TWEED RIVER WATERSHED CORRIDOR PLAN

WHITE RIVER PARTNERSHIP

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1.0 EXECUTIVE SUMMARY

In the spring of 2007 the White River Partnership (WRP), as part of a project funded by the Vermont Department of Environmental Conservation River Corridor Grant Program, initiated development of a community-based river corridor management plan for the Tweed River basin including portions of the river and its tributaries in Stockbridge, Pittsfield, and Killington. The Tweed River drains the southwestern flank of the White River basin, comprising the largest tributary in the upper third of the larger watershed. The White River of central Vermont is one of the last free-flowing rivers in Vermont and is noted for its natural beauty, significant fisheries and wildlife habitat, vital natural resources, ecologic integrity, and recreational values. WRP has been working to enjoy and improve these assets in the watershed for more than a decade, and this project seeks to augment other efforts in the White River basin to effectively enhance the overall health of the watershed and its communities.

The draft of a Tweed River corridor plan presented here is designed to integrate information from previous stream assessments and preliminary corridor planning. By assessing underlying causes of channel instability at both watershed and localized scales, and encouraging the stream's return to equilibrium conditions, management efforts can be directed toward long-term solutions that help curb escalating costs and efforts directed toward resolving conflicts with ongoing stream processes. These efforts can help reduce flood and erosion hazards along the river corridor, improve water quality and aquatic habitat, and enhance recreational opportunities along and in the river.

The results of Phase 1 (using remotely sensed data such as topographic maps and aerial photography) and Phase 2 (rapid field assessment) geomorphic assessments of the White River conducted in 2001 and 2006–2007, respectively, are briefly summarized in this report. The results are analyzed 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 stepwise process designed to identify and catalogue technically feasible projects consistent with reducing conflicts with stream dynamics in an economically and ecologically sustainable manner, assess the social feasibility of these projects, and make recommendations for the next steps toward implementation of protection and restoration efforts.

Based on the results of those assessments, the following list of projects, in recommended order of importance, were prioritized:

- All areas: Incorporation of fluvial erosion hazard (FEH) zones and belt-width corridors into town planning processes, as well as other efforts to protect the vital function of floodplains in providing flow, sediment, and nutrient storage and attenuation in particular
- Numerous areas: Bridge and culvert sizing recommendations and support for inventory, prioritization, and capital budget planning at town, state, and private levels
- Tweed River mainstem reach T6.02 between the confluence with Guernsey Brook (Stockbridge/Pittsfield town line) and Diablo Ln.: corridor protection, buffer establishment, and conservation of attenuation assets

- Guernsey Brook reach T6.1-S3.01A between Rte. 100 and the confluence with the Tweed River mainstem: corridor protection, buffer augmentation, and passive geomorphic restoration of attenuation assets
- Tweed River mainstem reach T6.01 segments D, F, and G between South Hill Rd. (Stockbridge end) and the confluence with Guernsey Brook (Stockbridge/Pittsfield town line): corridor protection, buffer establishment, and conservation/passive restoration of attenuation assets
- Tweed River mainstem reach T6.04 between Bakers Rd. and Stonewood Crossing: bridge assessments and possible replacement to provide sediment transport continuity, further assessment of stream ford impacts on stream dynamics
- West Branch of the Tweed reach T6.2-S1.01 above Pittsfield village: buffer establishment and maintenance for flood hazard mitigation above the village
- Tweed River mainstem reach T6.01 segments A and B between the confluence with the White River and the swimming hole downstream of the Rte. 107 bridge): corridor protection, buffer establishment, and conservation/passive restoration of attenuation assets

Analysis contributing to these recommendations indicates that:

- Portions of the watershed included in the Project area, under equilibrium conditions, would provide flow, sediment, and nutrient storage and attenuation in most stream reaches (reaches are portions of the stream with similar characteristics in terms of channel geometry, valley, and floodplain settings)
- Due primarily to extensive straightening and channelization, leading to increased stream power that has historically incised (cut down) through erodible bed materials, many of these stream reaches have lost access to historical floodplains and these floodplains have been subsequently developed
- Almost all included reaches are now functioning primarily as transport reaches that transfer flow, sediment, and nutrient loads to downstream portions of the watershed. Sediment loads are being deposited primarily at constrictions that reduce stream power sufficiently to accelerate deposition or when they become too great for the power of the stream to transport further
- Loss of access to floodplain means greater flows are now contained within the channel at high flow events; channelization means the stream now diffuses less of its power through meander patterns
- With many of the downstream reaches deeply incised, sediments are being recruited from tributaries, mass failures, and streambank erosion as the physical dictates of the stream system try to balance the increased stream power with its sediment load; ensuring sediment transport continuity by reducing constrictions will allow these sediments to fulfill that role as they are redistributed throughout the stream network

- A combination of increased stormwater inputs in conjunction with frequent ledge and bedrock outcrops in the upstream portions of the Tweed mainstem appears to be elevating the effects of increased stream power on downstream reaches, and careful attention to stormwater management can help mitigate these dynamics
- A passive restoration approach is generally recommended for the Project area due to low cost, moderate land-use conflicts, and high to extreme stream sensitivity (indicating the rate at which the river will return to dynamic equilibrium given its own energy and watershed inputs). This approach would reduce costs for project implementation in comparison with active floodplain or meander restoration, or approaches such as continued channelization or armoring, but will require an emphasis on protection of the river corridor to reduce conflicts between land use and stream evolution processes. The primary goal would be regaining access to floodplains and reestablishment of stream meander geometry, both intended as a means of diffusing stream power and permitting greater nutrient and sediment storage within the watershed.
- Opportunities for floodplain access and meander reestablishment are already limited by extensive road encroachment and development constraints; limiting further development in floodplain and riparian corridor areas will help avert further conflicts with inevitable river dynamics.
- Most reaches in the Project area are at a stage of channel evolution marked primarily by overwidening and lateral migration of the stream
- Channel evolution is likely to entail further widening and lateral migration, increasing the susceptibility of corridor encroachments to flash flooding scenarios, as opposed to inundation flooding, and escalating costs for installation and maintenance of traditional management approaches. It is highly recommended that Stockbridge, Pittsfield, and Killington explore incorporation of FEH zones into town planning processes. Options might include setbacks, buffers, zoning overlay districts, or similar mechanisms.
- Traditional channel management in response to erosion and lateral migration has often entailed further channelization, gravel removal, and riprapping or hard armoring of banks for stabilization. These approaches have elevated both upstream and downstream impacts of increased stream power in particular, and localized sediment deposition, filling of pools, and formation of planebed features appears common in slackwater areas and overwidened portions of the channel.
- The Tweed watershed contains important agricultural lands, and an essential aspect of protection and restoration will involve development of fair and equitable solutions to allowing floodplain access and protection of key attenuation assets in areas of high-value agricultural lands.

Vegetated stream buffers will be important to the success of most protection and restoration activities in the watershed, where bank materials are often highly erodible. Planting activities can be completed independent of many other projects, but should focus on low-cost approaches using smaller stock in most areas due to lateral bank instability in areas where buffers are not already established.

2.0 INTRODUCTION

Vermont's rivers and streams have a long history of being utilized and impacted by humans, and dramatic changes in the landscape have resulted over the last two hundred years. Long-term processes resulting from this history of interaction and mounting concerns about the potential effects of a changing climate increase the need to acknowledge and understand the escalating level of investment required to rebuild and/or protect property and livelihoods from damage caused by weather events or by erosion and nutrient loading on ecosystems and recreational resources. With increasing recognition of this situation, and informed with data from geomorphic assessments, communities have the opportunity to reduce conflict with rivers and streams by practicing management that favors an equilibrium between the power of moving water and the transport and storage of sediment that is held within that water (Vermont Agency of Natural Resources-River Management Program (VT ANR-RMP) 2006). Understanding the balance of these forces at a watershed scale, and the fact that occurrences in any portion of a watercourse are linked to processes unfolding in other parts of the watershed over intervals of both space and time, are critical to successful implementation of such management practices. The time and thought that go into this work may transform perpetually frustrated attempts at control, with often unanticipated consequences, to enjoyment of enhanced, vital resources.

2.1 PROJECT OVERVIEW

The Tweed River drains the southwestern flank of the White River watershed, and is the largest tributary of the upper third of one of the last free-flowing rivers in Vermont. The White is noted for its natural beauty, significant fisheries and wildlife habitat, vital natural resources, ecologic integrity, and recreational values, and the Tweed River and its tributaries have been noted particularly for some of the finest trout fishing and recreational opportunities within the larger watershed. In the spring of 2007, the WRP, as part of a project funded by the Vermont Department of Environmental Conservation River Corridor Grant Program, initiated development of a community-based river corridor management plan for the Tweed River. The project seeks to augment a variety of efforts in the watershed, with an overarching goal of effectively enhancing the overall health of the White River watershed and its communities.

For more than a decade, the WRP has been an active partner and coordinator in developing and implementing community-based projects with numerous cooperators[1] throughout the watershed, including numerous stream restoration projects, community outreach, riparian buffer restoration, stream assessments, and preliminary corridor

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[1] In addition to numerous citizen participants, many of whom are active in local WRP 'Stream Teams', the White River Partnership 'Mission, History, and Principles' page on their website (http://www.whiteriverpartnership.org/index_files/page0001.htm) lists the following partners who had been involved as of 2002: Green Mountain National Forest, National Wildlife Refuge System, Partners for Fish and Wildlife, USDA Forest Service, USDA Natural Resources Conservation Service, Vermont Agency of Natural Resources, Two Rivers-Ottauquechee Regional Commission, Vermont Institute of Natural Science, Trout Unlimited, National Wildlife Federation, U.S. Department of the Interior Fish & Wildlife Service, Connecticut River Joint Commissions, and the U.S. Environmental Protection Agency.

planning. The following excerpt from the WRP website (http://www.whiteriverpartnership.org/) summarizes many of the key issues of concern in the overall White River watershed, and these issues aptly describe the main concerns on the Tweed:

> The White River is one of the last free-flowing rivers in Vermont…. The combination of forest, agricultural fields, farms and historic towns make the watershed one of the most picturesque in New England. But it is more than just a pretty picture, the White River is of great economic and ecologic importance to the region providing many opportunities for fishing, wildlife viewing, boating, tubing, hunting and swimming. The White is also important in the Connecticut River Salmon Restoration Program, a Special Focus Area of the Conte National Fish & Wildlife Refuge, a National Showcase Watershed…and the main stem is the longest undammed tributary to the Connecticut River.
>
> While the White is still known for its trout fishing and scenic beauty, the watershed faces many challenges. Local communities are increasingly concerned about issues like riverbank erosion, water quality problems, wildlife and habitat loss, sedimentation, the decline of native fisheries, flood damage and limited public access.

