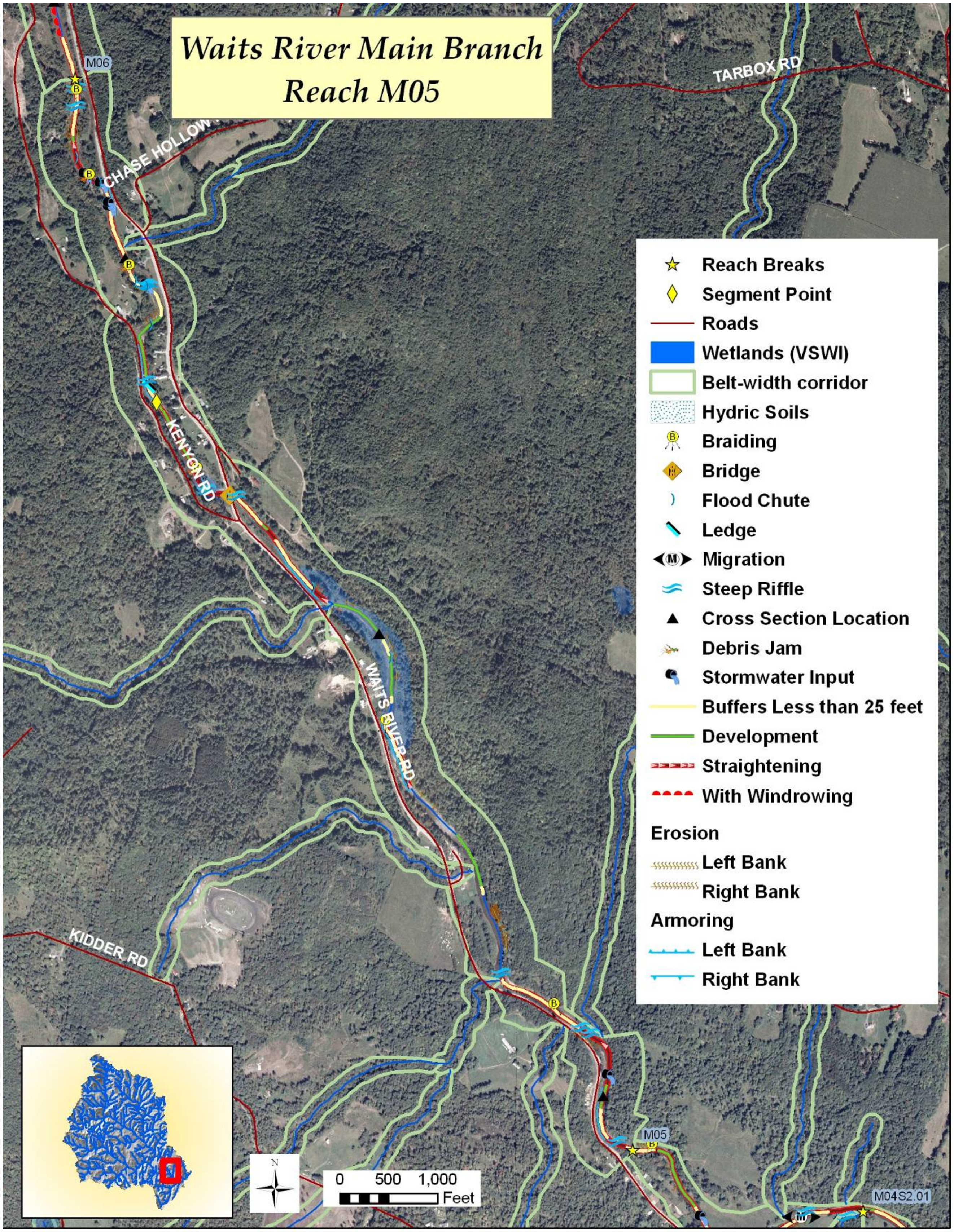


Figure 38. Waits River mainstem Reach M05

- Some evidence of windrowed stone along banks of segment M05B
- Dominant left bank buffers <25 ft, with subdominant class 26-50 ft buffer; right bank buffers dominantly >100 ft, with subdominant 26-50 ft class
- Flood chutes common; incision and widening appear limited by the presence of bedrock in both bed and banks"Headcut" noted in upstream portion of M05B was a nickpoint with significant erosion of what was probably a steep riffle to start, indicating effects of enhanced stream power from extensive straightening in next reach upstream
- River beavers have a bank lodge, but not damming mainstem; beavers have also plugged downstream end of an old flood chute/oxbow wetland at upstream end of this segment, with a pond extending upstream past the M06 reach break off right bank

Table 12. Waits River mainstem Reach M05 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M05A	Protect river corridor	High	Low	Y	Limited areas in vicinity of Johnson Dr. (mid-downstream) and Kenyon Rd off right bank
M05 A	Remove and/or replace existing bridge structures	Medium	Low	N	Old abutment presents channel and floodplain constriction Rte 25 bridge presents floodplain constriction
M05 B	Plant stream buffer	Low	Low	Y	Left bank; planting difficult as diminished buffers primarily due to road bank; Better Backroads has designs for incorporating willow stakes

6.1.6 Reach M06 – Waits River mainstem from upstream end of island ~1800 ft north of Chase Hollow/Waits River Rd. intersection to roughly 100 ft upstream of Waits mainstem/South Branch Waits River confluence

Reach M06 includes 7741 ft (1.5 mi) of the Waits River mainstem extending from Bradford Center to ~ 700 ft upstream of the iron bridge at the junction of the Waits River Rd./Rte. 25 and the Chelsea - Goose Green Rd. The reach was assessed as two segments of 4198 ft and 3543 ft, divided just upstream of the chalet visible from Rte. 25, where the road encroachment becomes convergent with the left bank of the stream (at Wrights Mtn. Rd.; Fig. 39). The reach was segmented due to differences in depositional features along with planform and slope changes. The downstream segment, M06A, appeared more degradational, with eroded riffles, while M06B indicated more aggradation.

M06A, the downstream segment, is 4198 ft and extends from the upstream end of the from the island located ~1800 ft north of the intersection of Chase Hollow Rd. and Waits River Rd. to ~ 890 ft south of Wrights Mountain Rd. Key features included:

- M06A is a B-type stream, plane bed with a cobble substrate in a semi-confined valley
- Valley has been narrowed by road encroachment, but even with full valley width and reference channel width the valley would still be semi-confined.
- Would border on being a C-type stream without heavy encroachment from Waits River Rd./ Rte. 25 along left bank
- Evidence of extensive windrowing; additional areas without windrowing, heavily influenced by road encroachment and riprap, amount to straightening throughout; suspect some windrowing close to channel has been washed out
- Active beaver dam in floodplain along the right bank at the base of reach, where beavers have dammed the downstream end of an old oxbow flood chute; beavers do not appear to be trying to dam the mainstem at all
- Bank armoring less extensive than upstream segment M06B, though ~ 800 ft of riprap armors Waits River Rd./Rte. 25 downstream of an apparent alluvial fan now occupied by a hayfield at the base of Wright's Mountain Rd.
- Left bank canopy cover and buffer virtually eliminated by road encroachment; right bank buffers generally >100 ft
- Plane bed features with cobble bed, eroded riffles, and 60-70% embeddedness indicate that segment has likely experienced erosion of riffles and subsequent deposition of fines
- Several sidebars noted, associated with bedrock outcrops on one bank; comprised of larger cobbles and not storing finer sediments

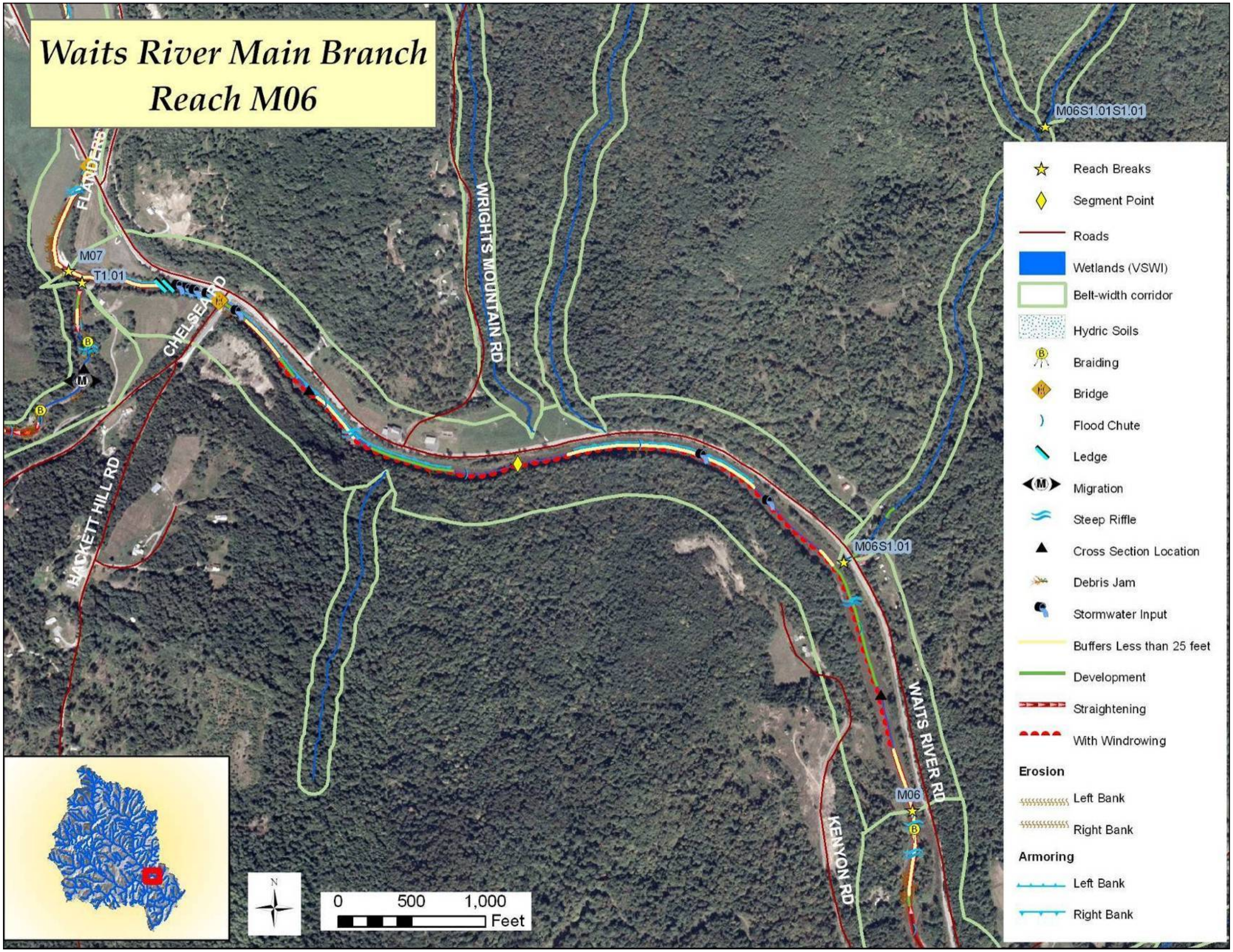


Figure 39. Waits River Main Branch Reach M06.

Segment M06B, the upstream segment, is ~ 3534 ft long and extends from ~ 890 ft south of Wrights Mountain Rd. to ~1000 ft upstream of the Chelsea Rd.bridge (which is also ~100 ft upstream of the Waits confluence with the South Branch).

- M06B is a B-type stream, riffle-pool dominant with a gravel substrate in a semi-confined valley
- Significant deposition of large cobbles was occurring below Chelsea Rd. bridge and at a delta bar at the confluence of an unnamed tributary on the right bank downstream of the bridge; mid channel and side bars also noted
- Left bank almost completely riprapped; right bank riprapped for ~400 ft, mostly near the bridge
- Significant deposition of fines although bed is gravel; 75-85% embeddedness in plane bed areas that were more limited in extent than in the downstream segment
- Left bank canopy cover and buffers basically non-existent due to road encroachment; right bank had 26-50 ft buffers with moderately reduced canopy cover in the residential and sand pit areas on upstream end of segment
- Significant ledge/waterfall grade control at upstream end of the segment creates a grade change totaling more than 5 ft; large scour pool at base provides a local swimming hole and fishing spot

Table 13. Waits River mainstem Reach M06 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M06A	Plant stream buffer	Low	Low	Y	Road bank: planting would require special techniques such as Better Backroads designs
M06 B	Replace existing bridge structures	Low	Low	N	Bridge presents floodplain but not channel constriction

6.1.7 Reach M07 – Waits River mainstem from ~1000 ft upstream of the iron bridge at the Waits River Rd./Rte. 25 and Chelsea Rd. intersection to just upstream of the transition between the field and the forest edge.

Reach M07 includes 6666 ft (~ 1.3 mi) of the Waits River mainstem from ~1000 ft upstream of the iron bridge at the junction of the Waits River Rd./Rte. 25 and the Chelsea Rd. to just upstream of the transition between open fields and the point where the stream corridor becomes forested on both sides of the river. The reach was not segmented during Phase 2 assessment. Rte. 25/Waits River Rd was rerouted in downstream section of reach, and the discontinued road is still evident: the valley wall is 20 ft high at the old bridge abutment on the right bank, but the left bank abutment at Flanders Brook Rd. is far enough back that it does not constrict the channel. The new Rte. 25 bridge in this area is 148 ft wide, but the angle of alignment to the Waits River and heavy riprapping of abutments inside the structure (reducing effective width to 105 ft), in combination with one pier mid structure, present some constriction of the channel and floodplain. Key features included:

- M07 is a C-type stream, plane bed with a gravel substrate in a semi-confined valley
- Road encroachment on both banks is significant; Waits River Rd. parallels the reach in it's entirety on the right bank; the left bank is encroached in the downstream portions of the reach
- Though there is narrowing of the valley by encroachment, even with full natural valley width and reference channel width would still be on upper end of semi-confined valley
- Canopy cover and buffers are basically non-existent due to road encroachment and heavy agricultural use; dominant buffers on both banks are < 25 ft
- Bank erosion on right bank was occurring downstream of bridge in lower portions of the reach

Figure 40. Waits mainstem reach M07, showing bank erosion in the lower portions of the reach, downstream of the Waits River Rd. bridge

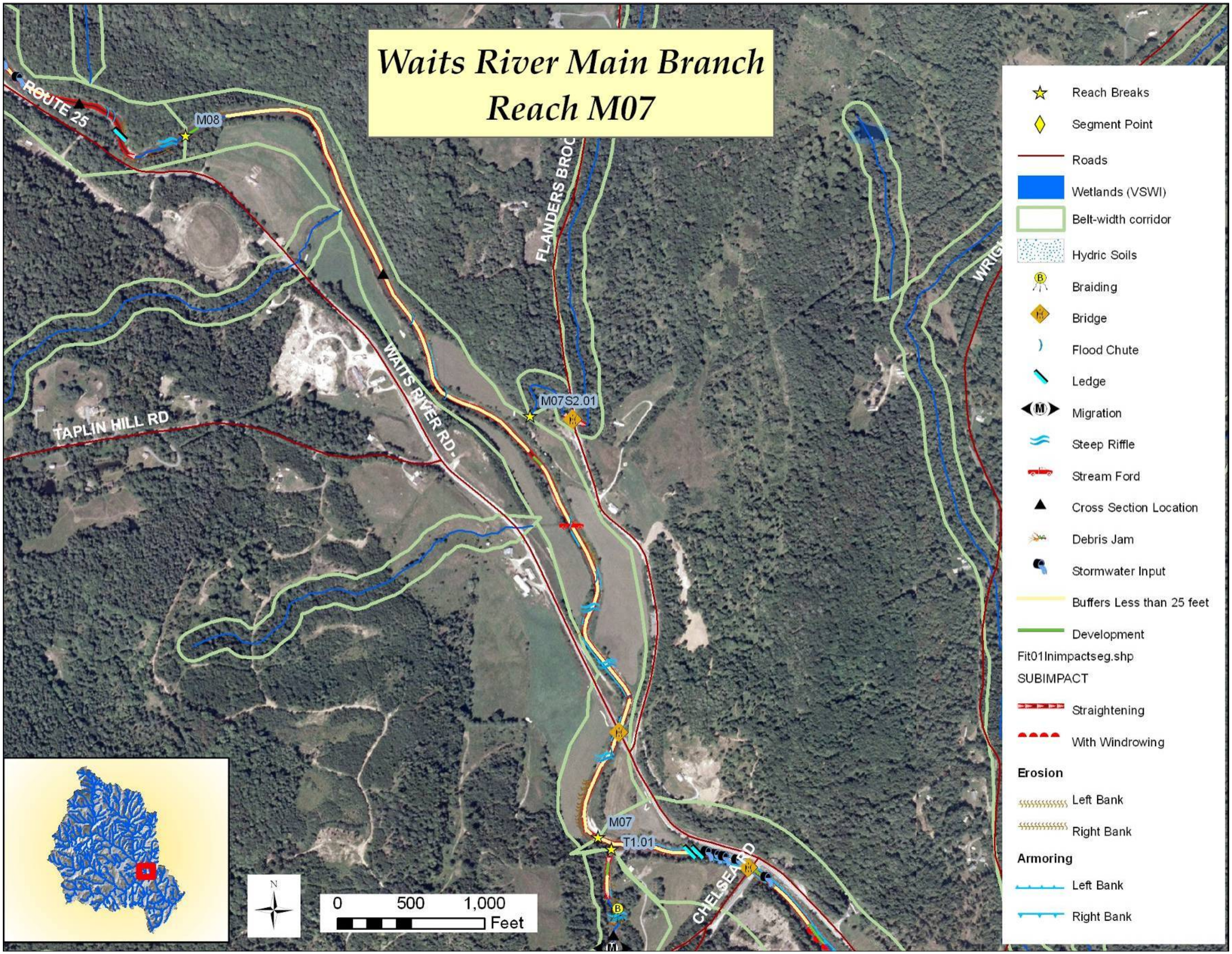


Figure 41.Waits River mainstem Reach M07

Table 14. Waits River mainstem Reach M07 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M07-0	Protect river corridor	High	High	Y	Valuable attenuation asset downstream of converted transport reaches, but narrow valley and floodplain
M07-0	Plant buffers	High	Medium	Y	Both right and left bank buffers non-existent; hay and pasture to stream edge, but erosion and riprap remarkably low considering this
M07-0	Replace existing bridge structure	Low	Low		Fairly new bridge will not be due for replacement for a long time, but angle of alignment presents some floodprone constriction

6.1.8 Reach M08 – Waits River mainstem from forest edge at the top of M07 to the confluence of Tabor Branch and the Waits mainstem.