Public forums hosted by WRP have specifically highlighted the concerns listed in the second paragraph of the website excerpt above (WRP 2007). Many of the cooperators present at those forums have been involved with restoration efforts in the watershed for more than a decade, and based on previous experience have expressed a desire to incorporate a process that would optimize the benefits and minimize the costs of future projects by including upstream and downstream dynamics in the planning process. In response, Phase 1 geomorphic assessment (phases and other methods discussed further in Section 4) of the full White River watershed was conducted by Shannon Hill in 2001. Phase 2 assessments of portions of the Tweed watershed were completed in 2007 through a joint effort of WRP, the VT ANR-RMP, the USDA Forest Service, and Ross Environmental Associates. WRP also spearheaded efforts to develop and start implementation of River Corridor Plans downstream of the Tweed on Ayers Brook (Bear Creek Environmental 2006) and upstream of the Tweed on the Upper White mainstem (Redstart 2007) following Phase 2 assessments in these areas.

The Tweed River Corridor Plan (hereafter "the Project") aims to augment these efforts by prioritizing protection and restoration efforts on six Tweed River mainstem and three tributary "reaches" (sections of river with similar slope and valley setting) comprising roughly 12.8 miles of stream (Fig. 1). The primary goal of the Project is to cooperate with landowners, community members, local towns, and other stakeholders to develop a community-based river corridor management plan for the Tweed that will effectively enhance community and ecological health within the watershed. VT ANR-RMP has been developing the framework for a process to facilitate such a prioritization strategy (VT ANR 2007), and earlier phases of that process helped to identify the reaches selected for inclusion in the Project area. The goal of the River Management Program is to manage toward, protect, and restore the equilibrium conditions of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner. The objectives include:

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

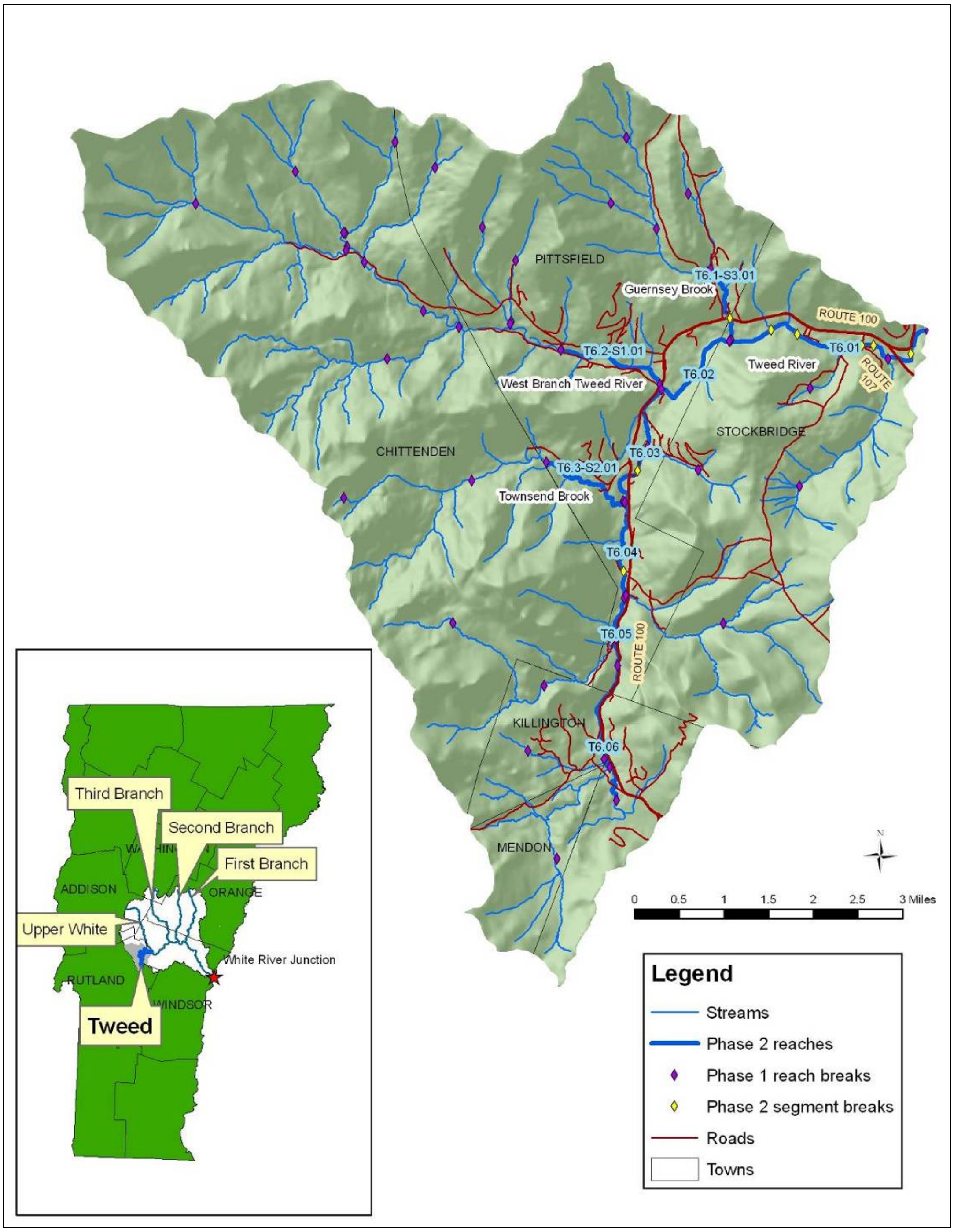


Figure 1. Six mainstem and three tributary reaches included in the Tweed River Corridor Planning process. Inset shows the location of this area in terms of the entire White River drainage basin in central Vermont.

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The Tweed River drains the southwestern flank of the White River watershed, and the White River is located within the Connecticut River basin (Fig. 1). The full basin of the White encompasses roughly 710 square miles ranging from roughly 3500 feet in elevation along the spine of the Green Mountains at the western flank of the basin to approximately 325 feet at the confluence with the Connecticut River on the eastern edge of the basin. The Tweed River basin encompasses roughly 51 sq. mi.(3500 feet in elevation down to 715 feet), and the mainstem of the Tweed includes roughly 9.3 miles of stream extending from its headwaters in Killington to a downstream terminus at the confluence with the White River mainstem in Stockbridge. The Project area also includes the first reach on each of three tributaries of the Tweed: Guernsey Brook, the West Branch, and Townsend Brook. From the confluence of the Tweed and White at the downstream end of the Project area, the White River mainstem enters its “middle” portion and is joined by the Third Branch before entering the “lower” section of the mainstem (where it is joined by the Second and First Branches), on its way to emptying into the Connecticut River at White River Junction.

3.1.2 Political jurisdictions

Project reaches in the Tweed River basin are located in the towns of Stockbridge and Pittsfield (Fig. 1). The drainage basin for these reaches also includes small portions of the towns of Killington, Mendon, and Chittenden. These towns lie within Windsor and Rutland counties (Fig. 1 inset). Stockbridge and Pittsfield are within the region covered by the Two Rivers-Ottauquechee Regional Commission, while the other towns within the basin are covered by the Rutland Regional Planning Commission.

3.1.3 Land use history and current general characteristics

An excellent background treatment and analysis of the Tweed watershed area has been included with a broader-scale analysis of the upper White River area prepared by the USDA Forest Service (USDA-FS 2001). Pertinent points of that report are the primary basis of land use history indicated here:

Current historical research indicates a long period of Native American use of this area, with the White River likely providing an important travel route between the Connecticut River and points north and west. However, low population densities and primarily nonintensive land use likely had minimal impact on the landscape. With the arrival of European immigrants, land-use and settlement patterns after the late 1700s had a more dramatic effect on the landscape and hydrology. “Land clearing, logging, altered stream channels, intensive agricultural practices, home building, and the establishment of road systems created the “classic” Vermont landscape of open hillsides, rural homesteads and stream-side roads and mills…” (USDA-FS 2001). This analysis is consistent with photo documentation of the Tweed valley (Fig. 2) available through the University of Vermont Landscape Change Program (http://www.uvm.edu/landscape/menu.php).

Figure 2. Pictures of the Tweed River valley from 1897 (Stockbridge looking east, left) and the early 1900s (Pittsfield looking south, right) show extensive areas of clearing in the valleys and portions of adjacent lower hillsides.

The lower portions of the Tweed River mainstem were particularly affected by straightening and maintenance along the valley wall when the "Lumber Railroad" was built along the river in the 19th century, pinning the river between the valley wall and the bed on which the railroad was built (Fig. 3). Tributaries were likely "snagged" to keep the channels clean for efficient transport of logs to the rail line. Water flows along the Tweed have also been significantly regulated, both historically and more recently, as evidenced by remnant dams and the remains of old sluices (likely used for manipulating flows to transport logs and run both grist and lumber mills) documented in fieldwork associated with this project.

According to 2002 land cover/land use analysis (UVM-SAL 2002), the Tweed River watershed in the early 21st century is nearly 90% forested, with roughly two-thirds of watershed land cover comprised of broadleaf forest; coniferous and mixed forests each cover a little over 10% of the watershed area (Fig. 4; Table 1). Ski areas at Killington and Pico mountains, as well as a recreational industry founded on more broad-based opportunities, augment the farming and wood-products industries that dominated the area in the 1800s and play a significant but less prominent role in the local economy today. Agricultural land use in the Tweed River watershed occupies roughly 3–4% of the land base, with much of this used for intensively cultivated row crop production. A similar proportion of the drainage basin is developed, with roughly 3% combined residential, infrastructure, and commercial land uses (Table 1). It should be noted that due to the relatively steep topography of the watershed, the bulk of these land uses are concentrated in the riparian corridors. Cultivated croplands, primary and secondary homes, and seasonal lodging and service industry facilities are often located in close proximity to the streams.

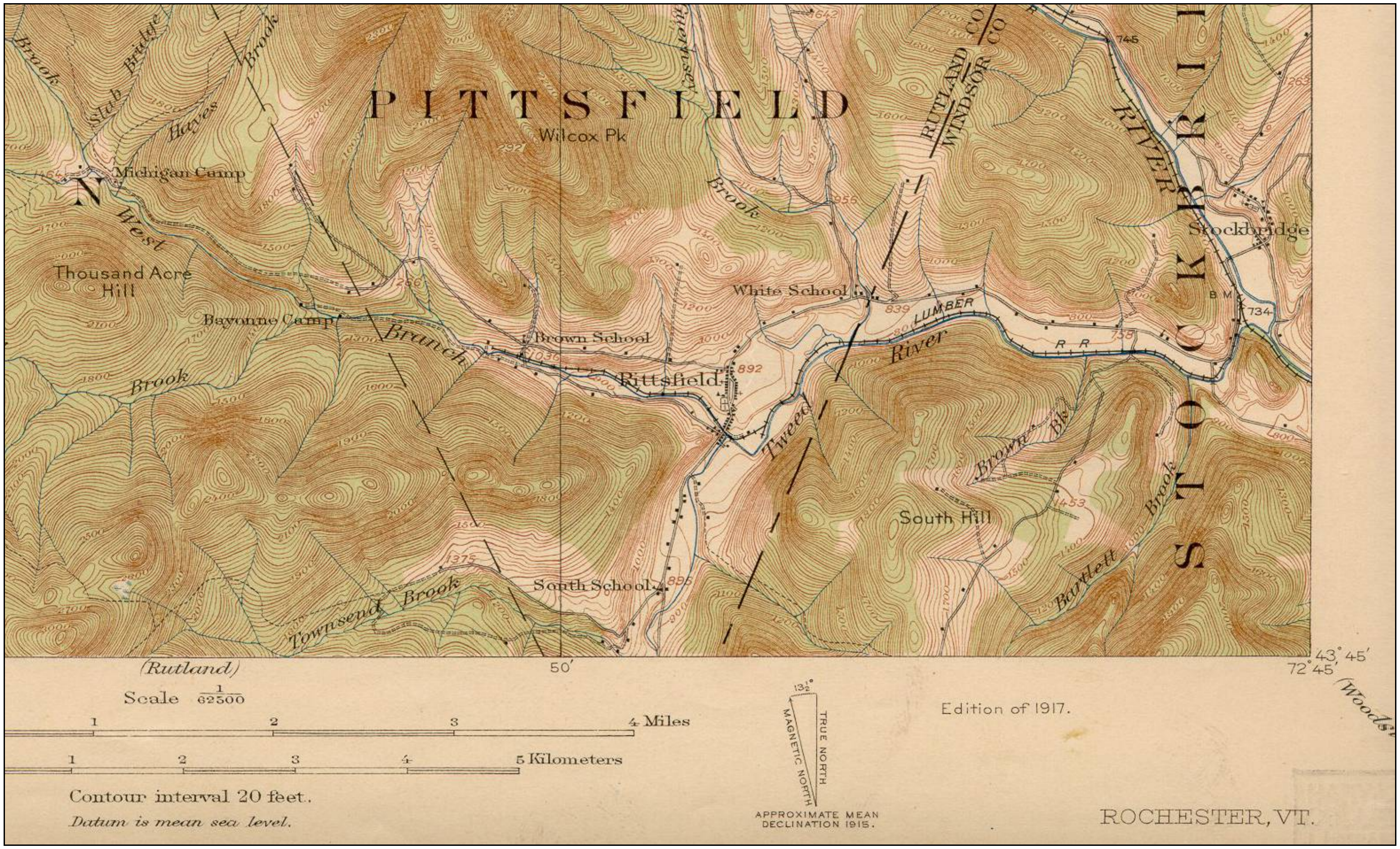


Figure 3. The Lumber Railroad built along the Tweed River in the 19th century appears along the lower portions of the mainstem and the West Branch in this 1917 map, effectively pinning the river to the valley wall (http://docs.unh.edu/VT/rochgc17se.jpg).

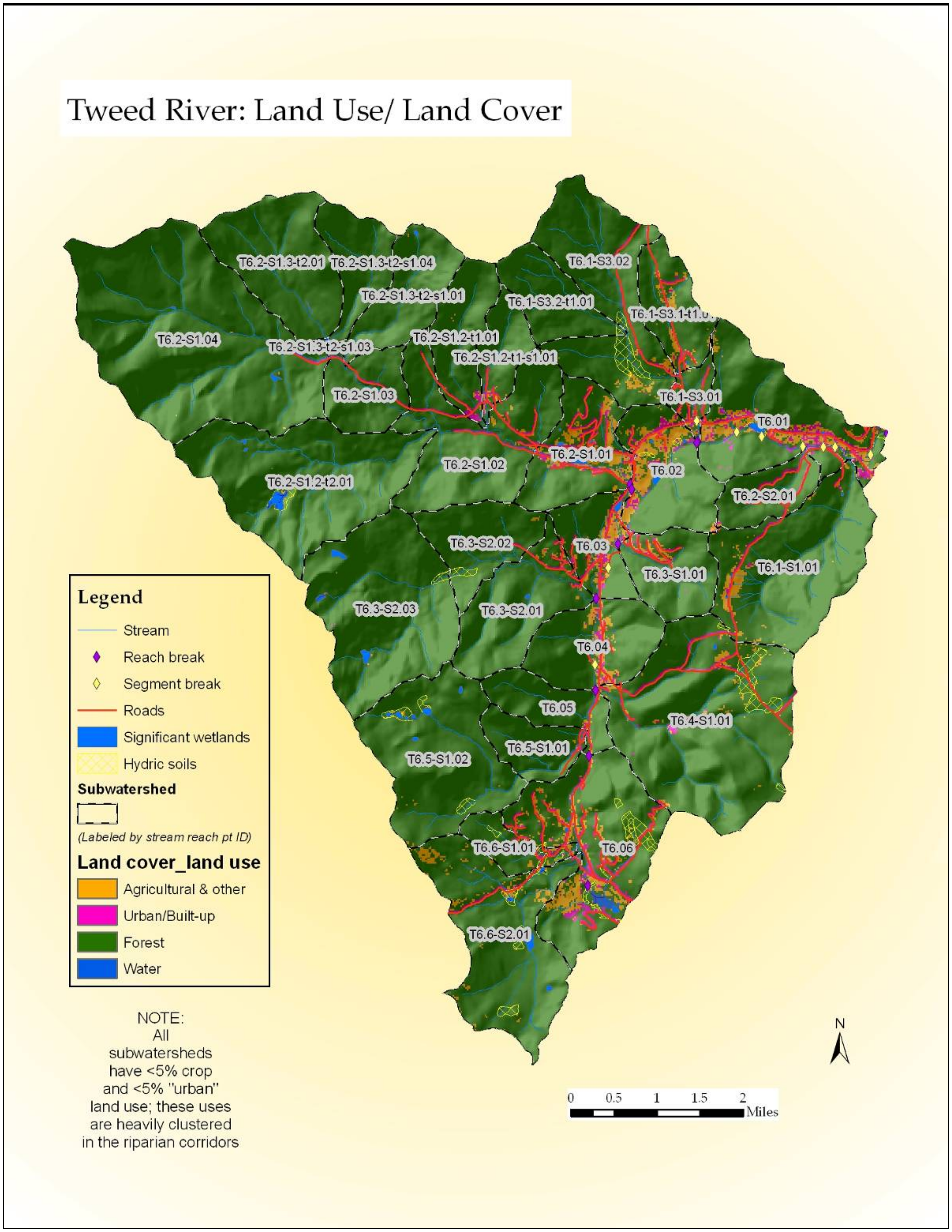


Figure 4. Land cover/land use analysis based on satellite imagery (UVM-SAL 2002) indicates extensive forest cover in the Tweed River drainage basin, with agricultural and developed land use heavily oriented toward the riparian corridors; overlaid soil maps indicate relatively few areas of hydric soils.

Table 1. Tweed River watershed land cover/land use from satellite imagery analysis

Category	
Broadleaf forest (generally deciduous)	67.6%
Coniferous forest (generally evergreen)	10.7%
Mixed coniferous-broadleaf forest	11.1%
Forested wetland	0.3%
Nonforested wetland	<0.1%
Water	4.0%
Row crops	2.9%
Hay/rotation/permanent pasture	0.5%
Other agricultural land	<0.1%
Residential	1.5%
Transportation, communication, and utilities	1.4%
Commercial, services, and institutional	<0.1%

3.2 GEOLOGIC SETTING

The Tweed River basin is bounded by the Green Mountains to the west and the Braintree ridge to the east. These mountains were originally in the bottom of the Iapetus Ocean and were pushed upward when continents collided in the Taconic Orogeny (Thompson and Sorenson 2000). The primarily acidic metamorphic mudstones that comprise the bulk of the bedrock geology have remained very resistant to erosion over time. There are numerous inclusions of calcareous bedrock evident in portions of the watershed, and the agricultural soils that have weathered from this bedrock are highly valued for their “sweet”, fertile nature. In addition, slivers of oceanic crust and deep mantle layers were forced upward to form local concentrations of talc and other unusual, localized formations such as verde marble, particularly along the eastern flank of the Green Mountains.

More recently, glaciation moved from northeast to southwest through this region, exposing bedrock at high elevations and widely depositing glacial till at mid and lower elevations. During the period of glacial retreat (15,000–12,000 years ago), fast-moving streams flowed over newly exposed bedrock and glacial till, depositing coarse sandy material (glacial outwash or ice-contact substrate) in stream channels. Outwash deposits remain within the valleys of the Tweed basin and are highly erodible. Ridgetops and sideslopes formed from loose or compacted glacial till, later weathering to well drained loams mixed with abundant cobble-sized stone. Upper sideslopes tend to be steep, shallow, and highly erodible. Soils on mid-to-lower sideslopes are frequently deep and often underlain by a hardpan that limits mass wasting and gully formation. Lower-elevation soils vary in erodibility depending on slope, wetness, and amount of organic matter.

The Tweed basin is characterized by steep to extremely steep valley walls on both sides of most streams (Table 2), although floodplains vary in width along the different valleys. Reaches included in the Project area are generally situated in the portions of the watershed with the widest valleys and potential floodplains. The soil formations in these lowest elevations are generally considered to be of lower erosion potential (Severe rather than Very Severe) due to gentler slopes than those along the hillside tributaries (Table 2), but the materials are highly erodible and can be a significant source of sediment from unstable stream banks. All of these factors combine to create a high sediment load system, as discussed further in Section 5.1.2 (Watershed-scale sediment regime stressors).

Table 2. Tweed River basin geology and soils (excerpted and combined from Phase 1, Step 3 (geology) and Step 3.5 (soils) analyses. Gray highlights indicate reaches included in the Project area for this plan. "%" indicates the dominant portion of a soil complex characterized by the stated rating.