Reach M08 comprises 6469 ft (~ 1.2 mi) of the Waits River mainstem extending from just upstream of the forest edge at the top of M07 to the confluence of the Tabor Branch and the Waits mainstem (just downstream of the Village Rd. Bridge leading to East Corinth village). The reach was not segmented during Phase 2 assessment. Key features included:

- M08 is a B-type stream (C to B stream type departure due to historic downcutting), plane bed with a cobble substrate
- Road encroachment from Waits River Road on the right bank changes valley confinement type from Narrow to Semi-confined; human-elevated incision ratio is

>2.0 and indicates loss of floodplain access; road obscures any indications of process-based incision

- Buffers are generally good; left bank buffer is forested and > 100 ft; right bank buffer is 0-25 ft primarily due to road encroachment
- Planebed bedform may be related to extensive historic straightening
- Boulders on left bank noted as bank armoring, but purpose was unclear (Fig. 42; abutment for former stream ford?)


Figure 42. Waits mainstem Reach M08 showing road encroachment (left) and a boulder pile of undetermined purpose on the left bank (right).

Table 15. Waits River mainstem Reach M08 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M08-0	Protect river corridor	Medium	Low	N	Extensive road encroachment but limited development; floodplain and valley significantly reduced
M08-0	Augment buffers	High	Low	N	Right bank, planting difficult as right bank is a road bank

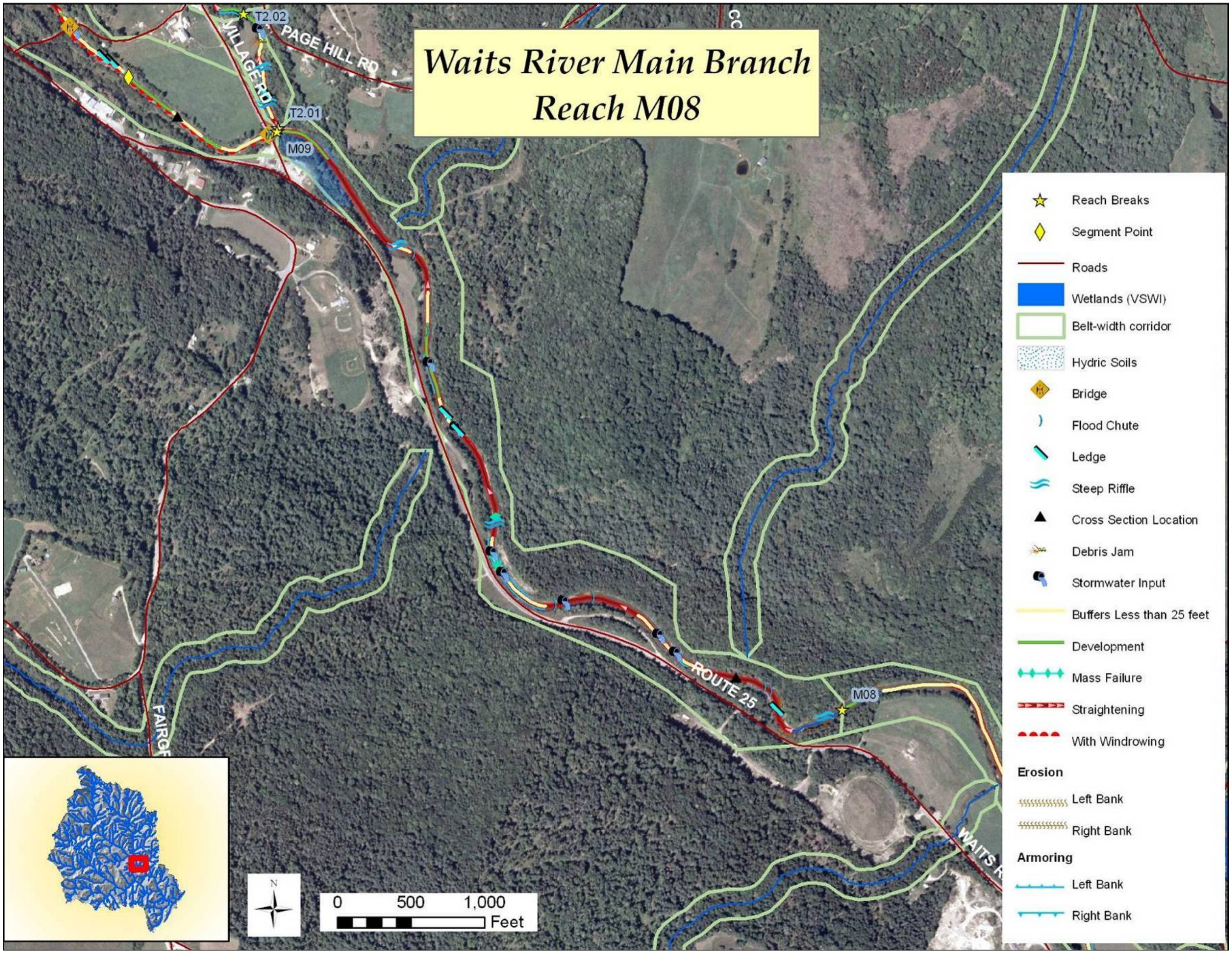


Figure 43. Waits River Main Branch Reach M08.

6.1.9 Reach M09 – Waits River mainstem from confluence of the Tabor Branch and the Waits mainstem to confluence of Pike Hill Brook and the Waits Mainstem.

Reach M09 includes 4390 ft (~ 0.8 mi) of the Waits River mainstem between the confluence of the Tabor Branch and the Waits mainstem (just downstream of the Village Rd. bridge leading to East Corinth village) and the confluence of Pike Hill Brook and the Waits mainstem (near junction of Rte. 25 and Brook Rd.) The reach was assessed as two segments of 1199 ft and 3191 ft, divided a short distance downstream of the Tillotson Ln. snowmobile bridge, where the stream begins to have significant amounts of bedrock outcrops present in the bed of the stream.

Downstream segment M09A was likely windrowed after a flood for bridge cleanout at the Village Rd. bridge. This bridge has one pier mid-span, and much of the right bank opening is obstructed by sediments and fill. Higher flows will overtop some of these sediments, but the degree of obstruction does appear to present some possibility for jams. Other features of note included:

- Bc-type stream ('c' subslope <2%), planebed with a cobble substrate
- Incision ration of 1.9 indicating significant loss of floodplain access (segment noted with C to B stream type departure)
- Straightening with windrowing through virtually the entire segment has likely limited erosion for the time being but increased stream power
- Windrowed stone on the left bank appears to at least partially berm M09A in vicinity of cross-section location, but a higher level of survey detail than that conducted for the Phase 2 assessments may be needed to determine if and how much floodplain access might be gained by removal of this stone.
- Buffers lacking along left bank hayfields


Figure 44. Reach M09. Picture on the left was taken 300 ft from the East Corinth general store and depicts a snowmobile trail running parallel to the Waits River (M09A). The picture on the right shows bedrock grade controls downstream of the confluence with Pike Hill Brook (M09B).

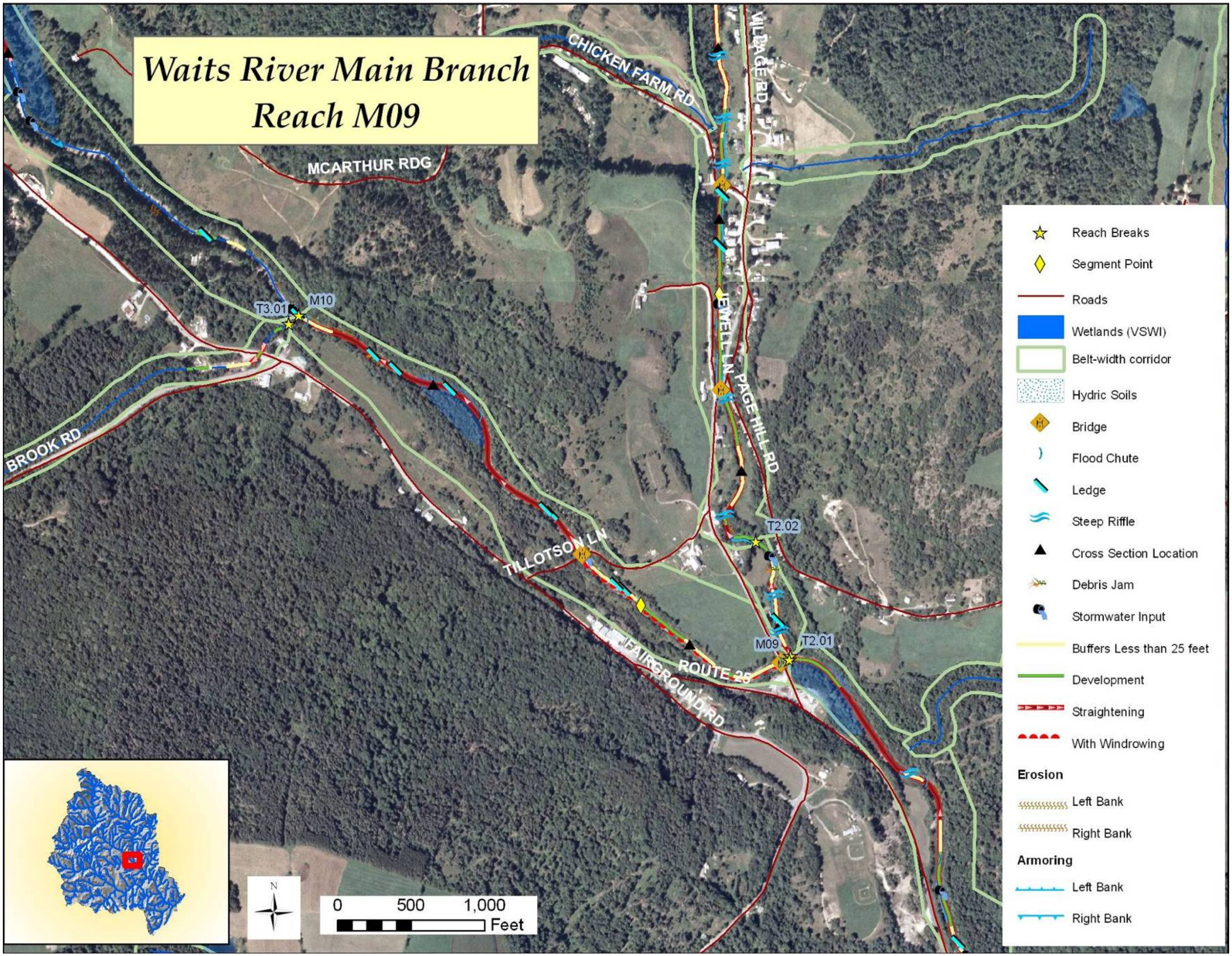


Figure 45.Waits River mainstem Reach M09.

- Though noted as neither dominant nor subdominant vegetation type in either segment M09A or M09B, there is significant Japanese knotweed presence on both banks between the Village Rd. and Tillotson Rd. bridges.

- The right bank buffer in M09A (and a short section of M09B) is bisected by a well-used snowmobile access road between the Tillotson Ln. bridge (a popular travel corridor) and the store by the Village Rd bridge.

The presence of frequent intermittent bedrock outcrops in the bed and banks of upstream segment M09B appears to have limited the extent of windrowing much beyond the downstream segment and was the primary basis for segmentation. The presence of this bedrock should limit upstream incision in response to the removal of stone from the bed in M09A but may enhance stream power and erosive forces. Key features noted in M09B include:

- Typed as a Bc stream (‘c’ subslope <2%), dominant riffle-pool and subdominant planebed bedforms, cobble substrate; Narrow valley confinement type
- Banks alternate between highly erodible and bedrock-controlled; stream "blows out" in areas lacking bedrock, leading to areas of overwidened channel, and the stream borders on F-type channel dimensions in these areas but was typed B due to the numerous other less entrenched areas in segment
- Incision ratio of 2.2; C to B stream type departure due to historic downcutting and significant loss of former floodplain access
- Extensive straightening noted primarily due to presence of long-standing encroachments rather than direct manipulation of channel; no bank armoring noted, but still only limited erosion likely due to combination of bedrock presence and limited recent encroachments
- Tillotson Ln. bridge is high above the channel, but the abutments due pose both a floodprone and channel constriction
- The area in the vicinity of M09B may be playing a role as a wildlife corridor, as raccoon and mink tracks were both observed along the segment and both bear and moose were observed during the Phase 2 assessment

Figure 46. Bear entering downstream at left side of this photo crossed the Waits River a short distance downstream of the M09B cross-section location.

Table 16. Waits River mainstem Reach M09 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M09 A	Protect river corridor	High	High	N	Priority should be informed by higher level survey data (see below – windrow removal)
M09 A	Plant buffers	High	High	Y	Left bank, buffer limited due to agricultural use
M09 A	Remove windrow/ berm	Medium	Medium	N	Needs higher resolution survey details and rough cost-benefit analysis of obtainable floodplain access
M09 A	Replace existing bridge structure	High	High	N	Village Rd. bridge presents channel and floodplain constriction; consider design without piers if bridge comes up for replacement
M09 B	Protect river corridor	High	Medium	Y	Lower priority than M09A (bedrock), but trail use lends significant potential social benefits
M09 B	Replace existing bridge structure	Low	Low	N	Tillotson Ln. bridge is for snowmobile use at this point and is high above the channel; abutments pose floodprone and channel constrictions but associated problems minimal to non-existent

6.1.10 Reach M10 – Waits River mainstem from confluence of Pike Hill Brook to a noticeable bedrock feature and a strong stream S curve, approximately 0.8 mi upstream.

Reach M10 consists of 4198 ft (~ 0.8 mi) of the Waits River from the confluence of Pike Hill Brook (near junction of Rte. 25 and Brook Rd.) to a noticeable bedrock feature and a strong stream S curve, approximately 0.8 miles upstream. The reach was not segmented during Phase 2 assessment. Key features included:

- Reach M10 is a C-type stream, plane bed with a cobble substrate in a narrow valley
- Current encroachments are limited
- Significant forested wetlands mapped in upstream portions of reach
- Large drainage ditches on left bank indicate likely past agricultural activity, historic sawmill located in next reach upstream
- Incision ratio of 2.0 but no stream type departure – floodprone height just barely clears right bank terrace at cross section
- Further downcutting appears limited by bedrock; bedrock in the stream is fairly common
- Buffers on both banks are now forested and are > 100 ft
- Overall adjustment processes are minor and channel evolution stage appears to be arrested stage III; not a lot of active erosion, and widening appears limited by buffers, coarse substrates, bedrock controls, and some floodplain access at flood flows

Figure 47. Reach M10 looking downstream: bedrock in stream is common and serves as a grade control.