(https://anrnode.anr.state.vt.us/ssl/sga/phase1_reports.cfm?pid=11&option=bytrib&menu=none&report=30; https://anrnode.anr.state.vt.us/ssl/sga/phase1_reports.cfm?pid=11&option=bytrib&menu=none&report=31)

	Geologic Materials			Valley Sideslope		Soils	
Reach ID	**Dominant**	**%**	**Subdominant**	**Left**	**Right**	**Erodibility**	**%**
T6.01	Ice-Contact	37.0	Alluvial	Extremely Steep	Extremely Steep	Severe	59.0
T6.02	Ice-Contact	51.0	Till	Steep	Extremely Steep	Severe	70.0
T6.03	Ice-Contact	65.0	Other	Extremely Steep	Extremely Steep	Severe	60.0
T6.04	Ice-Contact	53.0	Other	Extremely Steep	Extremely Steep	Severe	56.0
T6.05	Till	65.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	91.0
T6.06	Ice-Contact	81.0	Till	Steep	Very Steep	Very Severe	92.0
T6.1-S1.01	Till	99.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	99.0
T6.1-S3.01	Ice-Contact	52.0	Till	Extremely Steep	Extremely Steep	Very Severe	93.0
T6.1-S3.02	Till	100.0	—	Extremely Steep	Very Steep	Very Severe	99.0
T6.1-S3.1-t1.01	Till	100.0	—	Very Steep	Steep	Very Severe	99.0
T6.1-S3.2-t1.01	Till	100.0	—	Hilly	Extremely Steep	Very Severe	100.0
T6.2-S1.01	Ice-Contact	77.0	Other	Very Steep	Extremely Steep	Severe	66.0
T6.2-S1.02	Till	68.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	100.0
T6.2-S1.03	Till	100.0	—	Extremely Steep	Extremely Steep	Very Severe	100.0
T6.2-S1.04	Till	99.0	—			Very Severe	100.0
T6.2-S1.2-t1-s1.01	Till	100.0	—	Very Steep	Hilly	Very Severe	100.0
T6.2-S1.2-t1.01	Till	100.0	—	Extremely Steep	Extremely Steep	Very Severe	100.0
T6.2-S1.2-t2.01	Till	99.0	—	Very Steep	Very Steep	Very Severe	100.0
T6.2-S1.3-t2-s1.01	Till	99.0	—	Very Steep	Very Steep	Very Severe	100.0

	Geologic Materials			Valley Sideslope		Soils	
Reach ID	Dominant	%	Subdominant	Left	Right	Erodibility	%
T6.2-S1.3-t2-s2.01	Till	100.0	—			Very Severe	100.0
T6.2-S1.3-t2-s2.02	Till	99.0	—			Very Severe	100.0
T6.2-S2.01	Till	61.0	Glacial Lake			Very Severe	100.0
T6.3-S1.01	Till	76.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	99.0
T6.3-S2.01	Till	44.0	Ice-Contact	Steep	Extremely Steep	Very Severe	86.0
T6.3-S2.02	Till	100.0	—	Very Steep	Extremely Steep	Very Severe	99.0
T6.3-S2.03	Till	99.0	—	Steep	Steep	Very Severe	99.0
T6.4-S1.01	Till	82.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	99.0
T6.5-S1.01	Till	95.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	99.0
T6.5-S1.02	Till	99.0	—	Steep	Very Steep	Very Severe	99.0
T6.6-S1.01	Till	89.0	Ice-Contact	Hilly	Hilly	Very Severe	94.0
T6.6-S2.01	Till	88.0	Ice-Contact	Hilly	Steep	Very Severe	81.0

3.3 GEOMORPHIC SETTING

For the purpose of geomorphic assessment and corridor planning, streams in the Project area were divided into “reaches,” nine of which are included in the Project area for this plan. 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. Six mainstem reaches of the Tweed (T6.01–T6.06) and the most downstream reach of each of three tributaries (Guernsey Brook, T6.1-S3.01; the West Branch of the Tweed, T6.2-S1.01; and Townsend Brook, T6.3-S2.01) were included in Phase 2 field assessments. Five of the mainstem reaches were identified as C-type streams in the Phase 1 study, with one mainstem reach and each of the three tributary reaches identified as a B-type (Table 3; stream typing in Table 4).

Table 3. Reference stream types and geomorphic characteristics for Tweed basin reaches included in 2008 corridor planning Project area.

Reach Number	Stream Type/ Bed Form	Confinement (Valley Type)	Channel Slope (%)	Channel Length (ft)	Grade Controls
T6.01	C4/Riffle Pool	Very Broad	0.56	14273	Ledge
T6.02	C3/Riffle Pool	Very Broad	0.71	6195	None
T6.03	C3/Riffle Pool	Very Broad	0.92	8349	None
T6.04	C3/Riffle Pool	Very Broad	1.09	6156	None
T6.05	C3/Plane Bed	Broad	2.24	4424	None
T6.06	B3/Step Pool	Narrow	2.42	9876	Ledge
T6.1-S3.01	B3/Step Pool	Broad	3.61	5092	Ledge
T6.2-S1.01	B3/Plane Bed	Very Broad	2.11	6792	Ledge
T6.3-S2.01	B3/Step Pool	Narrowly Confined	5.56	6582	None

Table 4. Reference stream type classifications summary (VT ANR 2007 Phase 1 Protocols, p. 28).

Reference stream type	Confinement (Valley Type)	Slope
A	Narrowly confined (NC)	Very Steep: >6.5%
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%
D	Unconfined (NW, BD, VB)	Moderate–Gentle: <4.0%

A longitudinal profile of the Project area indicates gentle gradients along the lower reaches of the mainstem, with increasing slopes proceeding upstream above reach T6.04 (Table 3). The most downstream reach of the West Branch (T6.2-S1.01) has a relatively gentle gradient as well (2.1%), but the other tributaries are steeper. Ledge grade controls are present in the most downstream and upstream reaches of the mainstem in the Project area (T6.01 and T6.06), as well as in the lowest reaches of Guernsey Brook (T6.1-S3.01) and the West Branch (T6.2-S1.01; the grade control is in the most upstream portion of this reach). Although no alluvial fans were identified in either Phase 1 or Phase 2 assessments, it should be noted again (see section 3.2 on geologic background) that the Tweed basin has very steep slopes and highly erodible materials above the mainstem reaches. With extensive clearing for agricultural use and development along the mainstem, it is conceivable that alluvial fans would be masked.

3.4 HYDROLOGY

3.4.1 Tweed 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 (application description: http://water.usgs.gov/osw/streamstats/ssinfo.html; Vermont state application: http://water.usgs.gov/osw/streamstats/Vermont.html). Basic characteristics for the Tweed drainage basin are summarized in the following report:

*Streamflow Statistics Report**
Date: Wed Nov 21 2007 14:28:45
Site Location: Vermont

Latitude: 43.7762
Longitude: -72.7537
Drainage Area: 51 mi^2

Peak Flow Basin Characteristics

100% Statewide Peak Flow (51 mi^2)

Parameter	Value	Minimum	Maximum
Drainage area (mi^2)	51	0.211	850
Percent lakes and ponds (%)	0.13	0	6.86
Percentage of basin above 1200 ft (%)	88.5	0	100

Streamflow Statistics

Statistic	Flow (ft^3/s)	Prediction Error (%)	Equivalent Years of Record	90% Prediction Interval	
				Minimum	Maximum
Q2	1620	42	1.4	845	3100
Q5	2410	40	2.3	1270	4560
Q10	3000	41	3.2	1580	5730
Q25	3880	42	4.6	2020	7440
Q50	4580	43	5.5	2360	8910
Q100	5330	44	6.3	2680	10600
Q500	7290	49	7.6	3420	15500

*These are peak flow statistics, where Qx = x-year peak flood, i.e., maximum instantaneous flow that occurs on average once in x years

Figure 5. USGS StreamStats peak streamflow and basin characteristics statistics reports for the Tweed River drainage basin.

Although these statistics indicate a relatively small percentage of lakes and ponds in the basin, which when present provide storage and attenuation of flows within the watershed, it should be noted that there are some significant wetlands and ponds in the headwaters portions of the Tweed basin (Fig. 4). The peak flow characteristics help in flood history comparison with other watersheds, as discussed below.

3.4.2 Tweed watershed flood history

There are no continuous-record stream gages in the Tweed drainage basin. The nearest gage of this type is downstream on the mainstem White at Bethel, and has a limited track record, spanning years 1932–1955. A gage on Ayers Brook in Randolph, which enters the Third Branch of the White approximately 12 miles northeast of the Tweed confluence with the White, has a longer continuous record spanning the years 1941–2006; it monitors a slightly smaller drainage basin (30 sq. mi. as opposed to 51 sq. mi. for the Tweed). Figure 6 (VT ANR 2006, Appendix L) indicates that the 50-year flood peak discharge was exceeded on Ayers Brook in 1973 and 1998, while the 25-year flood level was exceeded in 1952.

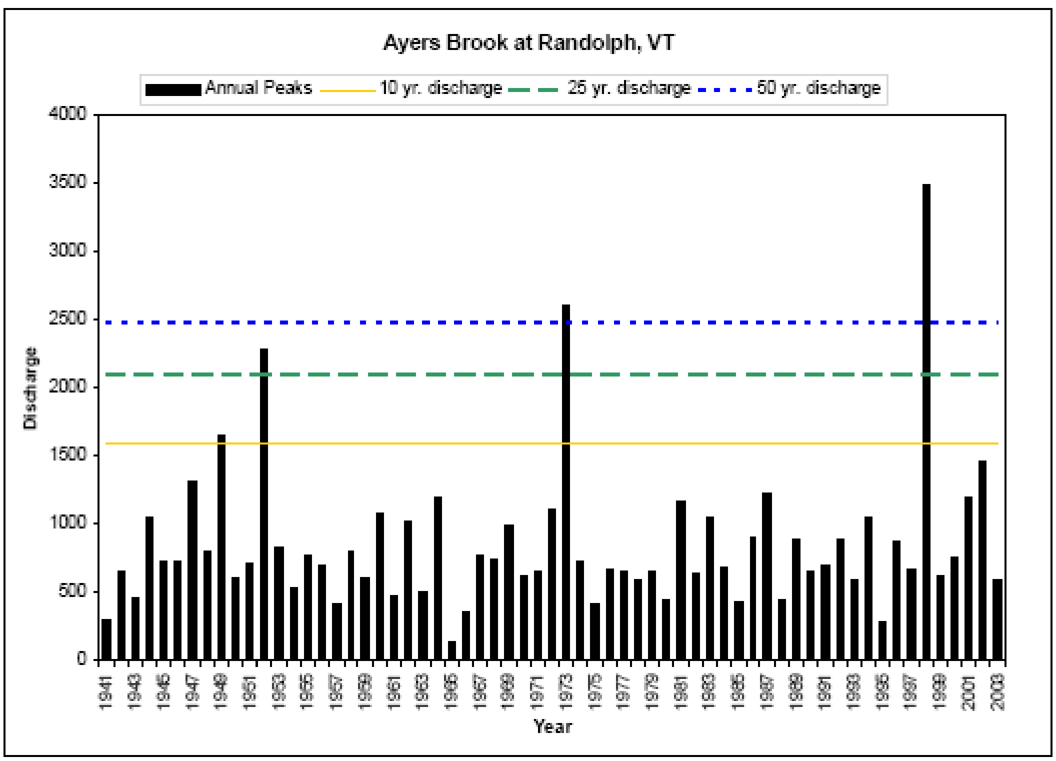


Figure 6. Annual and flood-level peak streamflows at the USGS continuous record stream gage on Ayers Brook. (Water years run from Oct. 1 to Sept. 30.)

Further downstream on the mainstem of the White, the USGS gage at West Hartford has a continuous record spanning 1912–2007, but monitors a drainage basin (including the

Tweed) of 630 sq. mi., more than 12 times the size of the Tweed basin. The magnitude of the 500-year discharge in 1927 is reflected in the records from this gage (Fig. 7), as are the tempering effects of the larger drainage basin on flow volumes, including inputs from more localized floods in upstream drainage basins, in other years. Noticeable is the fact that the 10-year flood level was not exceeded in 2000, a year when the Tweed did experience flooding (USDA-FS 2001). It is also noticeable that the 1998 flood that exceeded the 200-year discharge on Ayers Brook was experienced as a 10-year discharge on the mainstem White (Fig. 7). Flash flooding during a 6-inch rainstorm in less than 4 hours during July 2007 undercut a road directly across from the Tweed/White River mainstem confluence, caused extensive damage to two houses on Lillieville Brook a short distance downstream in Stockbridge and Bethel, and caused significant bank failures along the White mainstem in Stockbridge just downstream of the Tweed that contributed to a plume of distinctive light-colored sediments observed downstream on the Connecticut River as far south as Turners Falls, MA (pers. comm., Mary Russ, Executive Director, WRP); this localized flooding did not exceed the 10-year discharge level at the West Hartford gage.

Major floods occurred in upper portions of the White River basin in 1830 (USDA-FS 2001) and 1927 (Johnson 1928), with floods of lesser extent occurring in 1973, 1998, and 2000 (USDA-FS 2001). As was the case in much of central Vermont during floods in the 1970s, dredging and channelization occurred in response to these events during that time period in particular (USDA-FS 2001). Dredging and gravel removal have been practiced along much of the Tweed (pers. comm., Frederick Nicholson, VT ANR-RMP Stream Alteration Engineer) and were likely during this period.

The flood of 1927 caused extensive damage to railroad beds and many dams, and is thus largely responsible for the fact that the mainstem of the White River is today the longest undammed tributary of the Connecticut. All developed waterpower along the Tweed was taken out by the November storm; Pittsfield village was heavily damaged and recorded one of seven deaths experienced in the overall White River watershed after a dam on the West Branch ("the stream from Michigan") was breached; and a large clapboard and turned stock mill on the Tweed mainstem just over the Pittsfield line in Stockbridge was damaged heavily when the Tweed outflanked its dam, undermined the mill, and tore away outbuildings (Johnson 1928).

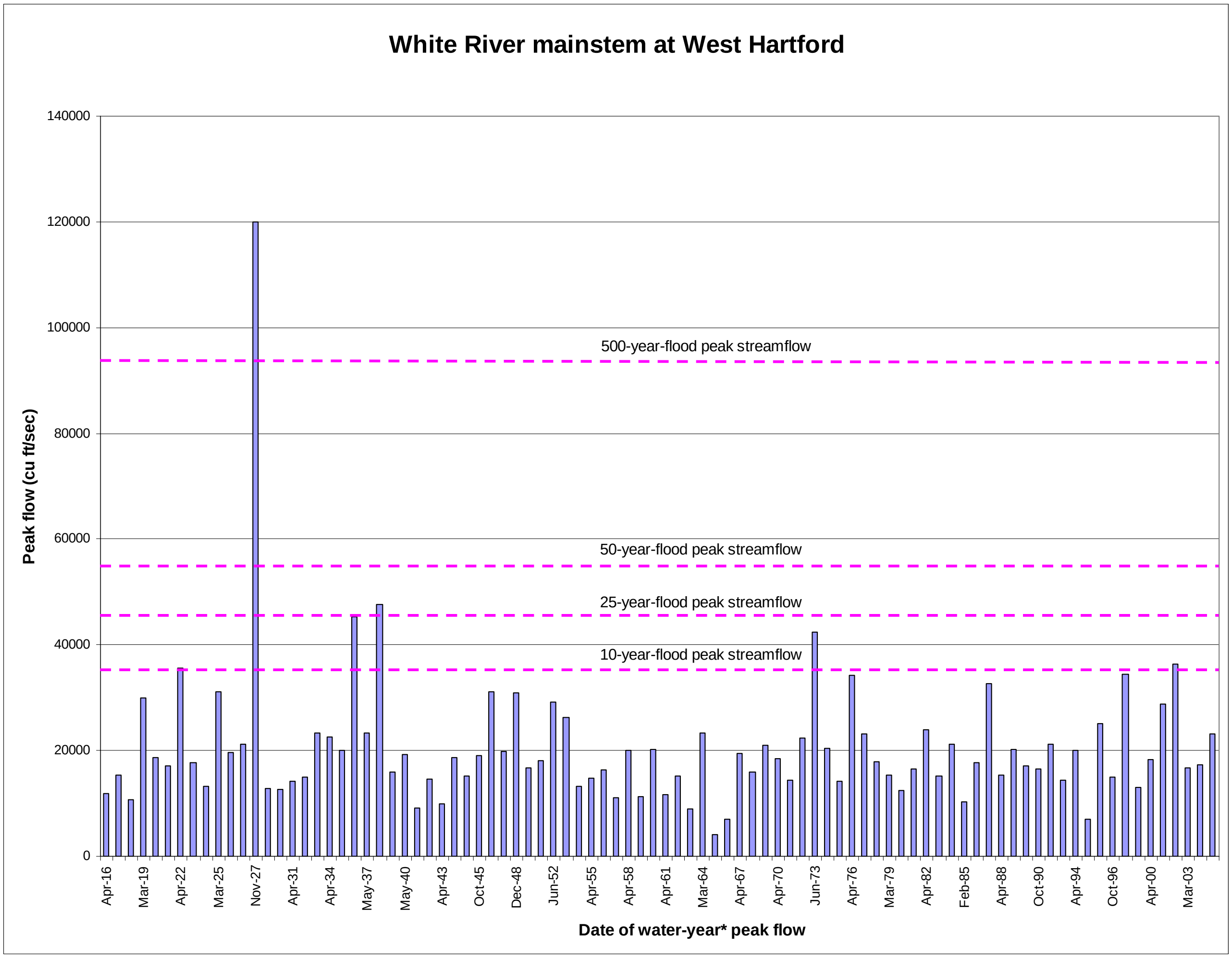


Figure 7. Annual and flood-level peak streamflows at the USGS continuous-record stream gage on the mainstem of the White River at West Hartford. (*Water years run from Oct. 1 to Sept. 30.)

In reviewing the records at these stream gages, it is important to recognize the sometimes localized nature of storms that can have significant flood impacts. While this is in part related to weather patterns, it is also important to recognize the impact of changes in hydrology over time, as further discussed in Section 5.1 (Watershed hydrologic stressors) of this report.

3.5 ECOLOGICAL SETTING

Portions of the Tweed River watershed have been long-standing favorites with trout fishermen in particular, and the basin is closely linked ecologically with other portions of the White River watershed, particularly the Upper White corridor extending upstream from the confluence with the Tweed. Because the mainstem White River and Tweed are free-flowing rivers, a relatively rare situation in much of the northeast United States, portions of the basin are important for Atlantic salmon restoration in the larger Connecticut River Basin's Anadromous Fish Restoration Program. The watershed hosts a native resident fish community including brook trout, slimy sculpin, and blacknose dace, along with naturalized Rainbow and Brown trout important to popular and economically important sport fisheries (USDA-FS 2001).

Wetland habitats are not common in the watershed largely due to the geological setting (contributing primarily well and moderately drained settings) and are generally not extensively documented. The Tweed basin does contain a few extensive areas of wetland habitat near upstream portions of the Project area, however, notably in the areas near the Killington town offices and recreational complex east of reach T6.06, as well as Colton Pond (includes a popular fishing and boating access point maintained by the State of Vermont). There are also a number of smaller high elevation ponds along the western boundary of the Tweed basin (Fig. 4). Several dragonflies and damsels are considered sensitive species for USDA Forest Service Region 9 (which includes the Tweed basin area) but have not been surveyed in wetland and riparian areas within the Project area (USDA-FS 2001).

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. The numerous inclusions of calcareous bedrock in the area contribute to potential habitat for a number of uncommon or rare species and support a good number of butternuts (a Region 9 sensitive species), particularly along the riparian corridor and adjacent hillsides along the lower reaches of the Tweed mainstem in Stockbridge. Although the large majority of these butternuts are declining due to the presence of butternut canker, there are current active interests in identifying potentially resistant trees that are staying healthy despite the omnipresence of the fungus responsible for butternut canker, as well as potential restoration habitat if such trees are identified (Michler et al. 2006).This tree is shade-intolerant, and open floodplain and agricultural areas as well as the locally abundant distribution in this area may indicate opportunities for such efforts.

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 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 the reach-scale dynamics that have been a primary focal point of project planning in the past. 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 (VT ANR 2007b). 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. Phase 2 involves rapid assessment fieldwork to inform a more detailed analysis of what adjustment processes are taking place, whether the stream has departed from its reference conditions, and how it 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. 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.

As noted in the Project Overview, the Phase 1 Stream Geomorphic Assessment (SGA) was conducted for the White River watershed in 2001. The Phase 2 SGA was initiated on the Tweed during VT ANR-RMP trainings in 2006, with data collected by a number of consultants in conjunction with RMP river scientists. Phase 2 fieldwork was completed on the Tweed in 2007 by staff from Ross Environmental Associates and the USDA Forest Service Green Mountain National Forest, Rochester Ranger District. During the fall of 2007, RMP staff converted the White River Phase 1 data from an older database to the most current version of the VT ANR Stream Geomorphic Assessment Database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm), where they are available for public viewing. Phase 2 data were entered during late fall of 2007 by Ross Environmental staff. Phase 1 data were updated, where appropriate, using the field data from the Phase 2 assessment; these changes are tracked and documented within the SGA Database. Spatial data for bank erosion, grade control structures, bank revetments, debris jams, depositional features, and other important features were documented within all segments and entered into the spatial component of the statewide database (the Feature Indexing Tool, FIT) via the SGA Tool (SGAT) ArcView extension, which permits implementation of the data via geographic information systems. Maps displaying this information are 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

Quality assurance/quality control (QA/QC) checks of the Phase 1 data were initially conducted by RMP staff utilizing Quality Assurance Procedures delineated in the Phase 1 Protocols in place at the time (VT ANR 2003) and screened again with automated checks implemented in the SGA Database at the time of data migration in 2007. The Phase 2 data were collected in compliance with the State Quality Assurance Project Plan (VT ANR 2003) and checked with Quality Assurance procedures specified in the Phase 2 Protocols (VT ANR 2007). Review by both River Management Program personnel and the consultants conducting the assessments were cross-checked to verify integrity of the data. Documentation of the quality control checks is maintained within the SGA database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm). General questions about data collection methods can be answered by referencing the SGA Protocols (VT ANR 2007c).