Table 17. Waits River mainstem Reach M10 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M10-0	Protect river corridor	High	Medium	Y	Multiple ownerships

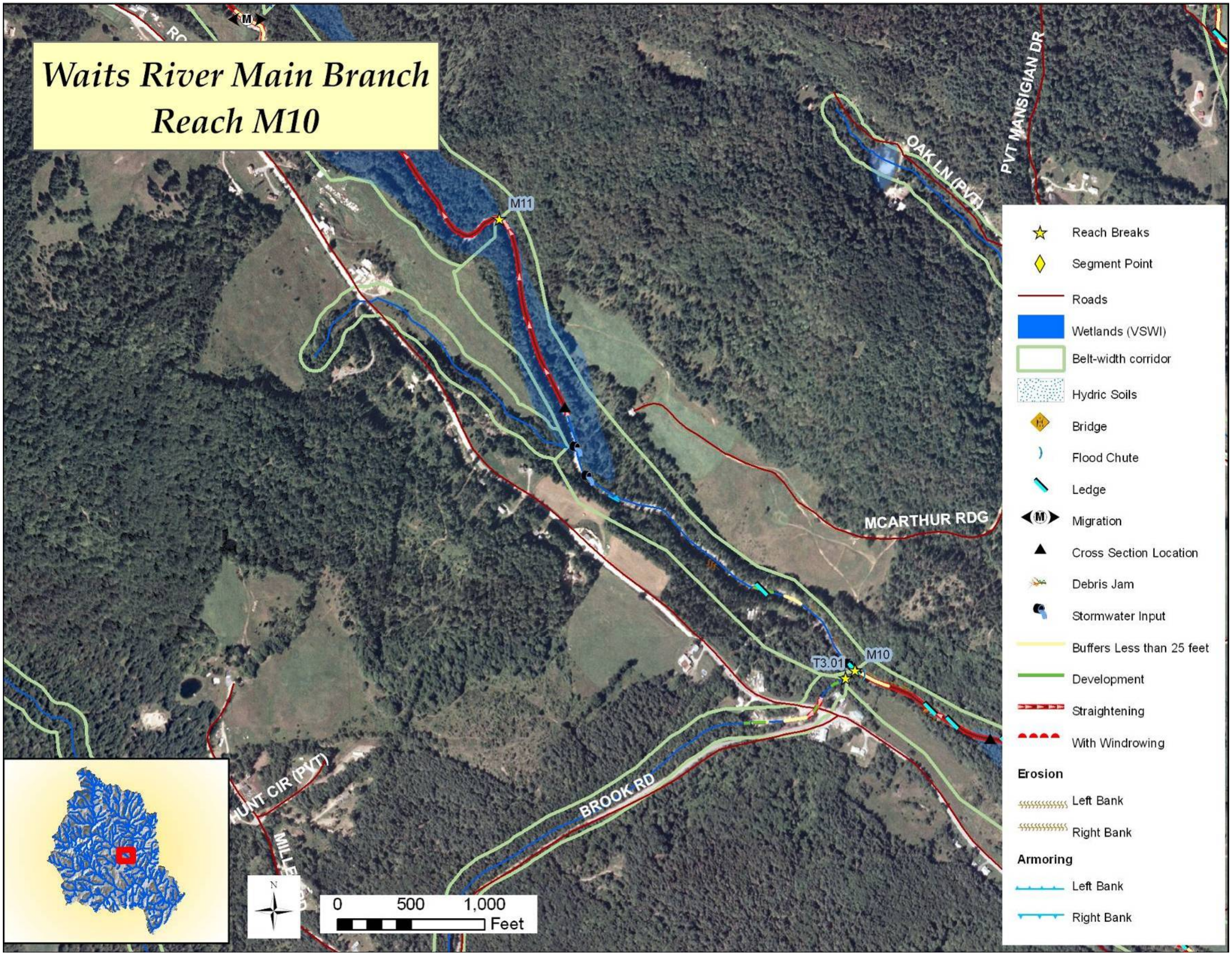


Figure 48. Waits River mainstem Reach M10

6.1.11 Reach T1.01 – South Branch of the Waits from confluence of the South Branch with Waits mainstem to second hayfield on Chelsea Rd. uphill from Waits River Rd./Rte. 25

Reach T1.01 consists of 3017 ft (~ 0.5 mi) ft of the South Branch of the Waits and extends from the confluence of the South Branch with the Waits mainstem to 100 ft upstream of a hay field located off of Chelsea Rd. The reach was not segmented during Phase 2 assessment. Key features included:

- T1.01 is a C-type stream, riffle-pool with a cobble substrate, in a Narrow valley
- Cobbles and boulders sizeable enough to form step-pool features, particularly in slightly steeper gradient upstream portion of the reach;
- Delta bars, over widened channel, and numerous flood chutes exacerbated by four current debris jams indicative of significant aggradation
- Two mass failures were noted in the reach, one on each bank; significant bank failure and extensive erosion along portions of both banks
- Two houses, one near the base of the reach and another on right bank upstream are close to the stream and/or located within the floodplain
- Incision ratio of 1.5 indicates restriction of access to historic floodplains, and historically cultivated field that occupies one third of the upstream portion of the riparian corridor is elevated well above the stream, indicating historical incision may have been even more significant along this portion of the reach
- Dominant buffer on right bank is <25 ft due to hay field and residence; left bank buffer is > 100 ft due to steep forested valley walls
- Low use logging road located in flatter portion of the corridor and a possible old stream ford is now obscured by the presence of large boulders and cobbles
- Japanese knotweed was not evident in 2007 in this reach or further upstream on the South Branch, which is a noticeable difference from the Waits mainstem

Figure 49. South Branch reach T1.01: Mass failure on left bank (left) and an island and flood chute indicative of significant aggradation (right).

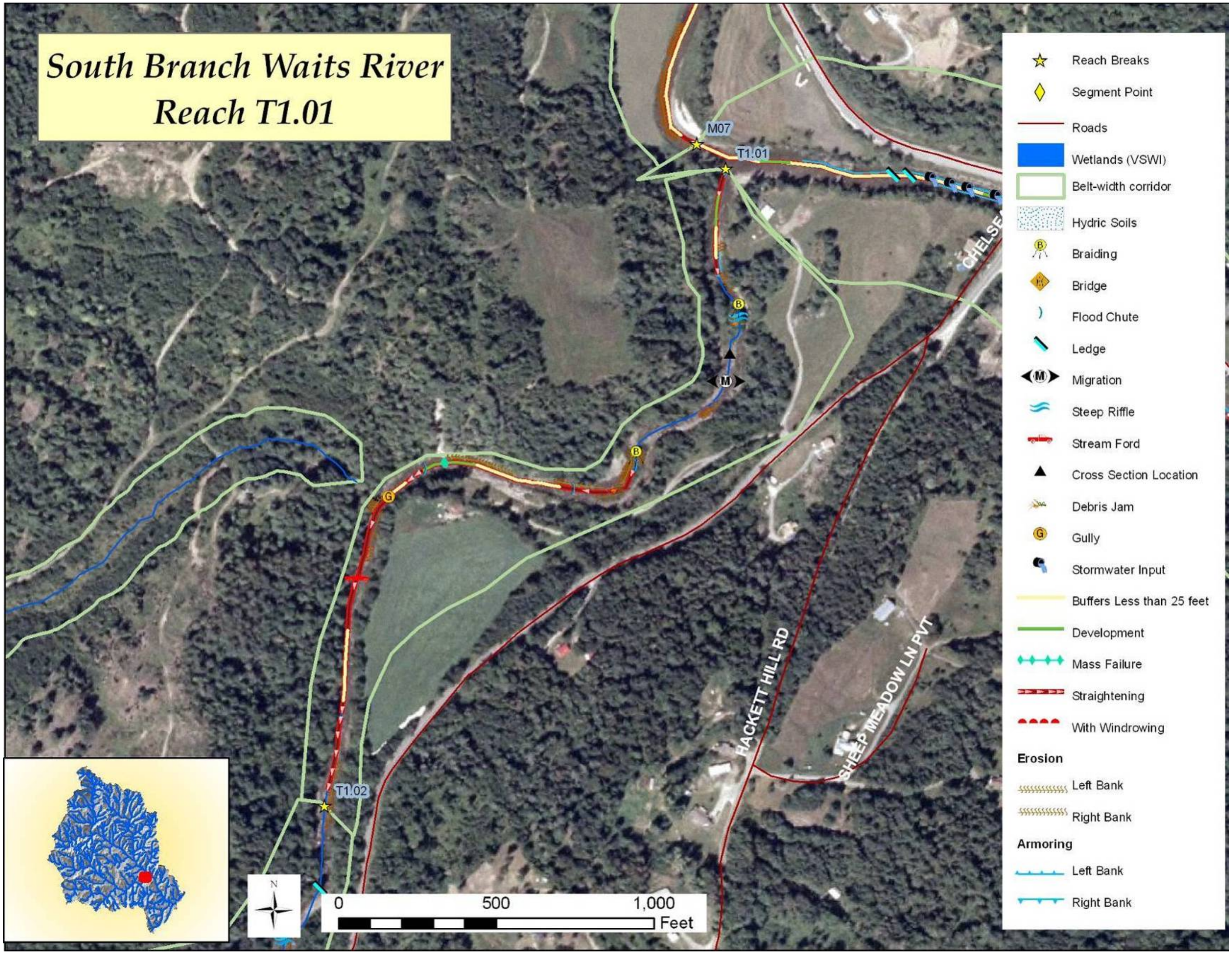


Figure 50. South Branch Waits River Reach T1.01

Table 18. South Branch of the Waits Reach T1.01 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.01-0	Protect river corridor	High	Medium	Y	Popular swimming hole at upstream end of reach; current attenuation assets somewhat limited by development encroachments
T1.01-0	Maintain and augment buffers	Medium	Medium	Y	Right bank, buffers limited due to agricultural use

6.1.12 Reach T1.02– South Branch of the Waits, from ~100 ft upstream of the second hayfield up the Chelsea Rd. to the first Chelsea Rd. bridge (~1.25 mi. uphill after leaving Rte. 25).

South Branch reach T1.02 is 4717 ft long (~ 0.9 mi) and extends from ~100 ft upstream of the second hay field off of Chelsea Rd to the first Chelsea Rd bridge off Rte. 25 (~1.25 mi. uphill), which is located upstream of a set of bedrock grade controls at the site of a United States Geological Survey stream gage that operated on the South Branch until 1951. The reach was not segmented for Phase 2 assessment. Key features included:

- T1.02 is a C-type stream, riffle-pool with a cobble substrate in a Narrow valley
- Stream appears straightened for ~900 ft below the bridge, in comparison with more sinuous downstream portion of the reach; road encroachment near the bridge has also narrowed the valley confinement in this area
- Valley briefly broadens into a shrub wetland in midsection of the reach
- Incision ratio of 1.5 indicated downcutting, but incision was noted as primarily historic and likely limited from further progression due to grade controls and bedrock outcrops
- Erosion was noted along >20% of the right bank, and an additional >20% of the right bank was armored
- Bed scour was noted in several areas, with exposed lodgement till and clay common on left bank; one mass failure was noted on each side of the reach

- Left bank buffers were >100 ft; right bank dominant buffers >100 ft, but a subdominant buffer of 26-50 ft was due to road encroachment; there is a snowmobile trail located in what was an old roadbed along the right bank in the upstream portion of the reach
- Bedrock channel (but not floodprone) constriction was noted at the downstream grade control, contributing to formation of a deep scour pool that is popular as a local swimming hole
- Floodprone and further channel constrictions were noted at the Chelsea Rd bridge and an old abutment in the upstream portion of the reach; constriction from existing bridge is due to alignment issues that reduce the effective width of the span
- Fair geomorphic condition, High sensitivity with major widening and planform adjustments, Stage III channel evolution

Figure 51. Reach T1.02 bedrock grade control at downstream end of reach, causing some channel constriction and creating a deep scour pool

Table 19. South Branch of the Waits Reach T1.02 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.02-0	Protect river corridor	High	Medium	Y	Multiple ownerships
T1.02-0	Remove old abutment, replace existing bridge	Medium	Low	Y	Old abutment presents channel but not floodplain constriction; current bridge is channel constriction due to alignment but no major issues appear associated with constriction

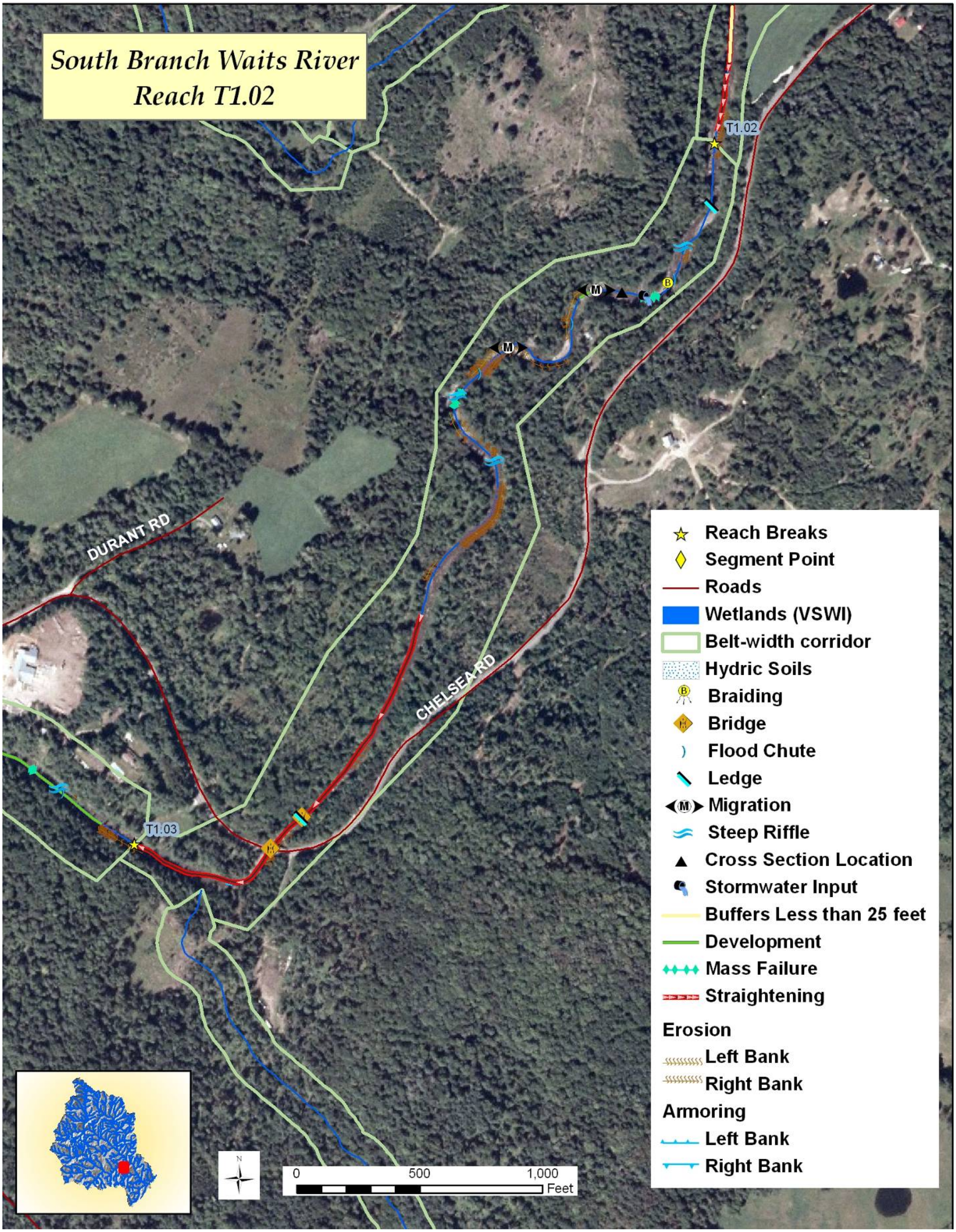


Figure 52. South Branch Waits River Reach T1.02

6.1.13 Reach T1.03 – South Branch of the Waits from the Chelsea Rd. bridge (by old USGS stream gage site) to Bradford/Corinth town line.

Reach T1.03 comprises roughly 2163 ft (~ 0.4 mi) of the South Branch from upstream of the Chelsea Rd. bridge to shortly upstream of the Bradford /Corinth town line, which was noticeable from the steam by the presence and absence of posted property signs on either side of the line. Unlike other sections of the South Branch, the stream sits well down below road level and behind Johnson's sawmill, so it is largely out of sight of the road. The reach was not segmented during the Phase 2 assessment. Key features included:

- T1.03 is a Bc-type stream ('c' subslope <2%), riffle-pool with a cobble substrate, in a semi-confined valley
- Steep valley walls alternate sides where they become nearly continuous with the stream banks, with a narrow portion of gentler slopes present on the opposite banks before the valley walls rise more steeply, gentler slopes more common on the left bank; right bank valley walls were noted as being 'mostly' continuous with the stream banks
- Incision ratio of 1.4 indicating some loss of floodplain access but bank erosion was not extensive
- Two mass failures noted on each bank; three of the mass failures were older and healing over, and all of the failures were being colonized by coltsfoot and bittersweet nightshade; more recent mass failure on right bank was accompanied by signs of increased hydrologic inputs suggesting land use change or stormwater input above the stream
- Four flood chutes were noted within reach
- Buffer widths >100 ft throughout most of the reach on both banks; bank canopies were relatively continuous (76-100%) although herbaceous vegetation (often coltsfood) dominated the near bank vegetation on both sides
- Sediment storage included numerous side bars, mid-channel bars and steep riffles; point bars were present but less frequent
- Bedrock constrictions in the upstream portion of the reach causing fines to drop out; both smaller gravel and sandy deposits noted
- Geomorphic condition Fair, sensitivity High, channel evolution stage III

Figure 53. Reach T1.03 on the South Branch, showing mass failure, steep riffle, and a bedrock outcrop on opposite bank

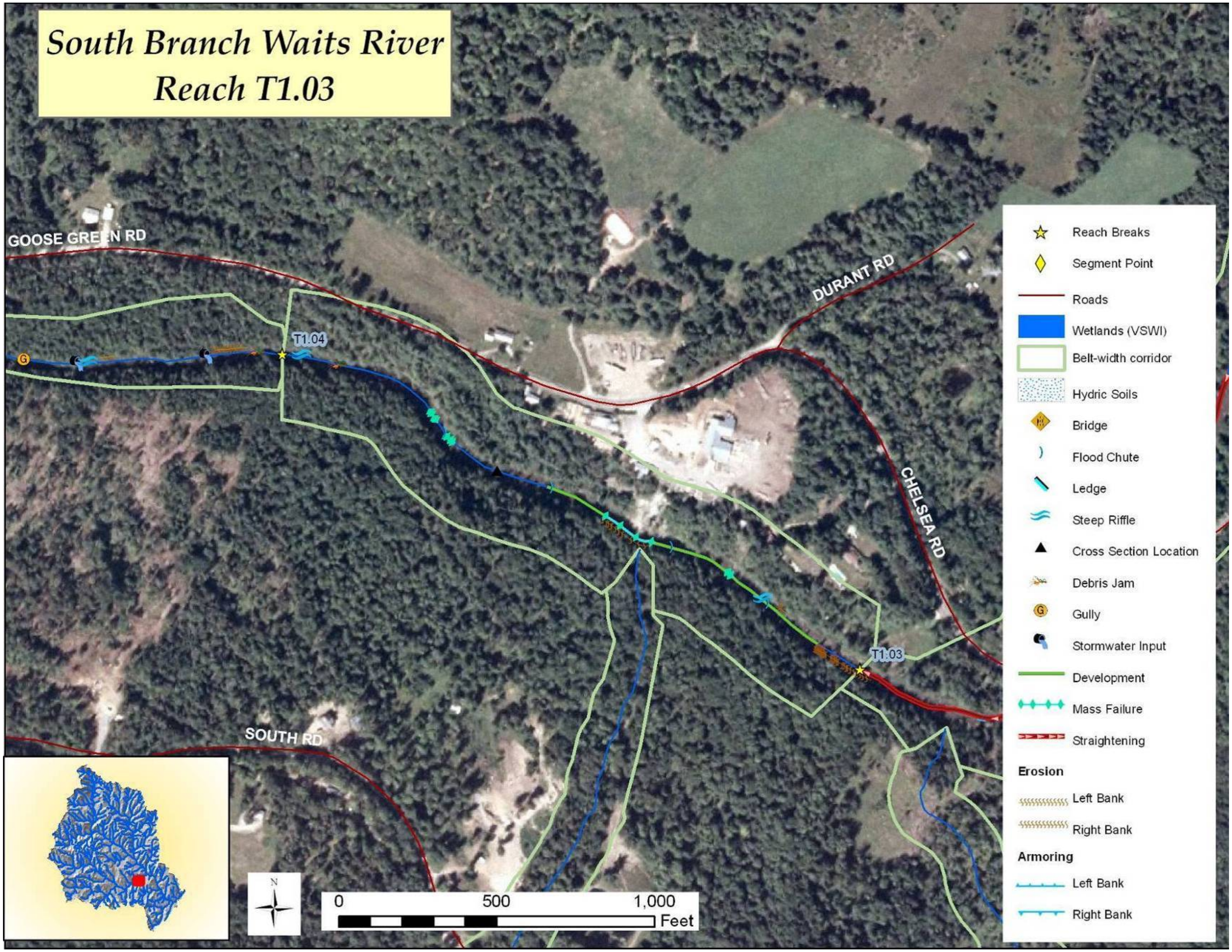


Figure 54. South Branch Waits River Reach T1.03.

Table 20. South Branch of the Waits Reach T1.03 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.03-0	Protect river corridor	High	Low	Y	Limited attenuation assets, primarily flood hazard avoidance and mitgation

6.1.14 Reach T1.04 – South Branch of the Waits, Bradford/Corinth town line to tributary confluence just downstream of South Rd.

Reach T1.04 comprises 3634 ft (~ 0.7 mi) of the South Branch between the Bradford/Corinth town line and the South Rd. intersection with the Chelsea - Goose Green Rd. The reach was not segmented for Phase 2 assessment. Key features included:

- T1.04 is a Bc stream ('c' subslope <2%), riffle-pool with a cobble substrate, in a semi-confined valley
- An incision ratio of 1.6 indicating reduced floodplain access
- Reach has low sinuosity and appears straightened primarily by maintenance of its relation to road encroachment and agricultural use rather than extensive signs of physical manipulation or armoring
- Agricultural use in the downstream portion of the reach appears to have decreased in intensity, as the right bank riparian corridor is regenerating
- Significant stormwater inputs off RB, with some potential gullying on the valley walls, but source was not clear - appeared to be primarily overland flow; area uphill appears to have some significant clearing, but 1998 b&w orthos indicate clearing and development in this area at that time as well; not clear if something else has shifted
- T1.04 has ~500 ft anomalous portion of the stream where the stream bottom was very sandy and soft, the right bank contained an adjacent wetland area, the stream broadened and there were numerous signs of beaver activity; may have been former beaver pond that blew out
- Heavy amounts of sand seemed to be related to surficial geologic materials rather than recent stream deposition, but some was clearly deposition
- One mass failure was noted on the left bank just downstream of a tributary confluence in this section of the stream

- Erosion common but not extensive in the reach; bank failure noted in section with beaver activity as well as ~900 ft at the head of reach where buffers were minimal to absent on the right bank (300 ft on the left bank)
- T1.04 buffers generally > 100 ft
- 36 pieces of large woody debris counted in the reach due to both beaver activity and erodible banks, playing some role in sediment storage
- Geomorphic condition Fair, widening following historic incision, sensitivity High


Figure 55. Stormwater or overland flow inputs appear to have cut through erodible sideslopes in reach T1.04 (left), where suspected former beaver dams were also observed (right).

Table 21. South Branch of the Waits Reach T1.04 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.04-0	Protect river corridor	Medium	Low	Y	Limited attenuation assets
T1.04-0	Plant stream buffers	Medium	Medium	N	Right bank, buffers limited by agricultural use; highly erodible fines in upstream portion of reach; plantings may need protection from beavers

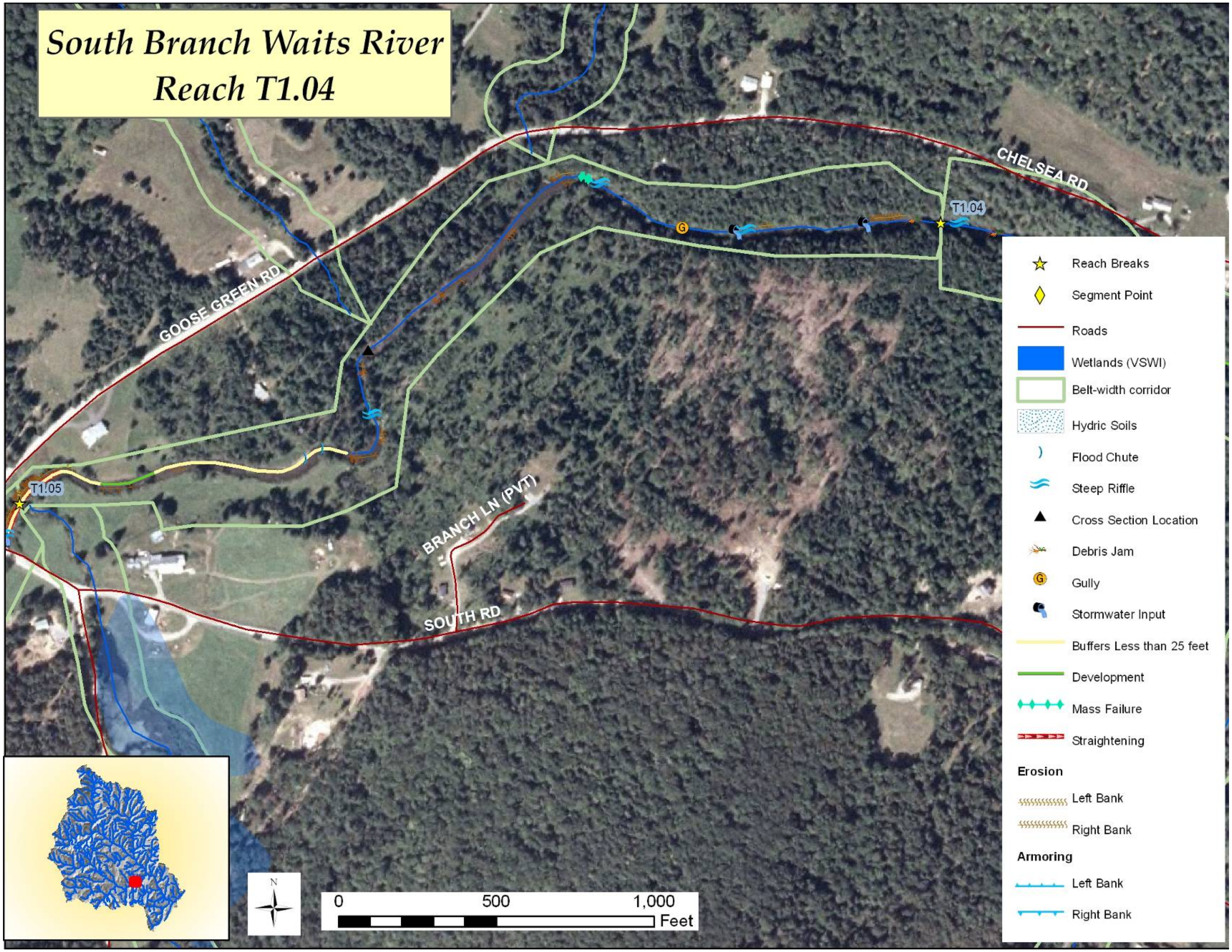


Figure 56. South Branch Waits River Reach T1.04

6.1.15 Reach T1.05 – South Branch of the Waits, from confluence with small tributary just downstream of South Rd. to ~1000 ft downstream of Corinth town garage

Reach T1.05 extends 13,429 ft (~ 2.5 mi.) from the confluence with a small tributary (roughly 160 ft downstream of South Rd. Bridge near intersection of South Rd. and Chelsea-Goose Green Rd.) to about 100 ft downstream of the Corinth town garage. The reach was broken into two segments about 1000 ft upstream of Bear Notch Rd. The reach was segmented primarily because of a change in stream type.

Segment T1.05A, the downstream segment, is roughly 11,000 ft. Key features include:

- T1.05A is an E-type stream, dune-ripple with a gravel bed, in a very broad valley.
- Meanders through mostly agricultural land and has some road and residential encroachment
- Segment has sand banks, extensive erosion, numerous signs of old flood chutes and changes in meander patterns
- Ditching was evident in the agricultural fields within the riparian corridor, as well as several road ditches that empty to the stream
- Although some loss of flood plain access was indicated by an incision ratio of 1.3, stream is not entrenched and still utilizes much of the very broad valley for floodplain
- ~500 ft of channel is affected by beaver dam
- Significant aggradation due primarily to deposition of fines
- Road encroachment occurs on both sides of the stream, but only in a short portion of the upstream end (~500 ft) and is present on both banks at the same time; several residential houses are located in close proximity to the stream

Figure 57. Segment T1.05A showing eroded banks (top) and development encroachments and agricultural proximity to the stream (bottom).

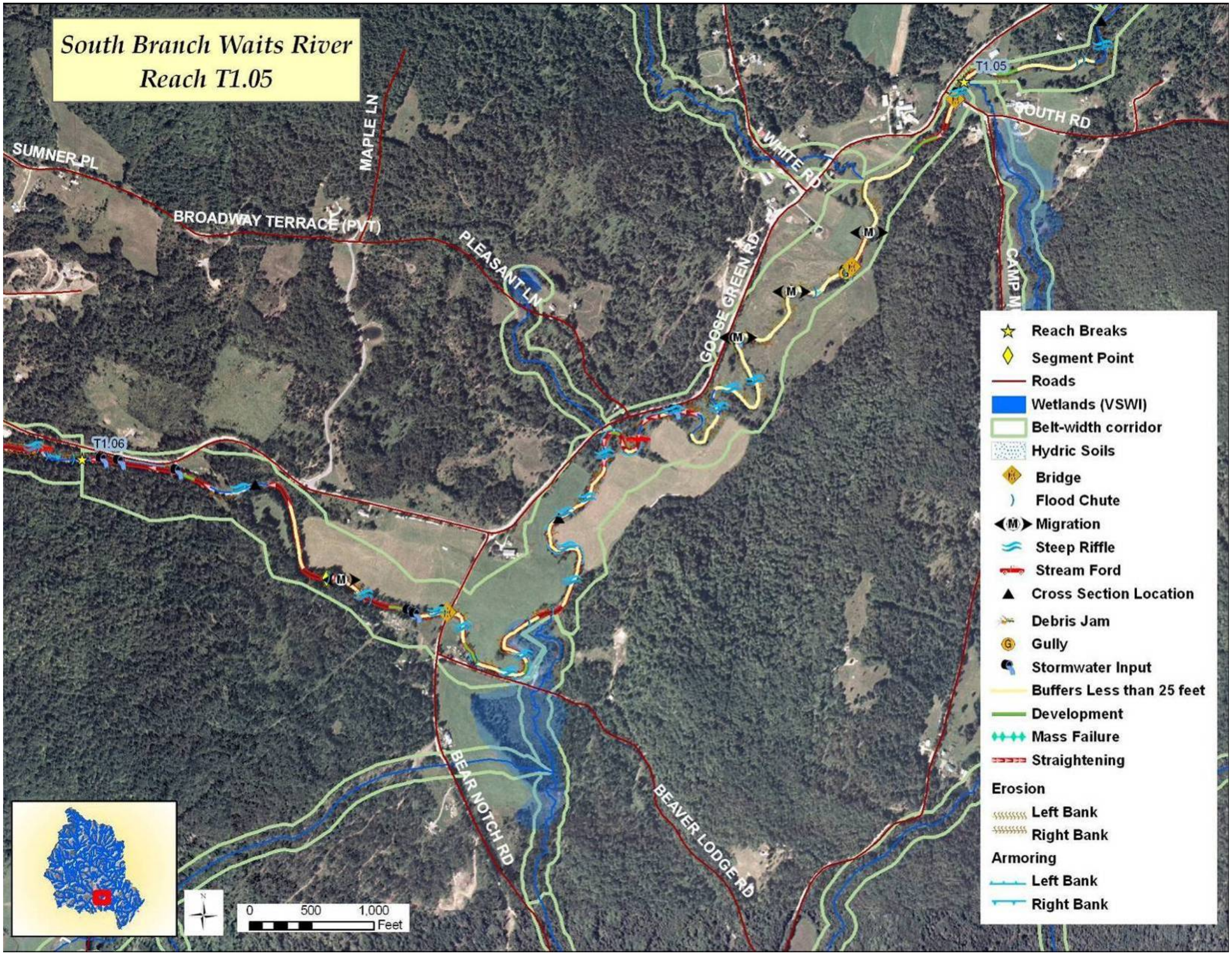


Figure 58. South Branch Waits River Reach T1.05

- Two relatively short (75 and 130 ft) berms were located in T1.05A; bank armoring was present along roughly 10% of each of the banks
- Neighbor reported that ~500-600 ft of the stream near the Bear Notch Rd/Beaver Lodge Rd. was rerouted 40-50 yrs ago; the stream currently makes a hairpin turn in this vicinity that is encroached upon and riprapped in several areas
- Channel constrictions were noted at a VAST snowmobile trail bridge; the old South Rd. bridge may have washed out in a flood, as twisted steel is visible from the road downstream of the crossing ; Bear Notch bridge being repaired in 2009
- Two stream fords cross portions of the stream
- Buffers were generally minimal to absent along almost the entire reach
- Geomorphic condition Fair, major widening adjustments, sensitivity Extreme

The upper segment, T1.05B, is roughly 2500 ft long, extending upstream from ~1000 ft upstream of the Bear Notch Rd. bridge. Key features included:

- T1.05B is a C-type stream, riffle-pool with a cobble substrate in a Narrow valley

- Stream is in a more wooded setting in this segment compared with the predominant hayfields along segment T1.05A

Figure 59. Segment T1.05B, showing wider C-type channel and more wooded corridor than in downstream segment T1.05A.

- Valley is narrowed by road encroachment off the left bank side
- Cobble bed was borderline planebed in many areas, but classified as riffle-pool due to depositional riffles; cobble in banks reduced the extent of bank erosion in comparison with downstream portions of the reach
- Some loss of floodplain access indicated by incision ratio of 1.7, but stream is not highly entrenched
- Appears straightened along ~70% of the stream; a road may have formerly been located closer to the stream
- Dominant 51-100 ft buffer widths on left bank due to road encroachment, with subdominant buffer widths >100 ft when road was further from stream; right bank buffers generally >100 ft
- Geomorphic condition Fair, stabilizing following historic incision with only minor current adjustments; High sensitivity

Table 22. South Branch of the Waits Reach T1.05 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.05 A	Protect River Corridor	High	High	Y	Some light development, mostly agricultural use
T1.05 A	Plant stream buffers	High	High	Y	Both right and left banks non-existent due to agricultural use; low-cost plantings due to beavers and erosion
T1.05 A	Replacement of existing bridge structures, removal of old bridge abutment	Low	Low	Y	Old abutment is minor constriction; snowmobile bridge is channel but not floodplain constriction and had no problems noted; Bear Notch bridge being repaired in 2009
T1.05 B	Protect River Corridor	Medium	High	Y	Lower priority than segment T1.05A, but still high priority for watershed dynamics

6.1.16 Reach T1.06 – South Branch of Waits, from 1000 ft downstream of Corinth town garage to 350 ft downstream of intersection between the Goose Green Rd. and the Chelsea Rd.