It should be noted that protocols are periodically revised to increase the value of the data collected. At the time of Phase 2 data collection on the Tweed and its tributaries included in the Project area for this plan (2006–2007), data was not collected concerning parameters for areas of straightening with attendant windrowing (rows of stone pushed up high along the banks). Although the straightening was documented, rows of stone pushed up along the midstream portions of West Branch of the Tweed reach T6.2-S1.01 were not documented as windrows or berms. Changes in bed condition from removal of stone were captured in part by the plane bed assessment of the bed form of the reach, but the function of the windrows in increasing stream power during high flows does not appear on the maps; these parameters have been included with later editions of the Protocols.

Although current versions of the SGA protocols (VT ANR 2007) include delineation of areas with buffer widths <25 ft and <5 ft, protocols in place at the time of data collection for this Corridor Plan did not explicitly define areas of diminished or absent buffers. Data collection identified dominant and subdominant buffer widths, and these figures are incorporated into the reach descriptions and project identification as the best available information concerning these parameters. These areas are sometimes able to be discerned on the aerial photography accompanying reach and project identification maps.

Dredging and gravel removal appear to have been practiced with some frequency in the Tweed watershed, but exact dates and locations of these practices have not been documented (pers. comm., Frederick Nicholson, VT ANR-RMP Stream Alteration Engineer). This makes it difficult to determine the specific impacts on reaches upstream and downstream of mined reaches and estimated timeframes for channel evolution (discussed further in Section 5.1.4) and equilibration to occur, but channel adjustments noted in Phase 2 fieldwork suggest several portions of the watershed where it appears likely that these practices have been implemented. Areas where these concerns were raised in the analysis are noted in the reach descriptions and preliminary project identification in Section 6. It should be noted, however, that an "Impact assessment of instream channel modifications on channel morphology" (Center for Watershed Protection, Aquafor Beech Ltd., & Step by Step 1999) identified the West Branch of the Tweed as a "reference" stream used to compare with a study reach further upstream (Granville) on the Upper White River mainstem due to indications that instream modifications had been minimal on the West Branch. That same report found significant upstream and downstream channel impacts and adjustments from gravel removal on reaches very similar to the mainstem Tweed reaches analyzed for this report.

Full geomorphic Bridge and Culvert Survey data (VT ANR 2007b, Appendix G) was not available at the time of preparation of this report. Some data was available for structures located on Phase 2 reaches when the structure was field assessed as a channel constriction, but the importance of these structures in flow and sediment transport dynamics in this high-sediment-load watershed suggest that this data would be extremely valuable for a more complete picture of watershed dynamics, as well as important information for structure maintenance and replacement prioritization, scheduling, and capital budgeting.

5.0 RESULTS

The following sections summarize pertinent results of Phase I and II SGA data collection for the Tweed 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 ANR 2007). 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 ANR 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, and 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 Tweed 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 ANR 2006, Phase 2, Step 7.7; VT ANR 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.

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, the 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 ANR 2007).

Current forest species and age distributions indicate that the Tweed watershed likely experienced extensive areas of deforestation, with accompanying changes in hydrology including higher peak flows and direct-runoff discharges, lower minimum flows, and significant inputs of sediment. These trends appear to have peaked around 1920, with a reduction in peak flows and higher minimum flows gradually returning as the watershed was reforested through the 20th century (USDA-FS 2001). Similar to the Upper White mainstem further upstream from the confluence of the Tweed, the higher peak flows through aggraded sediment inputs were likely contributors to a high degree of historical incision noted on the Tweed during the data collection for the current Project.

Roads, parking lots, construction areas, lawns, and similar land uses are broadly classed in remote-sensing data from aerial imagery (Phase 1 data; Fig. 4) under “urban” land uses, which can reduce infiltration capacity and hence attenuation of flows. These land uses are significant in the Tweed River basin, particularly within the riparian corridor, where 11 of 32 stream reaches assessed in Phase 1 accounted for “urban” land uses of 10–41% in the corridor area; three of those reaches (T6.1-S3.1-t1.01 (a tributary of Guernsey Brook), T6.05, and T6.06) exceed 25% (Fig. 8). While agricultural land uses never exceeded 5% in the area analyzed, even within the riparian corridor, these areas can generate considerable inputs of overland runoff as well as sediment (particularly if bare soil is exposed) during significant precipitation events. Phase 1 and 2 geomorphic assessment indicated that many roads and crop lands near the streams have been ditched over time, further contributing to intensified hydrologic inputs to streams. Analysis of hydric soils overlaid with current crop and developed land uses (Fig. 4) indicates some likely loss or impairment of wetland attenuation of precipitation inputs in the Tweed River watershed, although hydric soils are not extensive within the watershed and lack of baseline historical data makes it difficult to quantify and establish impact thresholds for this parameter.

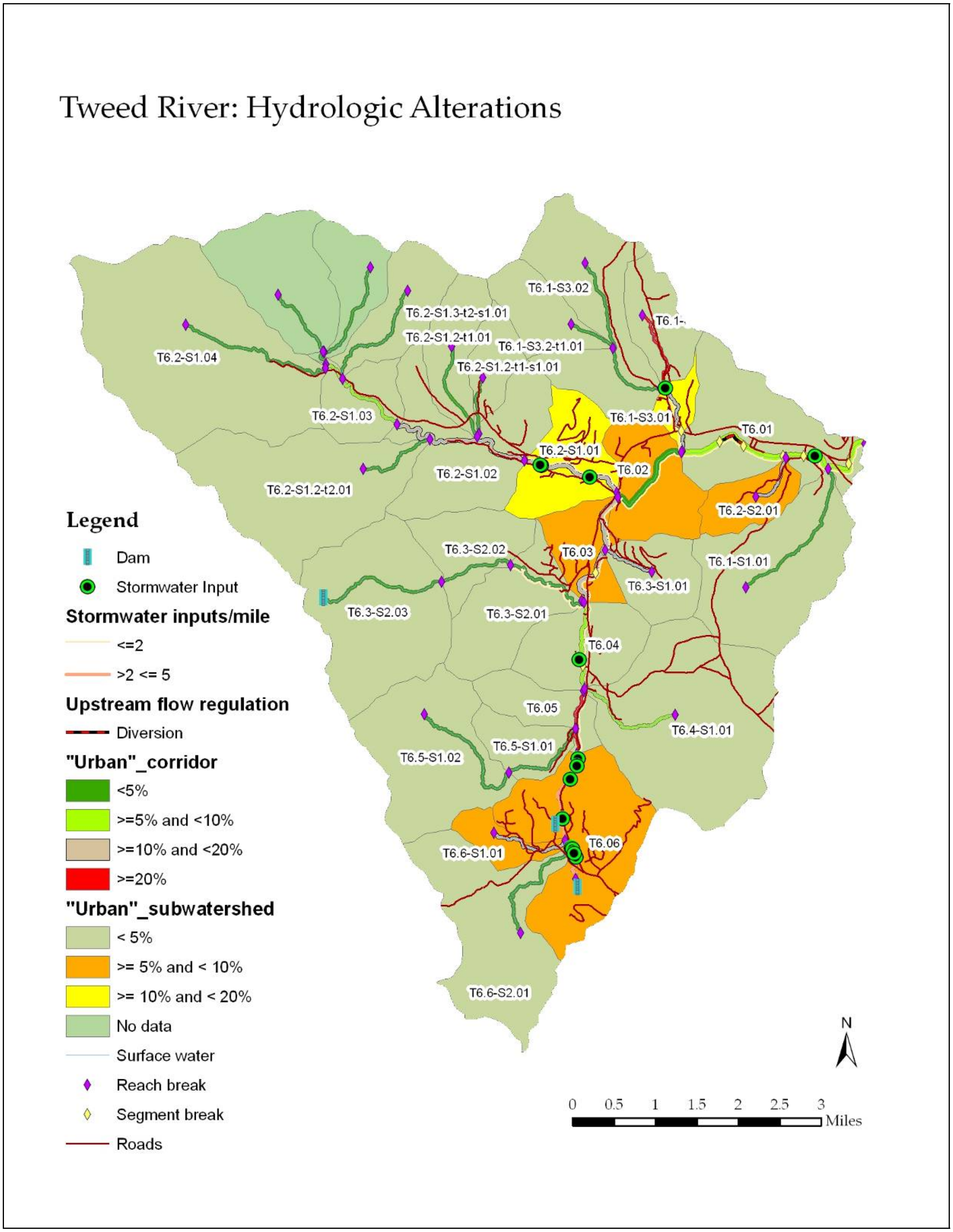


Figure 8. Hydrologic alterations map for the Tweed River watershed.

Current forest species and age distributions indicate that the Tweed River watershed probably experienced extensive areas of deforestation during the 19th century, with attendant changes in hydrology likely, including higher peak flows and direct-runoff discharges, lower minimum flows, and significant inputs of sediment (USDA-FS 2001). Historical clearing throughout much of Vermont in the late 18th and 19th centuries initially contributed to higher runoff of both water and sediment, which accrued in the river valleys. Removal of large woody debris from stream channels, often related to use of streams for log drives, mill power, and agricultural uses, frequently combined with road development and other encroachments, channel straightening, and bank armoring to change the rainfall-runoff regime in such a way that water inputs and power intensified through deposited sediments. Hydrologic regimes became more "flashy" as streams cut downward in areas where the stream bed was erodible, and greater stream flows were consequently contained within the channel.

Although it is difficult to quantify the extent of hydrologic changes due to deforestation, the active role of trees as "pumps" helping to cycle water and thus moderate both the amount and timing of water delivered to a stream system should not be underestimated. While this situation tended to diminish with reforestation, channel enlargement indicated by both current and historical channel incision, as well as current widening, were noted in Phase 2 data collection for the Tweed River watershed. Although the watershed is largely reforested today, the legacy of deforestation forms a backdrop that often exacerbates or otherwise influences adjustment processes evidenced in the assessed streams.

As noted in Section 3.1.3 of this report, Land use history and current general characteristics, snagging of channels and regulation of flows were practiced along the Tweed and its tributaries for transport of logs and to run mills. This can increase the erosive power of water at release times, further abetted by a reduction in the amount of sediment being moved by that water if the sediment is being held at dams and other constrictions. Although the railroad and berms are no longer present, the heightened stream power resulting from the slope increase caused by extensive straightening is still evident. Where downcutting has been sufficient to limit access to historical floodplains, high volume flows are now contained within the channel and smaller precipitation events can generate levels of geomorphic impact previously associated with more extreme precipitation events. Under these conditions, thunderstorms and microbursts, mid-winter rains, and snow melt events can cause significant hydrologic impacts.

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 Tweed River basin contributes heavily to a characteristically high bed-load system. Phase 1 analysis indicated that bedrock geology of the watershed is dominated by till and ice-contact features and steep to extremely steep topography (see Section 3.2 (Geologic background) of this report). In addition, soil data from the Phase 1 analysis indicates similar contributions to a high wash load, as all reaches showed soils with “Severe” to “Very severe” erodibility ratings (Section 3.2).