Reach T1.06 is the most upstream reach and is 1851 ft (~ 0.3 mi). It extends from ~1000 ft downstream of the Corinth town garage to ~350 ft downstream of the intersection between Chelsea -Goose Green Rd. and Brook Rd. This upstream point is also the confluence of the South Branch, Meadow Brook and Cookeville Brook at Goose Green (the South Branch becomes Meadow Brook above this point). Key features included:

- T1.06 is a C-type stream, riffle-pool with a cobble substrate in a Narrow valley
- Road encroachment has reduced the valley type from Very Broad but the stream is still unconfined
- Bed is characteristically cobble with numerous depositional features contributing to riffle-pool bedform; limited number of bedrock outcrops noted along the banks
- An incision ratio of 1.3 was based on a recently abandoned floodplain in a hayfield off the left bank of the channel cross-section, while a higher terrace on the right bank indicated that there had likely been additional historic incision
- Elevated fill across from the town garage has plugged an old flood chute and created a narrower valley and deeper incision ratio in a limited portion of the downstream end of the reach, and there is an unimproved snowmobile trail above the stream in the riparian corridor on the right bank
- The reach is straightened with roughly 15% of the left bank armored and erosion noted on about 25% of each bank; bank failures noted on the right bank in the downstream portion of the reach; log ends still held in place on the right bank while the midstream ends of the logs are dislodged
- Buffers are lacking in the upstream portion of the reach, contributing to a subdominant buffer of <25 ft on both banks; dominant buffer widths exceeded 100 ft on the right bank but were reduced to 51-100 ft on the left bank
- Sediment storage was occurring in mid-channel and diagonal bars in addition to point bars; flood chutes were noted along each side of the stream in the downstream portion of the reach

Figure 60. Reach T1.06 showing old stream ford, bank failure and mid-channel bar

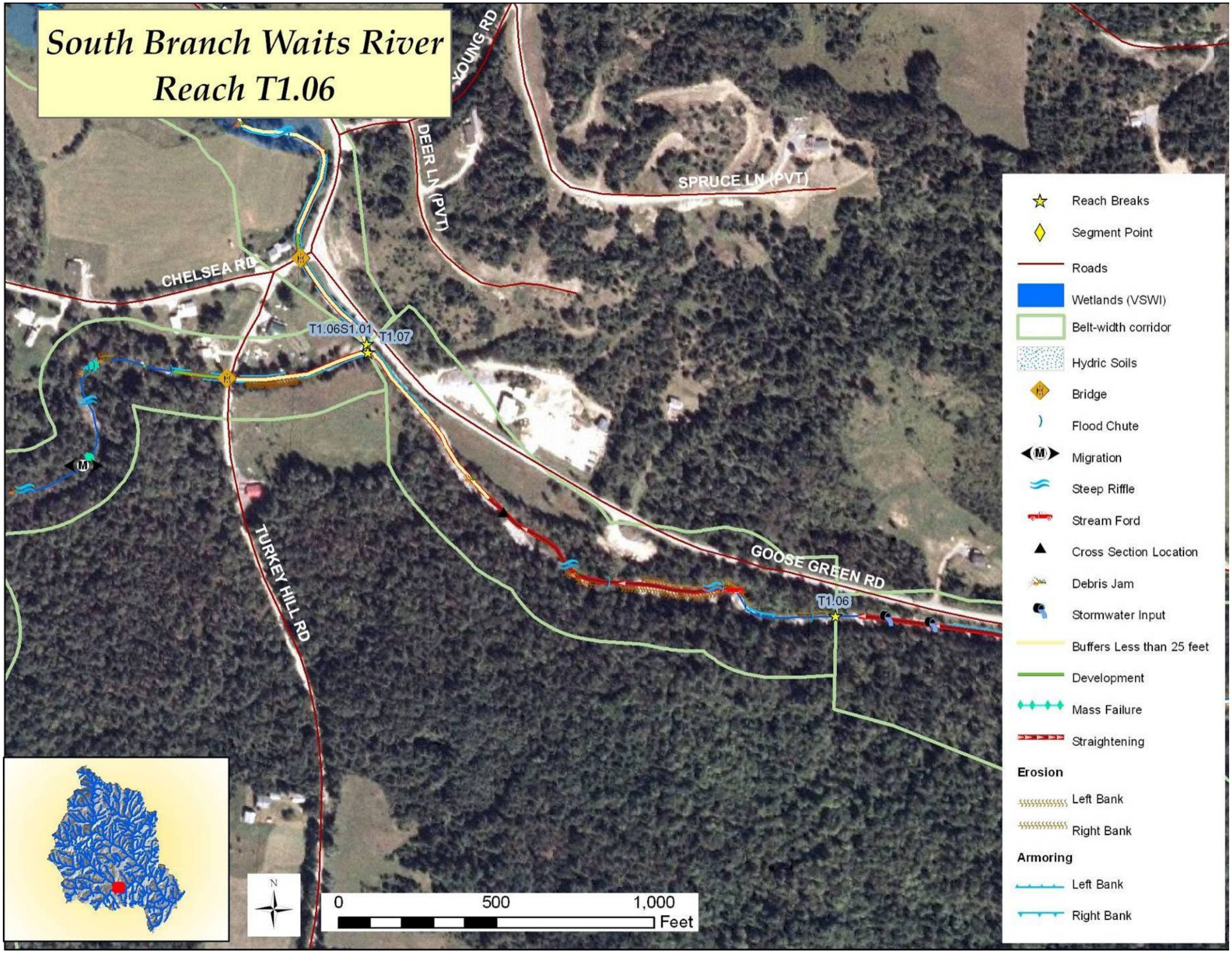


Figure 61. South Branch Waits River T1.06.

Table 23. South Branch of the Waits Reach T1.06 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.06	Protect River Corridor	High	Low	Y	Attenuation assets somewhat limited in extent
T1.06	Plant/ augment stream buffers	Medium	Low	Y	Both left and right banks lacking buffers in upstream portion of reach, planting difficult on left bank: road bank
T1.06	Remove fill	Medium	Medium	Y	Weigh cost/benefit analysis: limited floodplain gain may be offset by increased risks to road

6.1.17 Reach T1.06S1.01 – Cookville Brook, from ~350 ft downstream of the Chelsea-Goose Green Rd. bridge at Goose Green to west (upstream) end of Devins farm buildings

Reach T1.06S1.01 is 5413 ft (~ 1 mi) and extends from ~350 ft downstream of the bridge at Goose Green (intersection of Brook Rd. and the Chelsea-Goose Green Rd.) to ~1900 ft upstream, past the buildings of Devins dairy farm where the valley narrows. The reach was divided into two segments, the second segment beginning ~180 ft south of the Cookville Rd. crossing.

Segment T1.06S1.01A, the downstream segment, is ~3517 ft long. Key features included:

- Segment is an E-type stream, riffle-pool with a gravel substrate, in a Very Broad valley
- Buffers diminished due to current hay and pasture use; dominant buffers <25 ft on both banks, but 26-50 ft subdominant buffers on both banks contribute to good amounts of large woody debris noted as playing an important role for habitat and sediment retention
- Erosion on ~10% of left bank, 5% of right bank; bank armoring on ~30% of left bank and ~25% right bank
- Significantly straightened, with road encroachments along >50% of the left bank

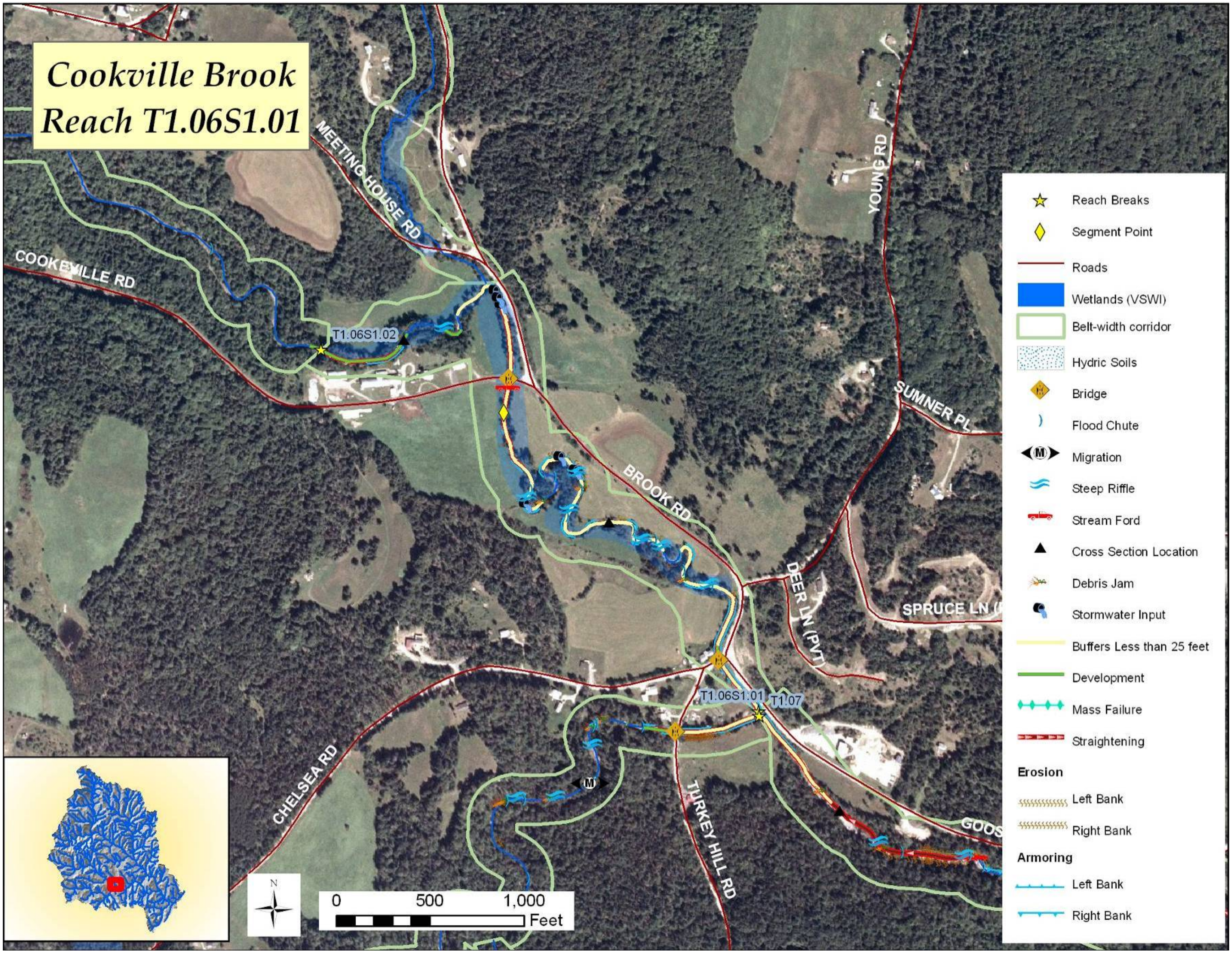


Figure 62. Cookville Brook Reach T1.06S1.01

- Nice deep pools in portions of T1.06S1.01A
- Three field ditches contributing stormwater
- Historically, carding mill and gristmill located further upstream on Cookville Brook; some historic incision noted
- Alluvial fan located in next segment upstream (T1.06S1.01B) and aggradation is primary current adjustment process noted in T1.06S1.01A
- Chelsea-Goose Green Rd. bridge is a floodplain constriction and is sized slightly less than bankfull width but poses a channel constriction due to alignment
- Incision limited due to banks being more erodible than stream bed; stage IIc aggradation and widening, D model channel evolution (see sec. 5.1.4, *Channel evolution*)
- Fair geomorphic condition, Extreme sensitivity

Segment T1.06S1.01B, the upstream segment, is approximately 1896 ft long. Key features included:

- E-type stream bordering on C-type characteristics (primarily wider channel) due to stage of evolution , plane bed with a gravel substrate, in a Very Broad valley
- T1.06S1.01B appears to be located on an alluvial fan downstream of historic mill locations
- Some historic incision noted, but current primary adjustments are aggradation and planform change; widening currently somewhat limited due to significant bank armoring
- Combined development and road encroachments virtually throughout entire length of segment, but only on one bank at a time; encroachments on right bank from farm buildings, on left bank from road
- Diminished buffers due to agricultural use and encroachments: <25 ft dominant on right bank, subdominant on left bank; 26-50 ft dominant on left bank, subdominant on right bank
- Fair geomorphic condition, Extreme sensitivity, stage IIc aggradation and planform change

Figure 63. Reach T1.06S1.01 showing bank toe armoring on the left bank.

Table 24. Cookville Brook Reach T1.06S1.01 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.06S1.01A	Protect River Corridor	High	High	Y	High priority for channel management easements
T1.06S1.01A	Plant stream buffers, fencing	High	High	N	Both right and left banks minimal due to agricultural use
T1.06S1.01A	Replace existing bridge	Medium	Medium	Y	Channel and floodplain constriction, channel due to alignment; replacement would need to consider impacts to encroachments
T1.06S1.01B	Protect River Corridor	High	High	Y	High priority for channel management easements
T1.06S1.01B	Plant/ augment stream buffers, fencing	High	High	N	Both right and left banks diminished due to agricultural use
T1.06S1.01B	Replace existing bridge	Medium	Low	Y	Channel constriction but not floodplain constriction

6.1.18 Reach T1.07– Meadow Brook, from the confluence with the South Branch and Cookville Brook at Goose Green to waterfalls approximately 3775 ft upstream

Reach T1.07 is 3786 ft (~ 0.7 mi) long and includes the length of stream from the confluence with Cookville Brook and the South Branch to a large bedrock grade control feature approximately 3775 ft upstream. This reach was not segmented during the Phase 2 assessment. Key features include:

- T1.07 is a Cb-type stream ('b' subslope 2-4%), step-pool with a cobble substrate, in a Narrow valley with extremely steep sideslopes
- Lower portions of the reach were the historic location of a linen mill and factory, have been bermed and rip-rapped, and have some bank instability; berm removal would potentially impact development along the stream
- Bank erosion and mass failures were noted in the lower part of the reach
- Upper portions of the reach are much less impacted; buffers on both banks are forested and > 100 ft
- Large woody debris is playing a significant role in sediment retention and diffusion of stream power (meander development, 7 flood chutes noted on reach) and retention of access to limited floodplains; 71 pieces of large woody debris were noted in the reach
- Turkey Hill Rd crossing is sized at 44% of reference channel width, posing both a channel and floodplain constriction, and had deposition noted both upstream and downstream of the structure as well as scour downstream; structure is an arch incorporating the existing stream substrate, however (good for aquatic organism passage) and appears in good shape other than undersizing
- Geomorphic condition Fair, minor aggradation, widening and planform change following historic incision; sensitivity High

Figure 64. Turkey Hill Rd. stream crossing in reach T1.07 is undersized but is an excellent design for fish and other aquatic organism passage.

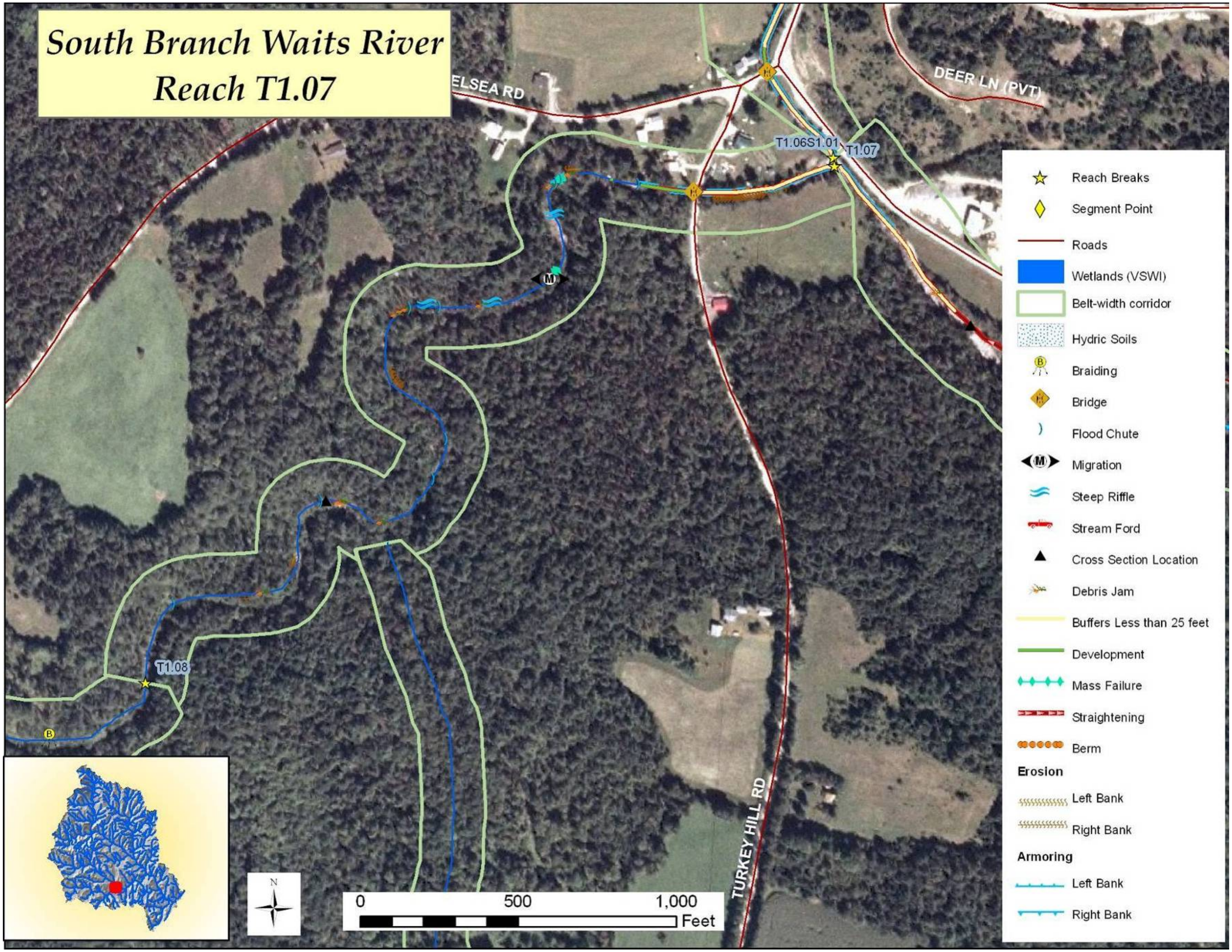


Figure x. South Branch Waits River Reach T1.07

Table 25. South Branch of the Waits Reach T1.07 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.07	Protect River Corridor	Medium	Low	Y	Extremely steep sideslopes make further encroachment unlikely but protection has benefits of flood hazard avoidance
T1.07	Plant buffers	Low	Low	Y	Buffers lacking in downstream end of reach; water quality and temperature benefits
T1.07	Replace existing structure	Medium	Low	Y	Arch culvert undersized, presenting both floodplain and channel constriction, but is in good shape and is good design for fish and aquatic organism passage

6.1.19 Reach T1.08– Meadow Brook, from waterfalls ~0.5 mi downstream of Dearborn Hill Rd. bridge to the beaver impoundment at the downstream edge of hayfields below Dearborn Hill Rd. bridge.