Geomorphic instability related to the downcutting of streambeds in the Tweed River basin (and loss of floodplain access), leading to concentration of flows in the stream channel and hence increased stream power, has resulted in adjustment processes that are manifested largely in redistribution of fine sediment loads in concentrated areas of the lower Tweed River mainstem in particular (Fig. 9, reach T6.01). Many of these finer sediments stay suspended in high flows and continue to be transported further downstream to the mainstem of the White River as well. Larger bed-load sediments are moving through the watershed in episodic flood-related discharges, often appearing as sediment “slugs” deriving from mass failures and evidenced as concentrated areas of steep riffles and other depositional features (Fig. 9; e.g., in the tributary reaches assessed in Phase 2 on Guernsey Brook (T6.1-S3.01), the West Branch (T6.2-S1.01), and Townsend Brook (T6.03-S2.01), as well as reach T6.04 on the mainstem).

Additional stressors in this system can include sheet and gully erosion on exposed soils of construction areas and tilled croplands in the river corridor in particular, as well as both field and road ditching systems and overland flows that can transport these materials easily in runoff events. Mass failures were contributing large amounts of various-sized sediments along portions of the upper Tweed River mainstem, as well as each of the tributaries walked in Phase 2 field assessments.

Important implications of this sediment regime departure in the Tweed River basin include heavy deposition when stream power decreases at constrictions such as bedrock outcrops, old breeched dams, and undersized culverts and bridges, with an accompanying increase in the likelihood of channel avulsions and similar changes in channel direction (e.g., flood chute access and formation) in high-water events. Flood chutes were frequently observed in the Phase 2 assessments in areas of heavy deposition (Fig. 9).

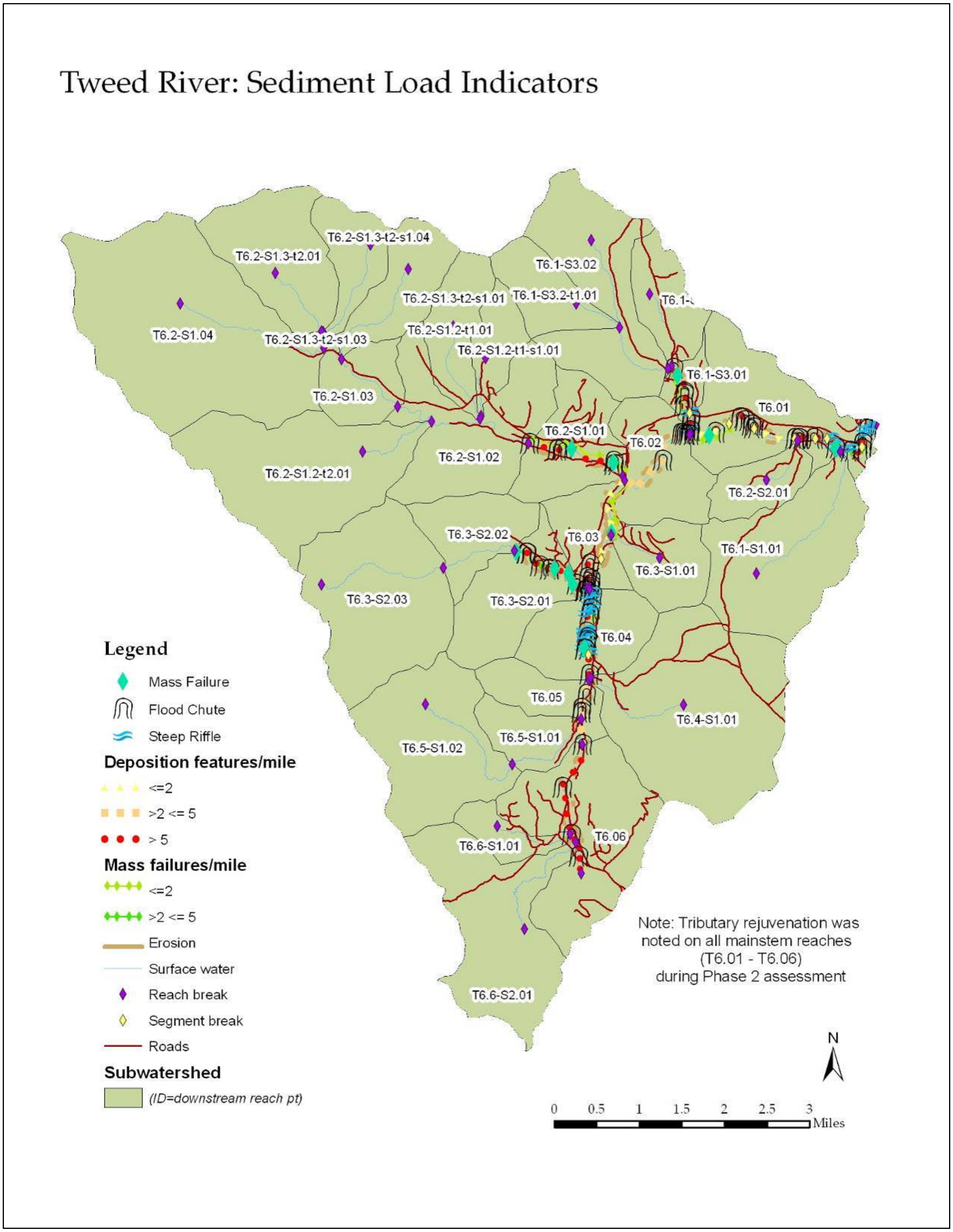


Figure 9. Watershed-scale sediment load indicators map for the Tweed River watershed.

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, at the reach scale can change the hydraulic geometry, and thus change the way sediment is transported, sorted, and distributed (Table 4). Phase 1 and Phase 2 assessments provide semiquantitative data-sets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified.

Table 4. Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (VT ANR 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, and 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. The primary hydrologic and sediment stressors in each stream segment assessed in the 2006 Phase 2 assessment of the Tweed River watershed are identified in Table 5.

Table 5. Tweed River Watershed Stressors Identification tables indicating some of the hydrologic and sediment load stressors that are likely causing or contributing to channel adjustment and a departure from equilibrium conditions

Tweed River mainstem *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.01A	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* Trib rejuvenation and mass failures upstream in T6.01B P2 deposition range: >5/mi P2 sum steep riffles & midbars: >5	*Increased stream power: slope* Straightening: >50% Encroachment: >20% *Increased stream power: depth* Dredging noted in reach, exact locations unknown *Decreased stream power: slope* P2: deposition range >5/mi *Decreased stream power: depth* Deposition upstream of White confluence	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% both banks Dom. buffer 26–50 ft LB *Increased bank resistance* Bank armoring: >20% LB, 5–20% RB
T6.01B	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* Trib rejuvenation and mass failures P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	*Increased stream power: slope* Straightening: 20–50% Encroachment: >20% Scour below bedrock *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition upstream of bridge and bedrock constrictions *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Increased bed resistance* Bedrock grade control *Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% LB, 5–20% RB Dom. buffer <25 ft LB *Increased bank resistance* Bank armoring: 5–20% each bank

Tweed River mainstem *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.01C	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)		*Increased stream power: slope* Straightening: >50% Encroachment: >20% Scour below bridge *Decreased stream power: slope* Deposition above and below bridge *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Snagging (woody debris = 5 pcs) Dredging *Decreased bank resistance* Erosion: >20% LB Dom. buffer <25 ft both banks *Increased bank resistance* Bank armoring: >20% RB
T6.01D	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: >50% *Decreased stream power: slope* P2: deposition range: >5/mi *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Snagging (woody debris = 5 pcs) Dredging *Decreased bank resistance* Erosion: >20% LB Dom. buffer <25 ft LB
T6.01E	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)		*Increased stream power: slope* Straightening: >50% Encroachment:>20% *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Dredging *Decreased bank resistance* Dom. buffer 26–50 ft, subdom. <25 ft LB

Tweed River mainstem *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.01F	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: >50% *Decreased stream power: slope* P2 deposition range: >5/mi *Increased stream power: depth* Dredging noted in reach, instream channel modifications (private excavator) *Decreased stream power: depth* Cobbled stream ford	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% LB, 5–20% RB Dom. buffer <25 LB, 26–50 ft RB
T6.01G	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* Trib rejuvenation P2 Deposition range: >5/mi	*Increased stream power: slope* Straightening: >50% Decreased stream power: slope P2 deposition range: >5/mi Increased stream power: depth Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Snagging (woody debris = 9 pcs) Dredging Decreased bank resistance Erosion: >20% LB Dom. buffer <25 ft LB
T6.02	*Increased flows* Deforestation Roads and ditching (P1 subshed: 5–10% urban)	*Increased load* Trib rejuvenation P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: >50% Encroachment: 5–20% *Decreased stream power: slope* P2 deposition range: >5/mi *Increased stream power: depth* Dredging; 8% bermed both banks	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% LB, 5–20% RB Subdom. buffer <25 ft LB

Tweed River mainstem *Stressors Identification Table*	Watershed Input Stressors		Reach Modification Stressors	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.03A	*Increased flows* Deforestation Roads and ditching (P1 subshed: 5–10% urban; P1 corridor: 10–20% urban)	*Increased load* Trib rejuvenation and mass failure	*Increased stream power: slope* Straightening: >50% Encroachment: >20% Scour below two bridges, also above one of the two *Decreased stream power: slope* P2 deposition range: >5/mi Deposition above two bridges, also below one of the two *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% LB, 5–20% RB Dom. buffer <25 ft LB, 26–50 ft RB *Increased bank resistance* Bank armoring: >20% LB, 5–20% RB
T6.03B	*Increased flows* Deforestation Roads and ditching (P1 subshed: 5–10% urban; P1 corridor: 10–20% urban)		*Increased stream power: slope* Straightening: >50% *Increased stream power: depth* Dredging noted in reach, exact locations unknown	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% both banks Dom. buffer <25 ft LB
T6.03C	*Increased flows* Deforestation Roads and ditching (P1 subshed: 5–10% urban; P1 corridor: 10–20% urban)	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: 20–50% Encroachment: 5–20% Scour above and below bridge *Increased stream power: depth* Dredging noted, exact locations unknown; 8% bermed one bank *Decreased stream power: slope* P2 deposition: >5/mi Deposition above and below bridge	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% both banks Dom. buffer 26–50 ft RB *Increased bank resistance* Bank armoring: 5–20% LB

Tweed River mainstem *Stressors Identification Table*	Watershed Input Stressors		Reach Modification Stressors	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.04A	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* Trib rejuvenation and mass failure P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 (Deposition: large steep riffles)	*Increased stream power: slope* Straightening: 20-50% Encroachment: 5–20% Scour below bridge *Increased stream power: depth* Dredging noted, exact locations unknown; 18% bermed one bank *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition above bridge *Decreased stream power: depth* Two stream fords	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% both banks Dom. buffer 26–50 ft both banks, subdom. buffer <25 ft RB
T6.04B	*Increased flows* Deforestation Roads and ditching (P1 corridor: 5–10% urban)	*Increased load* Trib rejuvenation P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	*Increased stream power: slope* Straightening: >50% Scour below bridge *Increased stream power: depth* Dredging noted in reach, exact locations unknown *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition above bridge	*Decreased bed resistance* Snagging (woody debris = 1 pc) Dredging *Decreased bank resistance* Erosion: 5–20% RB Dom. buffer <25 ft RB