Reach T1.08 is 1898 ft (~0.36 miles) long and begins at the waterfalls at the top of reach T1.07 and extends to the forest edge and beaver impoundment at the downstream edge of hayfields downstream of the Dearborn Hill Rd. bridge. The reach was not segmented for Phase 2 assessment. Key features included:

- T1.08 is Bc-type stream (‘c’ subslope <2%), step-pool with a cobble substrate, in a Narrowly Confined valley
- The reach is largely bedrock-controlled, with a 20 ft. waterfalls marking the downstream end of the reach and two ledge grade controls mid-reach; although

bedrock was well vegetated and not immediately evident in the valley walls, there was a notable lack of mass failures and erosion in T1.08

- Incision ratio of 1.3 suggested some historic downcutting
- Minor widening evidenced by undercut banks, but intact forested buffers >100 ft on both banks combine with the significant bedrock presence to stabilize the reach
- Two stream fords were noted in the reach, possibly associated with logging operations, and there appeared to be the remains of some sort of structure (temporary skidder bridge?) at one of these fords
- Geomorphic condition Good, sensitivity Moderate, channel evolution stage IV (stabilizing)
- As a natural Transport reach, T1.08 is likely to transfer any impacts from upstream to downstream reaches

Figure 65. Two fords were noted in reach T1.08, and timbers in the stream may have been the remains of a temporary skidder bridge or similar structure for a logging operation

Table 26. South Branch of the Waits Reach T1.08 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.08	Protect River Corridor	Medium	Low	Y	Encroachment unlikely but impacts to buffers could initiate adjustments likely as mass failures and erosion

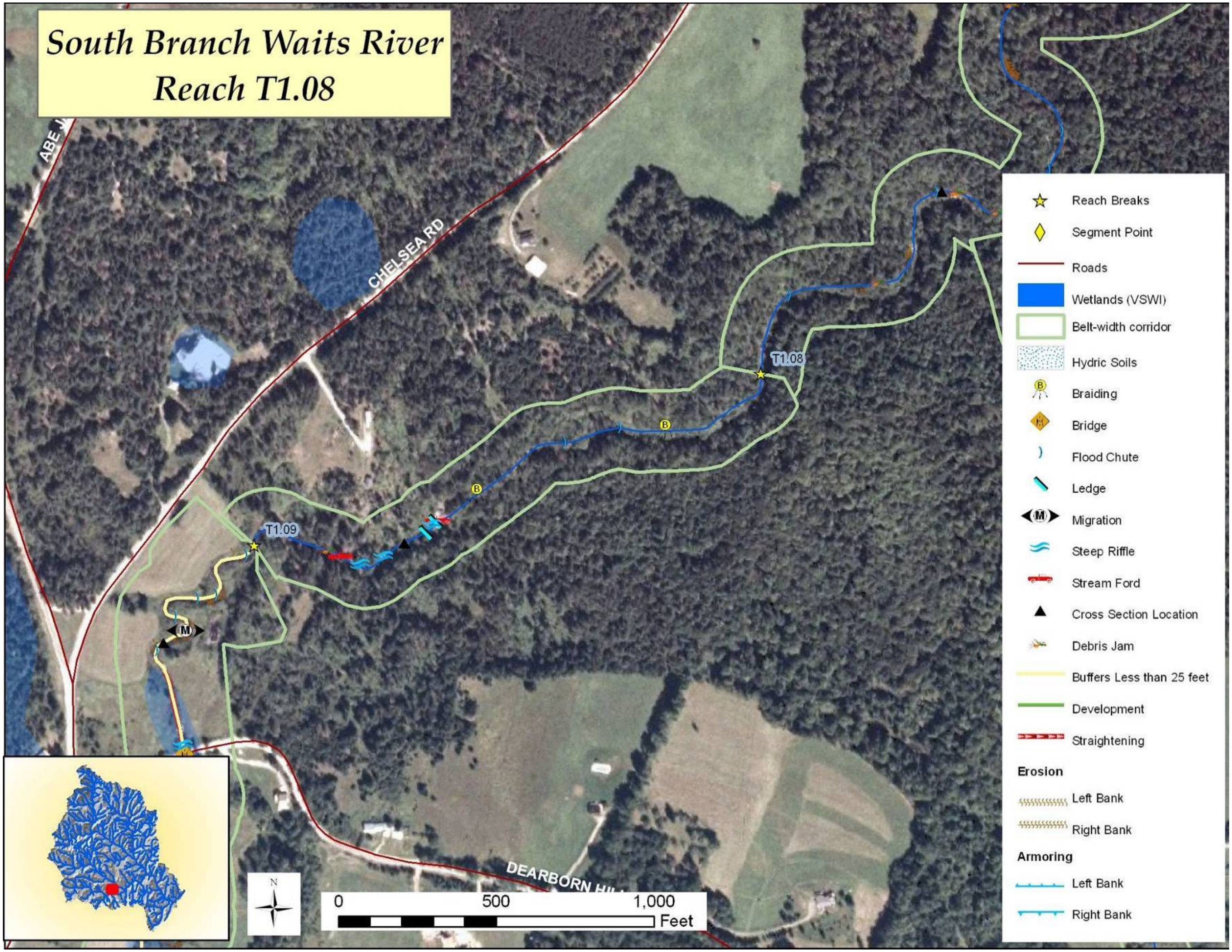


Figure x. South Branch Waits River Reach T1.08

6.1.20 Reach T1.09– Meadow Brook, from ~500 ft downstream of Abe Jacobs Rd./ Chelsea Rd. intersection (and ~970 ft downstream of Dearborn Hill Rd. bridge) to ~700 ft. downstream of Eagle Hollow Rd.

Reach T1.09 is 7520 ft (~ 1.4 mi) long and extends from ~500 ft downstream of the Abe Jacobs Rd./Chelsea Rd. intersection to the confluence with a small unnamed tributary ~700 ft downstream of Eagle Hollow Rd. The reach was assessed as three segments, primarily due to differences in depositional features, buffer conditions, and corridor encroachments; all three segments were noted as E-type streams.

Segment T1.09A, the most downstream segment, is 3519 ft long and extends from ~500 ft downstream of the Abe Jacobs Rd./Chelsea Rd. intersection to just upstream of the South America Rd. bridge. Key features include:

- E-type stream, dune-ripple with a sand substrate, in a Very Broad valley
- T1.09A is heavily influenced by beaver activity in lower portions; transitory beaver dams add to temporary alterations of sediment flow (storage at impoundments and subsequent surges when dams are blown out)
- Both banks are poorly buffered, dominant < 25 ft; lack of forested buffer related to agricultural use (primarily hayfields)
- Fine substrate present on both bed and banks, but on banks particularly makes for elevated levels of erosion and aggradation, especially where buffers are lacking
- Arch culvert at Dearborn Hill Rd. is partially obstructed by a beaver dam just upstream of the inlet
- Due to extensive presence of alluvial soils, banks erode more easily than the bed and stream appears to evolve according to D model evolution (see sec. 5.1.4, *Channel evolution*)
- Only minor current adjustments noted; localized widening and aggradation due to erosion (lack of buffer) and beaver activities
- Geomorphic condition Good, sensitivity High, channel evolution D-model stage III (stable)

Figure 66. Arch culvert at Dearborn Hill Rd. in segment T1.09A is partially obstructed by a beaver dam just upstream of the inlet

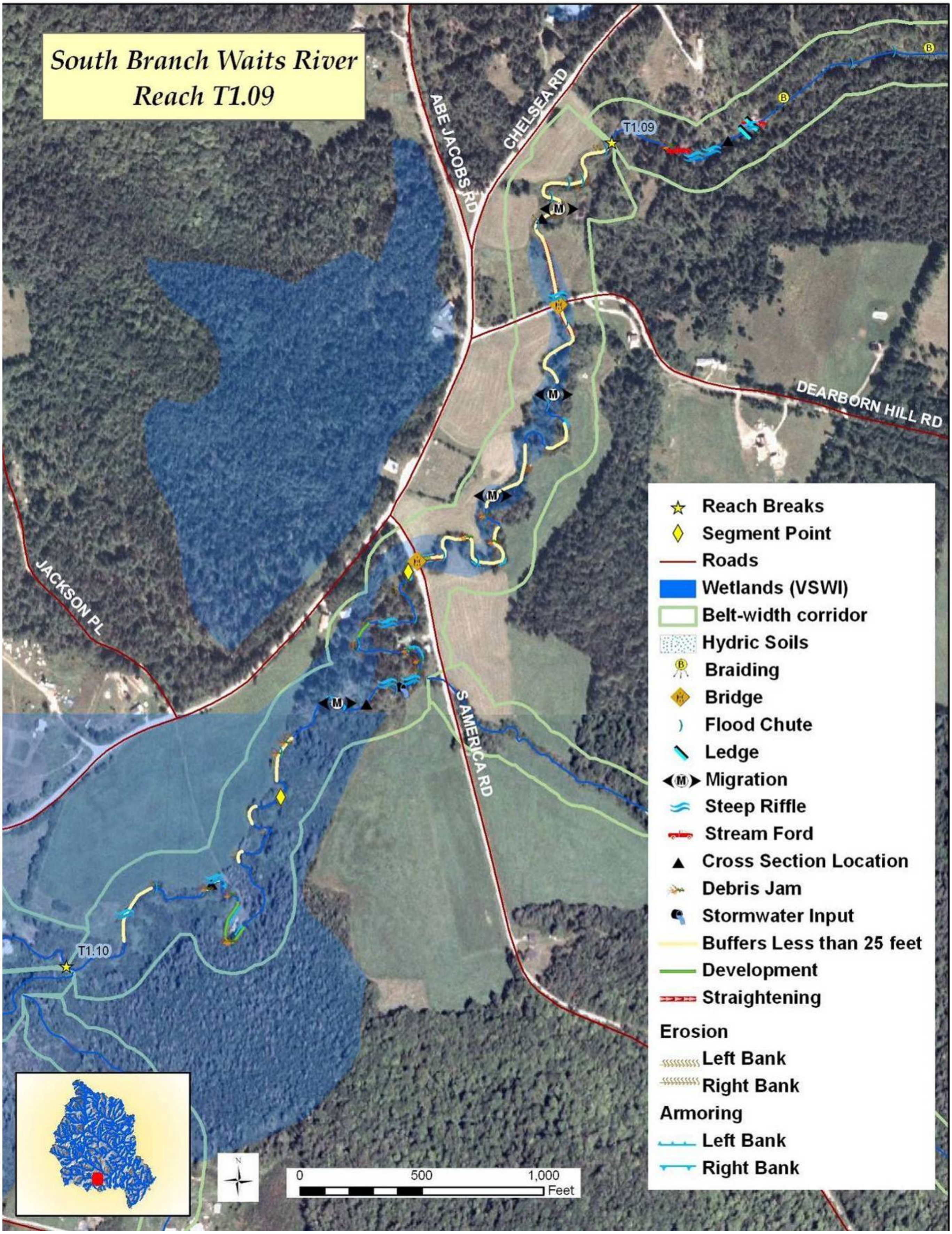


Figure 67. South Branch Waits River Reach T1.09

Segment T1.09 B, the middle segment, is 1889 ft long and extends from just upstream of the South America Rd. bridge to Jackson Place and Chelsea Rd. intersection. Key features included:

- T1.09B is an E-type, dune-ripple with a sand substrate, in a Very Broad valley
- Channel is showing considerable planform and aggradation adjustments, and was segmented primarily on the basis of a large increase in depositional features noted in this segment in comparison with segment T1.09A. Numerous pieces of dislodged bank were found in the stream, and beaver dams in the area appeared recently blown out. June and July 2008 were the wettest on record (as reported by Steve Maleski, WVPR Eye on the Sky; 114 years of record at Fairbanks Museum, St. Johnsbury) and summer 2008 was the third wettest on record statewide for the same period (Northeast Regional Climate Center). In addition, a 100-year peak flow was registered at the East Orange Branch stream gage not far from here in July 2007 (see sec. 3.1.4, *Flood history*). Additional recent changes upstream have included significant riprapping of banks by the Eagle Hollow Rd. bridge near the T1.10 reach break, and two more intense microburst storms were experienced upstream after the Phase 2 assessment of this reach was completed in late July 2008.
- Encroachments affect more of this segment than segments downstream and upstream within reach T1.09, but still impact <5% of the segment; forested and wetland buffers are present and generally exceed 100 ft
- Due to extensive presence of alluvial soils, banks erode more easily than the bed and stream appears to evolve according to D model evolution (see sec. 5.1.4, Channel evolution)
- Geomorphic condition Fair, sensitivity Extreme, channel evolution D model stage IIc: major aggradation and planform adjustments

Figure 68. Beaver dams in segment T1.09B appeared recently blown out.

Segment T1.09 C, the furthest upstream segment, is 2112 ft long and extends from the vicinity of the Jackson Place/Chelsea Rd. intersection to the head of the reach, ~700 ft downstream of Eagle Hollow at the confluence with a small unnamed tributary. Phase 2 assessment noted:

- E-type stream, dune-ripple with a sand substrate, in a Very Broad valley
- Buffers on right bank are > 100 ft; dominant left bank buffers are <25 ft
- Planform adjustments appear more moderate than other two segments in reach, likely due to good buffers and unrestricted floodplain access
- One house encroachment clearly in floodplain in close proximity to the stream, bank toe stabilization and a footbridge placed in same area; footbridge has deposition upstream
- Geomorphic condition Good, sensitivity High, channel evolution D model stage IIc, minor aggradation, widening and planform change

Figure 69. Development encroachment in segment T1.09C; bank toe stabilization placed on both banks; bridge is a channel constriction with some deposition noted upstream

Table 27. Meadow Brook Reach T1.09 Projects and Practices Table.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.09 A	Protect River Corridor	High	High	Y	High priority due to impacts noted upstream and potential for rapid response, with implications for sediment and flow discharges affecting equilibrium conditions of downstream reaches
T1.09 A	Plant stream buffers	High	High	Y	Both left and right banks have minimal buffer
T1.09 A	Repair or replace existing structures	High	Medium	Y	Arch culvert at Dearborn Hill is significantly undersized and further obstructed by beaver dam just upstream of inlet Bridge at S. America Rd. is both floodplain and channel constriction, less critical than Dearborn Hill; consider upsizing when due for replacement
T1.09 B	Protect river corridor	High	High	Y	Significant current adjustments, Extremely sensitive, implications for sediment and flow discharges affecting

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
					downstream reaches
T1.09 B	Plant/ augment stream buffers	High	High	Y	Left bank lacking significant buffer
T1.09C	Protect River Corridor	High	High	Y	High priority due to recent microbursts, road washouts, channel straightening and land clearing noted upstream (after Phase 2 assessment completed) and potential for rapid response, with implications for sediment and flow discharges affecting equilibrium conditions of downstream reaches
T1.09 C	Plant/ augment stream buffers	High	High	Y	Left bank lacking significant buffer

6.1.21 Reach T2.01– Tabor Branch, from confluence of Tabor Branch with mainstem of the Waits River to where the stream turns to approach the Village Rd.

Reach T2.01 is 848 ft (~ 0.2 mi) and extends from the confluence of the Tabor Branch and the mainstem of the Waits River to where the stream turns to approach the Village Rd. (about 750 ft). The reach was not segmented for Phase 2 assessment. Key features included:

- C-type stream, riffle-pool (subdominant planebed) with a cobble substrate, in a Very Broad valley
- T2.01 has a very broad valley because it shares the valley with the Waits main stem in vicinity of reach M09
- Two significant bedrock features stabilize the stream bank and influence the bedform
- Encroachment is significant on the right bank; one residential house is located only 3 ft from the stream bank
- Village Rd. restricts access to historic floodplain; incision ratio of 2.2 is based on human elevated floodplain restriction associated with this road. This encroachment is long-standing and floodplain access off the right bank would be unlikely without significant relocation of the road
- Process-based incision ratio of 1.4 indicates likely historical incision as well; historically, six dams operated concurrently upstream on the Tabor Branch
- Historic maps from different eras indicate significant road reconfigurations in the vicinity of the crossing of the Waits and up the Tabor Branch (this reach) into East Corinth village, including rerouting of Rte. 25 and likely extensive straightening of both of these streams in this area

Table 28. Tabor Branch reach T2.01 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.01	Plant stream buffers	Low	Low	Y	Right bank lacking buffer in upstream parts of reach

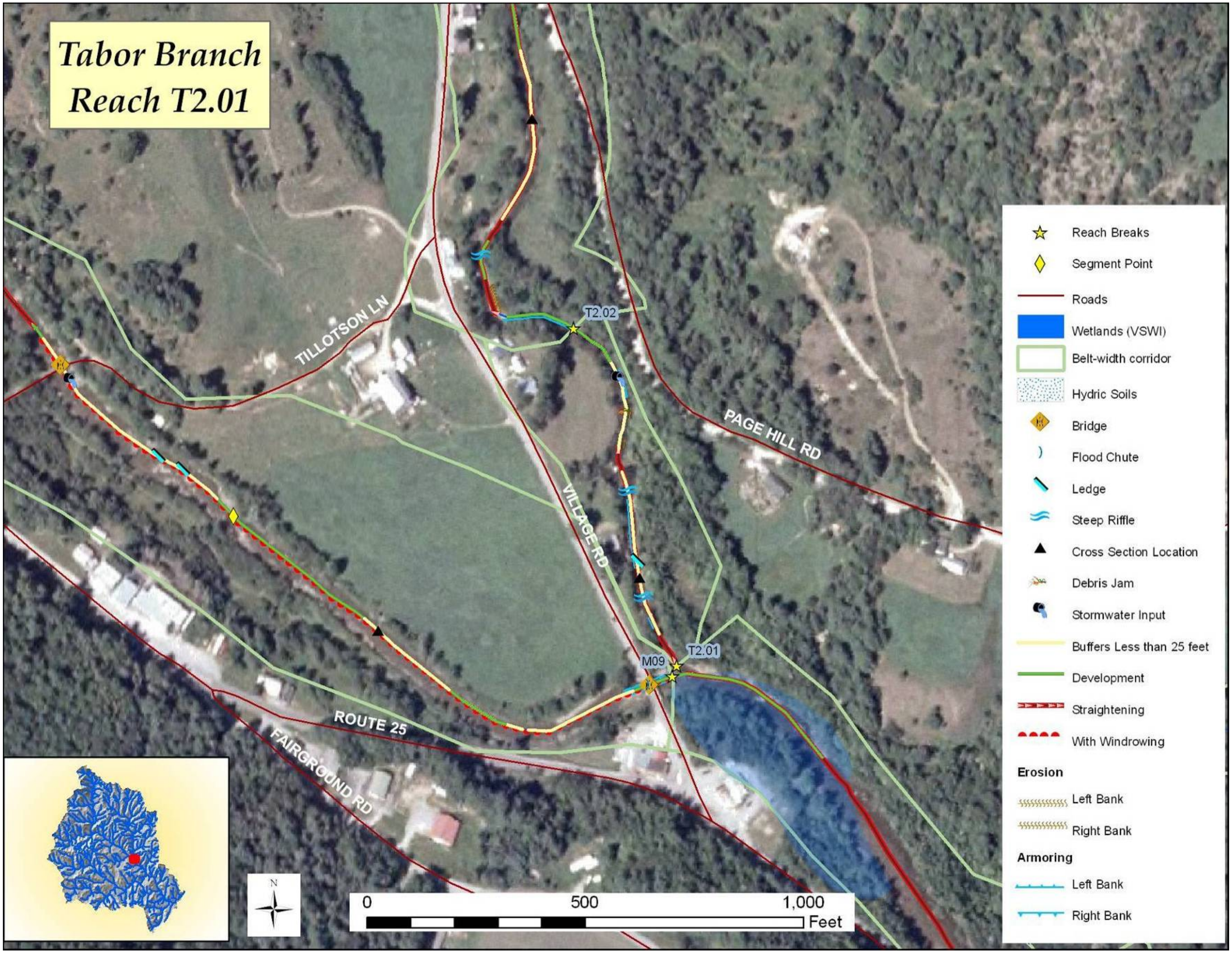


Figure 70. Tabor Branch Reach T2.01

6.1.22 Reach T2.02- Tabor Branch, from ~300 ft downstream of Tillotson Ln./Village Rd. intersection to confluence of a small tributary and the Tabor Branch west of Thompson Rd. /Village Rd. intersection.

Reach T2.02 is 4669 ft (~ 0.9 mi) long and extends from ~300 ft downstream of the Tillotson Ln./Village Rd. intersection to the partially breached dam from the old bobbin mill at the north end of the main village of East Corinth. The reach was assessed as three segments, primarily due to the significant differences in stream form and setting in the bedrock-controlled mid-section of the reach that is situated behind the East Corinth Historical Society.

According to a mill dam owner (old bobbin mill that was in operation until the 1960s) in the upstream portion of the reach, Tabor Branch historically had six mills (between East Corinth and Topsham Four Corners) operating concurrently at one point, with flows allocated through the course of the day to power the mills successively.

Segment T2.02 A, the most downstream segment in the reach, is 1886 ft long and extends from ~300 ft downstream of the Tillotson Ln./Village Rd. intersection to approximately 0.5 mi north of Waits River Rd. (Rte. 25) intersection, where the old abutments of a bridge that formerly crossed the Tabor Branch to what is now Jewell Ln. mark the downstream extent of significant bedrock controls in bed and banks . Key features included:

- T2.02A is a C- type stream, riffle-pool with a gravel substrate, in a Very Broad valley
- This segment comprises a small area of floodplain in a reach that has been significantly confined (both by humans and naturally) further upstream
- Buffers are generally poor on both banks, < 25 ft
- Incision ration of 1.9 indicates significant loss of access to historic floodplain; possible indications of more recent incision (particularly a lower terrace off the right bank were difficult to verify due to presence of encroachments on both banks (development and road on the right bank; snowmobile trail, hayfield and road on the left bank) that make it difficult to determine the true height of terraces that may have been influenced by construction and maintenance
- Village Rd. bridge on the upstream end of segment T2.02A presents a channel constriction and a partial floodplain constriction, and shows evidence of abutment scour and failed riprap downstream of the structure
- Geomorphic condition Fair, sensitivity Very High, widening and some aggradation following historic incision; planform change limited by encroachments

Figure 71. Encroachments on both sides of T2.02A have obscured terraces that might indicate the extent of access to historic floodplains along the Tabor Branch

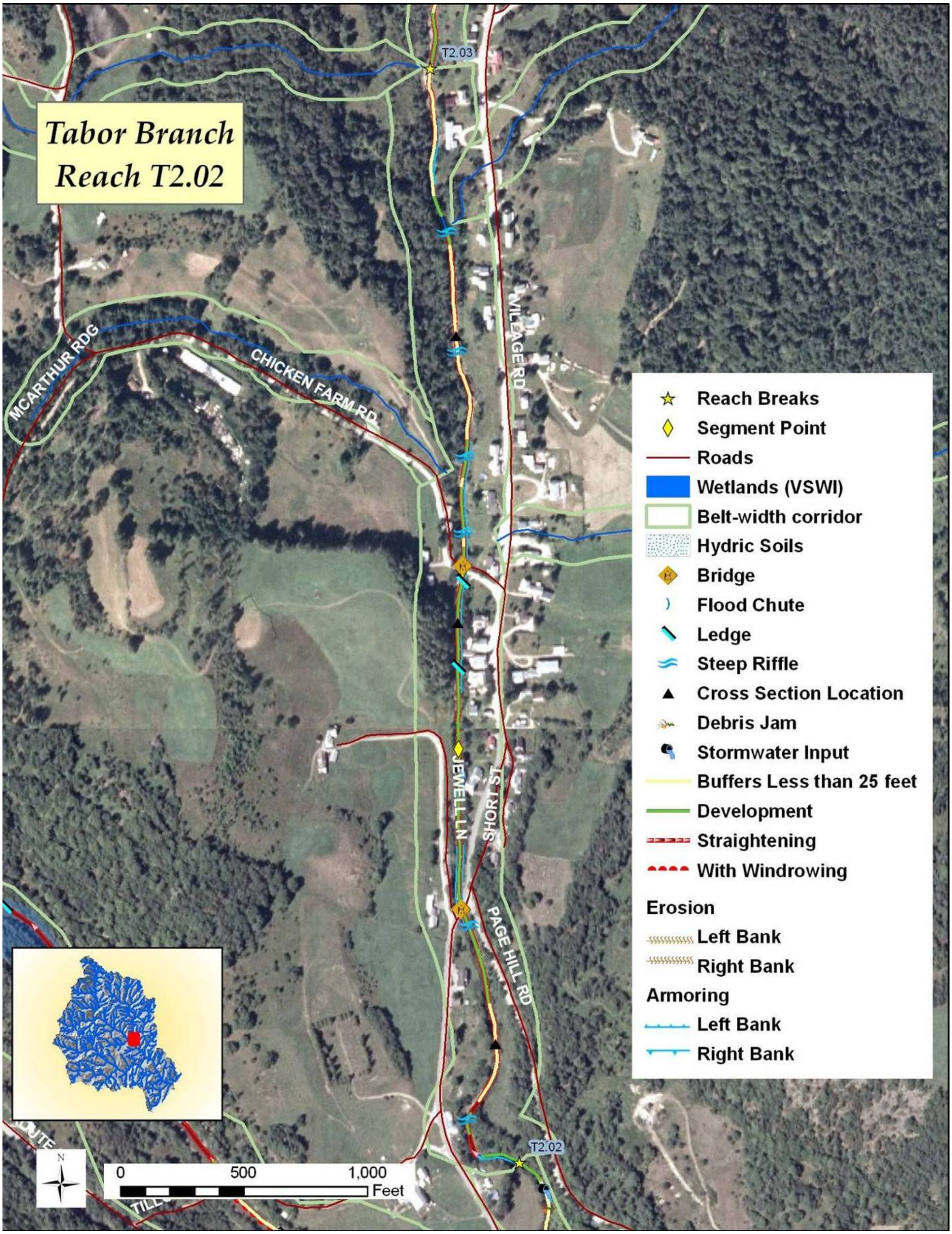


Figure 72. Tabor Branch T2.02

Segment T2.02B, the middle segment in the reach, is roughly 725 ft long and extends from the old abutments of the bridge that used to cross to Jewell Ln., ~ 0.5 mi north of the Waits River Rd. (Rte. 25) intersection, to just upstream of the Chicken Farm Rd. bridge. Key features included:

- T2.02B was typed as an F stream by reference, plane bed with a boulder substrate, in a Narrowly Confined valley
- Segment is bedrock controlled, augmented by historic and existing bridge abutments
- This stream type assessment was made primarily because there were no indicators of historic incision discernible on the bedrock walls along the stream, but given the history of intensive flow regulation along the Tabor Branch it is quite conceivable there has been extensive downcutting in this section of the stream (sufficient to cause a B to F stream type departure indicating loss of access to historic floodplain) that is no longer apparent because the bedrock has been scoured repeatedly over time. An alternative scenario would be that the stream never incised much, and mills were located in this area primarily because of the bedrock that was already exposed
- Geomorphic condition Good, sensitivity Low, channel evolution D model stage III, stable, with primarily historic planform change due to straightening and windrowing; minor aggradation appears transitory, and widening is limited by bedrock, abutments, and coarse substrate

Figure 73. Tabor Branch segment T2.02B still has old pieces of equipment from mills that operated in this bedrock-controlled section of the stream.

Segment T2.02 C, the furthest upstream segment in the reach, is 2058 ft long and extends from the Chicken Farm Rd. bridge to the confluence of a small tributary and the Tabor Branch, just west of Thompson Rd./Village Rd. intersection, at the old bobbin mill dam that is currently owned by Gordon Kittredge. The dam at the upstream end of the segment is only partially breached (Mr. Kittredge is interested in restoring it for power generation).

Figure 74. The old bobbin mill dam at the upstream end of segment T2.02C is still partially intact, and the current owner hopes to restore it to generate power.

Key features in segment T2.02C included:

- Bc-type stream (‘c’ subslope <2%), riffle-pool with a gravel substrate, in a Narrow valley
- Incision ratio of 1.2 indicated some historic channel downcutting, and it is strongly suspected that the bankfull depth at the cross-section was indicative of flows during ice jams, and the actual incision ratio is significantly higher than this
- Frequent signs of ice damage on upstream side of trees along the stream and riparian landowner indicated ice jams are common
- Road and/ or development along virtually the entire length of the riparian corridor on left bank
- ~40% of the left bank is armored
- Buffers <25 ft on almost the entire left bank of the stream
- Chicken Farm Rd. bridge is high above the channel and is a constriction not because of the structure but because of the natural bedrock constriction on which the bridge is situated
- Geomorphic condition Fair, sensitivity Very High, channel evolution stage III with major aggradation adjustments following historic incision; widening and planform change currently limited to some degree by encroachments and armoring

Table 29. Tabor Branch Reach T2.02 Projects and Practices Table

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T2.02A	Plant buffers	Medium	Medium	Y	Buffers lacking or minimal on both banks; water quality and temperature benefits, some flood hazard mitigation (mechanical barrier/stream power dissipation), reduce rate at which stormwater enters the stream
T2.02A	Replace bridge	Low	Low	Y	Village Rd. bridge is channel and flood-plain constriction; if and when bridge comes up for replacement, consider better alignment and sizing to accommodate transfer of both water and sediment in high flows
T2.02C	Plant buffers	Medium	Medium	Y	Buffers minimal or lacking along left bank; water quality and temperature benefits, some flood hazard mitigation (mechanical barrier/stream power dissipation), reduce rate at which stormwater enters the stream

6.2 PROJECT PRIORITIZATION

The current hydrologic and sediment transport regimes in the Waits River watershed place the highest priority, in terms of project prioritization, on two factors:

1) Protection of, and unrestricted access to, existing floodplains as a primary means of:
   c) attenuating flood flows; and
   d) retaining fine sediments within the watershed while permitting coarser sediments to move through the watershed and rebuild a more even distribution of bed features, particularly in downstream reaches of the Waits mainstem
2) Accommodation of planform adjustments, permitting both:
   c) Rapid lateral migrations and room for mass failures and channel avulsions; and
   d) Full meander development

Due to the particular importance of flash flooding in these dynamics in the watershed, the design and success of downstream restoration projects will be strongly affected by discharge and sediment loads further upstream in the watershed. Project prioritization thus emphasizes upstream restorations of equilibrium conditions whenever feasible, and when this is not feasible encourages attenuation of impacts in the shortest possible distance downstream. The widespread distribution of the important stream assets needed for this restoration work (and the narrow valleys of the watershed that to some extent naturally limit the extent of these assets in any given area) makes parcel by parcel corridor protection efforts extremely challenging, and municipal governments can achieve many of the same goals much more efficiently and effectively. This is why the top priority recommendation in this report is for the Towns of Bradford and Corinth to consider belt-width corridors or similar measures for augmentation of current development review specifications. Fluvial Erosion Hazard zones (FEH) are recommended as a scientifically based method that uses the size, inherent sensitivity, and current adjustment processes of the stream to determine and map appropriate setbacks. Methods to develop these zones and models of various options for implementing them are explained in the Municipal Guide to Fluvial Erosion Hazard Mitigation published by the Vermont River Management Program (VT-RMP FEH 2008). Draft maps portraying these zones have been developed for the Waits mainstem, South Branch and Meadow Brook (Corinth) in conjunction with the assessments reported here and are currently available in draft format through the Vermont River Management Program, Two Rivers-Ottauquechee Regional Commission, and the Towns of Bradford and Corinth. These maps undergo periodic revision based on the best available information, and it is recommended that towns incorporate language in planning documents to reference the current version of these maps held by these same organizations.

While the streams included for primary analysis in this report are located within Bradford and Corinth, the prominent role of flash flooding dynamics in the watershed suggests that many of the smaller streams in the watershed are susceptible to high erosion and sudden and potentially catastrophic (when development conflicts exist) channel changes that subsequently play a large role in downstream dynamics. This strongly suggests that the long term health (physical, biological and economic) of the communities and streams in the watershed would benefit from similar planning efforts in the towns of Topsham, Newbury, Vershire, Chelsea, Washington, West Fairlee and Fairlee. It would be difficult to overemphasize the importance the role of these small streams play in a watershed with the type of geologic and topographic setting of the Waits. Given the small size of the majority of the streams outside of the Waits mainstem and its largest tributaries (primarily the South Branch and Tabor Branch), 100 foot development setbacks from streams would accommodate belt-width corridors on the large majority of streams in these towns, providing a level of flood protection and accommodation of stream processes that will help break a cycle of impacts being passed to downstream reaches. (Belt-width corridors are based on over 30 years of research and data collected from hundreds of streams around the world, and approximate the extent of lateral adjustments likely to occur over time in a meandering stream type. This is generally a minimum of 3-4 times the stream channel width on each side of the stream).

While such measures help limit further development and infrastructure encroachments, the Waits watershed already has a high density of existing roads and a diffuse settlement pattern, and straightening is the most prominent impact noted in geomorphic assessments conducted within the watershed. It is likely that these patterns will be slow, challenging, and/or unlikely (in some instances) to change, and there is thus a high priority for protecting key assets for attenuating the elevated flows and sediment discharges engendered by these impacts. Concentrated development and road encroachment in the numerous but scattered villages along the Waits and its tributaries has already restricted access to valuable floodplains and limited the amount of room available for meander development and lateral migration. The impairment of these attenuation assets increases the importance of protecting remaining assets, with an emphasis on protection of broader floodplains to attenuate upstream discharges. Accommodation of floodplain access for streams, the valuable nutrients stored on these floodplains, and room for meander development makes these areas generally more appropriate for accommodation of stream processes and agricultural purposes than developed land uses. One of the most prominent examples of this in the Waits watershed is in the vicinity of the Appleton farm in Bradford where the installation of Interstate-91 cut off nearly half of the historical floodplain, dramatically increasing the importance of the remaining available floodplain for storing flood flows in particular. It appears that only a portion of this area lies within the current delineation of the Federal Emergency Management Administration Special Flood Hazard Area, and it is recommended that the current Town of Bradford floodplain ordinance, zoning regulations and FEMA mapping be reviewed to ensure that adequate protection and enforcement mechanisms are in place to ensure the critical functions of this area in protecting the health and safety of the citizens of Bradford , the Waits River, and the Connecticut River into which it flows.

Wide floodplains are somewhat uncommon in the Waits basin, and highlighted assets include the alluvial fan at the base of Cookville Brook (Devins Farm), the very broad floodplains (mostly hayfields visible from the Chelsea-Goose Green Rd.) along Meadow Brook in Corinth, and major tributary confluences such as those of the South Branch and Waits mainstem (Bradford near the iron bridge at the Chelsea Rd.) and the Tabor Branch and Waits mainstem (East Corinth). Additional important attenuation assets for conservation and protection include narrower floodplains with limited existing development conflicts, such as the areas along the Waits mainstem near Kenyon Rd. in Bradford.

It is important to bear in mind that restriction of stream processes in straightened areas, particularly structural measures and other practices designed to maintain streams in a fixed location, will contribute to prolonged stages of disequilibrium and the erosion and lateral migration that streams will use to balance the energy of stream power (which is elevated by straightening) and sediment loads. Bank armoring and bank toe stabilization are common along road encroachments and at stream crossing structures, and were observed to a lesser (but not uncommon) degree on undeveloped sites such as agricultural fields in the watershed. Channel straightening is a challenging issue to address at a municipal level, and may need to be addressed more often at a localized scale. It has contributed significantly to the transfer of impacts to downstream reaches in the Waits River watershed. Ample buffer establishment in straightened areas and downstream of them is important not only to bank and soil stabilization but also flood mitigation (diffusing stream power) and decreasing the rate and intensity of precipitation entering the stream. Fine grained alluvial soils exposed in portions of Waits mainstem reach M04 (Bradford upstream and downstream of the South Main St. bridge) and more extensive areas of reaches T1.05 and T1.09 on Meadow Brook in Corinth are particularly prone to high rates of erosion in areas lacking buffers and are highly to extremely sensitive to changes in watershed inputs. Sediment inputs from erosion of these banks do not contribute stability to the type of features (riffles and pools) that will be important in channel evolution leading to stream equilibrium. These sediments are often transported long distances downstream or contribute to infilling of planebeds, rather than contributing to more stable feature formation that creates better habitat and water quality. Well vegetated woody buffers play a very different role in diffusing stream power and stabilizing banks (as well as how impacts are transferred downstream) than does bank armoring. Buffer plantings in these areas thus receive a relatively high priority and could be completed independently of other projects if sufficient guarantees are ensured for the protection of these plantings. Low cost plantings and/or permitting natural regeneration are generally recommended in these areas due to the likelihood of lateral migration as streams evolve, and beaver impacts will need to be considered in planning for these efforts. There are a number of cost-share options for landowners wishing to establish buffers, including the Conservation Reserve Enhancement Program (within the Natural Resources Conservation Service).

At this point in the watershed's history, further bed degradation and active downcutting appears to be limited by a variety of factors, including numerous grade controls interspersed throughout the watershed. Localized nickpoints appear to be "washing out" with the recruitment of more sediment, but formation of planebeds and removal of these sediments: a) decreases the transfer of coarse sediments to downstream reaches, thereby limiting development of normal bed features (riffles and pools); b) increases transfer of stream power (heightening erosive power) and fine sediments; and c) inhibits meander development. Stream dynamics in the watershed would thus benefit from not removing or windrowing sediments from the stream in most instances, an approach that tends to run counter to deeply in grained historical patterns of stream management, particularly in the aftermath of flash floods when such management approaches are often implemented in a short period of time. Implementing such an approach would also dovetail with ongoing evaluations of bridge and culvert designs and replacement prioritizations, as a number of current designs throughout the watershed include piers, alignment, and sizing issues that encourage aggradation in a manner that poses likely ongoing conflicts between stream processes and accommodation of infrastructure.

The large majority of reaches selected for inclusion in the Waits River 2007-2008 geomorphic assessments range from highly sensitive to extremely sensitive to changes in watershed inputs. Given these conditions, passive geomorphic restoration projects, which leverage these inputs and the river's own energy to facilitate a return to equilibrium conditions, are generally preferred for prioritization due to the likelihood of rapid stream evolution (this may be on a scale of decades for these streams to fully recover from a degraded state that is hard to recognize from a limited historical perspective). Lower investments associated with this approach are desirable considering an inherent degree of uncertainty in the success of engineered approaches in an active system.

With these considerations as a general backdrop, Table 30 lists potential prioritized projects with the greatest benefits in terms of restoring equilibrium conditions in the assessed portions of the Waits River watershed, in recommended order of priority. Project prioritization should be considered preliminary and will need to be adjusted based on further information and community interest.

Table 30. Waits River watershed 2007-2009 Prioritized Project and Strategy Summary

Waits River watershed 2007-2009 Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
1	FEH: Waits River M4-M10; South Branch T1.01-T1.06; Meadow Brook T1.07-T1.09; Cookville Brook T1.06S1.01; Tabor Branch T2.01-T2.02 large majority High to Extreme sensitivity Belt-width: Other streams in watershed	Heightened stream power resulting primarily from straightening, some historic loss of floodplain; development and encroachment restricts necessary room for flood hazard avoidance and mitigation, full meander development, and channel migrations	FEH and belt-width-based corridor planning, protection of attenuation assets	Feasible, highest priority; delineation process largely developed, model regulations and recommendations exist Upstream impacts strongly affect success of downstream projects	Flood hazard reduction, reduction of fine sediments (high in nutrients and organics) out of the watershed, prime farmland protection	Policy development and implementation; Distribution of outreach and educational materials	Depends on options chosen; see VT-RMP Municipal Guide to Fluvial Erosion Hazard Mitigation (Literature Cited section of this report)	Towns of Bradford and Corinth; Two Rivers - Ottauquechee Regional Commission; VT-RMP

Waits River watershed 2007-2009 Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
2	Waits River M04B Fair High	Appleton Farm and floodplain upstream of Mill Pond Brook confluence (Kenison property, Masonic Hall area)	Corridor easement or other protection, buffer plantings Ensure FEMA mapping and floodplain ordinance adequacy for Appleton Farm area	Feasible, highest priority	Flood hazard mitigation, farmland protection	Easement transactions, planting stock (low-cost recommended due to erosion hazards)		CREP, Upper Valley Land Trust, VT Land Trust, Connecticut River organizations
3	Meadow Brook T1.09 Fair - Good Extreme - High	Active aggradation and widening in segment B, recent microbursts and straightening upstream likely to contribute additional sediments	Corridor easement or other protection, buffer plantings	Feasible, high priority Buffer plantings could be completed independent but would need guarantees of protection	Flood hazard mitigation, wetland restoration, water quality and temperature	Easement transactions, planting stock (low-cost recommended due to erosion hazards)	Open land to buffers; need sign-off from landowners and some guarantee of protection, need full buffer width due to highly erodible banks	CREP, Corinth Conservation Commission, Orange County Headwaters, Upper Valley Land Trust, VT Land Trust
4	Cookville Brook T1.06S1.01 Fair Extreme	Alluvial fan in upstream portions of reach; farm buildings upstream but downstream has few current constraints	Corridor easement or other corridor protection, buffer augmentation	Feasible, high priority	Farmland protection, flood hazard mitigation, wetland restoration	Easement transactions	Some open land to augmented buffers	CREP, Orange County Headwaters, Upper Valley Land Trust, VT Land Trust

Waits River watershed 2007-2009 Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment* *Condition* *Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
5	South Branch T1.05 Fair Extreme	Active aggradation and widening coarser sediments moving downstream may place more pressure on highly erodible banks	Corridor easement or other protection, buffer plantings	Feasible, but previous recalcitrance; medium priority Buffer plantings could be completed independently but need protection guarantees	Farmland protection, flood hazard mitigation, area has been discussed for possible trails and has VAST snowmobile bridge currently	Easement transactions, planting stock (low-cost recommended due to erosion hazards)	Open land to buffers; need sign-off from landowners and some guarantee of protection; need full buffer width due to highly erodible banks; owner has been reluctant about full width in past	CREP, Corinth Conservation Commission, Orange County Headwaters, Upper Valley Land Trust, VT Land Trust
6	South Branch T1.01 (and T1.02 at reach break - swimming hole) Fair High	Swimming hole at upstream end, young floodplain forest moderately impacted by development; T1.01 shows significant aggradation at base of South Branch	Corridor protection, buffer augmentation	Feasible, some current development constraints; medium priority	Flood hazard mitigation; recreational use; hayfield is rented for public functions	Easement transactions	Restriction of further development, buffer augmentation	VT River Conservancy, Bradford Conservation Commission, Upper Valley Land Trust, Vermont Land Trust
7	Waits River M09 Fair High Tabor Branch T2.01 T2.02A Fair High – Very High	Windrow and historic downcutting restrict access to floodplain formerly shared by Waits and Tabor Branch	Windrow removal, corridor protection	Feasibility unknown; would require higher level of survey detail to determine amount of floodplain access that would be gained; medium priority	Farmland protection, flood hazard mitigation, popular snowmobile trail, wildlife corridor	Higher resolution surveying, equipment for removal, easement transactions	Buffer augmentation	Upper Valley Land Trust, Vermont Land Trust

Waits River watershed 2007-2009 Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
8	Waits River M07 Fair Very High	Narrow valley but some available floodplain with low current development conflicts, appears to play an important current role for attenuating discharges form upstream reaches that have been converted to transport sediment regimes	Corridor protection, possibly to include channel management easements, buffer plantings	Feasibility unknown; appears to largely be one or two landowners; high priority	Farmland protection, flood hazard mitigation	Easement transactions, planting stock and possibly fencing	Buffer widths may be an issue of concern due to narrow valley exacerbated by road encroachments	Upper Valley Land Trust, Vermont Land Trust, Bradford Conservation Commission
9	Waits River M05A Poor High	Narrow valley but some available floodplain with low current development conflicts in vicinity of Kenyon Rd.	Corridor protection	Feasibility unknown; multiple landowners; some existing development conflicts on opposite bank; high priority due to development potential, lower priority due to likely cost-benefit ratio	Wildlife and trail corridors may tie to Wrights Mtn. area; Flood hazard mitigation	Coordination with multiple landowners, easement transactions	Possible changes in development status	Upper Valley Land Trust, Bradford Conservation Commission

Waits River watershed 2007-2009 Prioritized Project and Strategy Summary								
Project No.	*Reach/ Segment Condition Sensitivity*	*Site Description Including Stressors and Constraints*	*Project or Strategy Description*	*Technical Feasibility & Priority*	*Other Social Benefits*	*Costs*	*Land Use Conversion & Landowner Commitment*	*Potential Partner Commitments*
10	Numerous	Undersized structures (culverts, bridges)	Capital planning and budgeting, replacement prioritization	Feasible, medium priority; no critical structure replacements noted in field assessments; data collection for many bridges (VTrans, consultants) and culverts (VT Fish & Wildlife) completed	Data display, collection and prioritization tools available online for both structural maintenance and fish/aquatic organism passage and retrofit potential	Variable		Municipal governments, VTrans

Literature cited

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://www.stillwatersci.com/resources/1997boothandjackson.pdf

Corinth 1964. History of Corinth Vermont, 1764-1964, Compiled and Edited by Town of Corinth History Committee. Town of Corinth, Corinth, Vermont.

CRWC 2007. The Connecticut River Boating Guide: Source to Sea, 3rd edition. Ed. J. Sinton , E. Farnsworth, W. Sinton. Connecticut River Watershed Council. http://www.ctriver.org/publication/boating%20guide/index.html

Doll, C.G. (ed.) 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/smrgttopleft.jpg

Doll, C.G. (ed.) 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/rightBASE.jpg

Dunne, T. and L.B. Leopold 1978. Water in Environmental Planning. New York, NY: W.H. Freeman and Co.

FERC 2008. Federal Energy Regulatory Commission licensing exemptions table.
http://www.ferc.gov/industries/hydropower/gen-info/licensing/exemptions.xls

Johnson, L.B. 1928. Vermont in Floodtime. Reissued as The '27 Flood: An Authentic Account of Vermont's Greatest Disaster, 2nd ed. 1998. Randolph Center, VT: Greenhills Books.

McKeen, S. 1875. A History of Bradford, Vermont; J. D. Clark & Son, Montpelier, Vermont. http://books.google.com/books?id=byY1AAAAIAAJ&printsec=frontcover&dq=A+History+of+Bradford,+Vermont

NOAA-BTV 2007. Monthly Report of Hydrologic Conditions, July 2007. National Oceanic and Atmospheric Administration, Burlington Weather Service. These reports are only archived online for two years, so this report is no longer available online.
http://www.weather.gov/climate/index.php?wfo=btv

Rosgen, D. L. 1994. A classification of natural rivers. Catena, 22(3), 169–199.

Schilling, K.E., and C.F. Wolter. 2005. Estimation of streamflow, baseflow, and nitrate-nitrogen loads in Iowa using multiple linear regression models. J. Am. Water Resour. Assoc. 41:1333–1346.

Schumm, S. A. 1977. The Fluvial System. New York: John Wiley and Sons.

Schumm, S. A. 1984. Incised Channels: Morphology, Dynamics and Control. Littleton, CO: Water Resources Publication (ISBN-0918334-53-5).

USDA-FS 2000. Upper White River Watershed Analysis - Part I. USDA Forest Service, Rochester Ranger District, Green Mountain and Finger Lakes National Forests.
http://www.fs.fed.us/r9/gmfl/green_mountain/resource_management/soil_water_air/water/upper_white_r_sec1.pdf

USFWS 2008. Restoring Migratory Fish to the Connecticut River Basin, Appendix G: Fish Passage Requirements Within the Connecticut River Basin. Connecticut River Coordinator's Office of the United States Fish & Wildlife Service.
http://www.fws.gov/R5CRc/Stuff/appg.html#table

US Census Bureau 2000. American Fact Finder.
http://factfinder.census.gov/home/saff/main.html?_lang=en

UVM-SAL. 2002. Vermont Land cover/land use data developed by the University of Vermont Spatial Analysis Lab. Available from the Vermont Center for Geogrpahic Information. http://www.vcgi.org/metadata/LandLandcov_LCLU2002.htm

VCGI 2000. Ecological Bedrock Classification in Vermont, a 5 category (9 subcategory) classification system delineated for the VT Biodiversity Project. Hosted by Vermont Center for Geographic Information. http://www.vcgi.org/dataware/search_tools/moreinfo.cfm?catalog_id=1&layer_id=113&layer_name=GeologicBedrock_BEDROCK9

VT ANR 2003. Programmatic Quality Assurance Project Plan. http://www.anr.state.vt.us/dec/waterq/rivers/docs/assessmenthandbooks/rv_sgaquappsigned.pdf

VT-DEC-WQ 2008. Basin 14 "Little Rivers" Water Quality Management Plan.Vermont Department of Environmental Conservation Water Quality Planning Division. http://www.anr.state.vt.us/dec/waterq/planning/docs/pl_basin14.final_plan.6-30-08.pdf

VT-RMP, Alternatives 2003. Alternatives for River Corridor Management: Toward resolving river and land-use conflicts in an economically and ecologically sustainable manner. Vermont Department of Environmental Conservation River Management Program Position Paper. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_managementAlternatives.pdf

VT-RMP, Fact Sheet1 2003. River Corridor Protection and Management Fact Sheet 1. Vermont Agency of Natural Resources River Management Program. http://www.anr.state.vt.us/dec/waterq/rivers/docs/Educational%20Resources/rv_RiverCorridorProtectionManagementFactSheet.pdf

VT-RMP FEH 2008. Municipal Guide to Fluvial Erosion Hazard Mitigation. Vermont Agency of Natural Resources River Management Program. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_municipalguide.pdf

VT-RMP, geoassesspro 2007. Vermont Agency of Natural Resources Protocol Handbooks. Vermont Agency of Natural Resources River Management Program. http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm

VT-RMP RCPG 2007. Vermont Agency of Natural Resources River Corridor Planning Guide: To Identify and Develop River Corridor Protection and Restoration Projects. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_rivercorridorguide.pdf

VT-RMP RCProtect 2008. Vermont Agency of Natural Resources River Corridor Protection Guide. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_RiverCorridorProtectionGuide.pdf

Wright, S. and F. Larsen 2004. Surficial geology of the Barre-Montpelier region. Vermont Geological Survey. http://www.anr.state.vt.us/DEC/GEO/pdfdocs/BarreWestwright.pdf

Appendix 1. Reach Summary Statistics and Channel Geometry Data

Appendix 2. Phase I Reach Summary Reports

Appendix 3. Phase II Reach Summary Reports

Appendix 4. Plots of Channel Cross Sections

Appendix 5. QA/QC Reports and documentation

Appendix 6. Consolidated project identification tables (sorted by priority)

Appendix 7. Large Format (11x17) Maps

Overview
Land cover/ Land use
Hydrologic alterations
Sediment load indicators
Channel slope modifiers
Channel depth modifiers
Boundary condition and riparian modifiers
Sediment regime departure

Appendix 8. Bridge and Culvert Survey Reports

Failure modes: Geomorphic incompatibility
Failure modes: Problem causes
Aquatic organism passage ratings: Passage, geomorphic compatibility, retrofit potential
Wildlife passage