Tweed River mainstem *Stressors Identification Table*	Watershed Input Stressors		Reach Modification Stressors	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
T6.05	*Increased flows* Deforestation Roads and ditching (P1 corridor: >20% urban)	*Increased load* Trib rejuvenation P2 deposition range: 2–5/mi	*Increased stream power: slope* Straightening: 20-50% Encroachment: >20% *Increased stream power: depth* Dredging noted in reach, exact locations unknown; 4% bermed one bank but Phase 2 reach notes state "Extensive berming indicates historic dredging and probable straightening" *Decreased stream power: slope* P2 deposition range: 2–5/mi	*Decreased bed resistance* Snagging (woody debris = 3 pcs) Dredging *Decreased bank resistance* Erosion: 5–20% RB Dom. buffer <25 ft RB, subdom. buffer <25 ft LB *Increased bank resistance* Bank armoring: 5–20% RB
T6.06	*Increased flows* Deforestation Roads and ditching (P1 subshed: 5–10% urban; P1 corridor: >40% urban) 9 stormwater inputs	*Increased load* Trib rejuvenation P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: 2–5	*Increased stream power: slope* Straightening: >50% Encroachment: >20% Reduced sediment supply below multiple grade controls *Increased stream power: depth* Dredging noted in reach, exact locations unknown Flow increases below stormwater outfalls *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: 2–5 *Decreased stream power: depth* Gravel mining	*Decreased bed resistance* Snagging (woody debris = 3 pcs) Dredging *Increased bed resistance* 11 ledge grade controls *Decreased bank resistance* Dom. buffer <25 ft, subdom 26–50 ft RB; dom. buffer 26–50 ft, subdom. <25 ft LB *Increased bank resistance* Bank armoring: 5–20% RB

Guernsey Brook *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
T6.1-S3.01A	*Increased flows* Deforestation Roads and ditching (P1 subshed: 10–20% urban; P1 corridor: 10–20% urban)	*Increased load * P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	*Increased stream power: slope* Straightening: >50% Scour below culvert *Increased stream power: depth* Dredging noted in reach, exact locations unknown *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition below bridge, above and below culvert	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% both banks Subdom. buffer 26–50 ft LB
T6.1-S3.01B	*Increased flows* Deforestation Roads and ditching (P1 subshed: 10–20% urban; P1 corridor: 10–20% urban)	*Increased load* Mass failure P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	*Increased stream power: slope* Straightening: >50% Encroachment: >20% Scour below two culverts *Increased stream power: depth* Dredging noted in reach, exact locations unknown *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition below one culvert	*Decreased bed resistance* Dredging *Increased bed resistance* 2 ledge grade controls *Decreased bank resistance* Subdom. buffer <25 ft both banks *Increased bank resistance* Bank armoring: >20% LB, 5–20% RB

West Branch Tweed River *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
T6.2-S1.01	*Increased flows* Deforestation Roads and ditching (P1 subshed: 10–20% urban; P1 corridor: 10–20% urban) 3 stormwater inputs	*Increased load* 2 mass failures P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: 2–5	*Increased stream power: slope* Straightening: >50% Encroachment: >20% *Increased stream power: depth* Dredging noted, exact locations unknown; 4% bermed one bank *Decreased stream power: slope* P2 deposition range:>5/mi P2 sum steep riffles & mid-bars: 2–5 Deposition above and below two bridges	*Decreased bed resistance* Snagging (woody debris = 9 pcs) Dredging *Increased bed resistance* 2 ledge grade controls *Decreased bank resistance* Erosion: 5–20% both banks Dom. buffer <25 ft RB Subdom. buffer <25 ft LB, 26–50 ft RB

Townsend Brook *Stressors Identification Table*	**Watershed Input Stressors**		**Reach Modification Stressors**	
T6.3-S2.01	*Increased flows* Deforestation	*Increased load* 4 mass failures P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	*Increased stream power: slope* Straightening: >50% Encroachment: >20% Scour below one bridge *Increased stream power: depth* Dredging noted, exact locations unknown *Decreased stream power: slope* P2 deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Deposition above and below one bridge	*Decreased bed resistance* Dredging *Decreased bank resistance* Erosion: >20% LB, 5–20% RB Dom. buffer 26–50 ft RB, Subdom. buffer <25 ft LB

5.1.3a Channel slope modifiers

Results for the Tweed River indicate that primary stressors include extensive straightening of the channel, along with road and development encroachment (Fig. 10). Phase 1 analysis indicated that 50–100% of the total reach length had been straightened in roughly half of the assessed stream reaches in the watershed, with the mainstem historically pinned against the valley wall by railroad construction up to the West Branch and the lower third of the West Branch limited from migration as well (Figs. 3 and 10). In areas with erodible boundary materials channel straightening can lead to slope increases through bed erosion in particular (exacerbated if there is a loss in floodplain access due to increased downcutting), and can play a significant role in enhancing sediment transport capacity as a result of the increased slope and depth at flood stage. On the Tweed tributary, rejuvenation was noted in all mainstem reaches, indicating that the mainstem has significantly incised. Tributary rejuvenation generally suggests increased sediment contributions from tributaries as downcutting proceeds upstream in the process of tributaries lowering their elevations to meet the lowered elevation of the mainstem. In this type of sediment regime, the enhanced transport capacity due to slope increases from straightening further contributes to stress in reaches downstream: instead of storing some of the increased load, the straightened reaches are now conveying sediment until a constriction or significant decrease in slope is encountered (these slope decreases often build on themselves as further deposits accrue in these same areas during high flow events). Roads and developments within the river corridor further contribute to an increased channel slope when structural measures are used to protect those encroachments.

Only one active headcut was noted in Phase 2 assessment, relatively high in the watershed (Reach T6.06, Fig. 10). Considered in conjunction with historical incision noted in all reaches in Phase 2 assessment, it is likely that downcutting (and accompanying increase in slope) has migrated up through the watershed over time. Only the lowest reach in each of Guernsey Brook, the West Branch, and Townsend Brook were assessed in Phase 2 (when head cuts would be documented, as opposed to Phase 1 which would not note their presence). It is conceivable that downcutting processes may be more active currently higher in the watershed. In areas where this process is contributing large amounts of sediment to the transport regime, this can lead to large deposits when flows slow down at areas of decreased slope such as undersized culverts, bedrock constrictions, and ledge grade controls, or sediment deposits left previously, and can increase the likelihood of flood chute access, channel avulsions, and similar stream migrations in high flows. This is discussed further in the next section on channel depth modifiers.

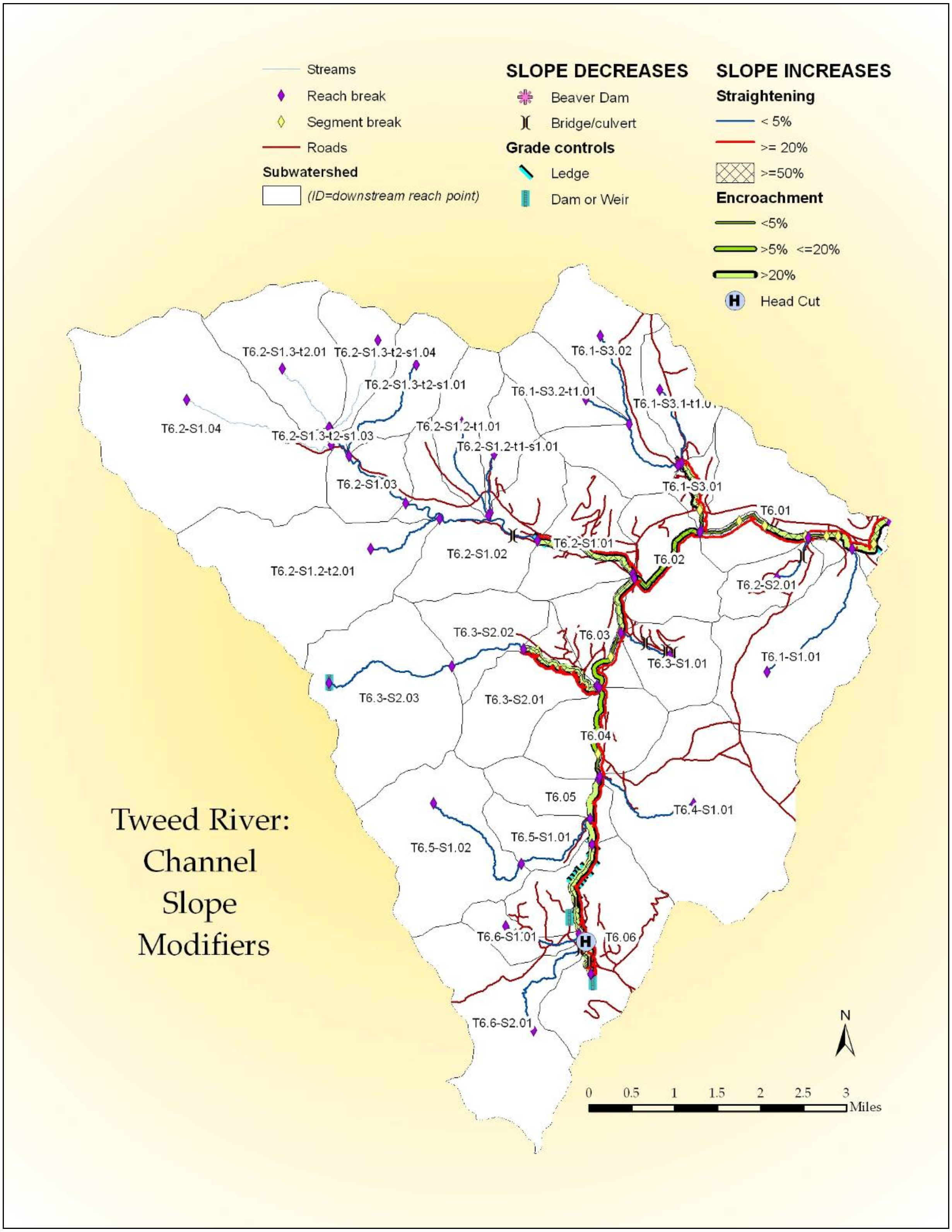


Figure 10. Reach-scale stressors: Channel slope modifiers map for the Tweed River watershed.

5.1.3b Channel depth modifiers

Phase 1 and 2 data collection on the Tweed indicated extensive road or berm encroachment in at least some portion of all but one reach assessed in Phase 2 (10 of 19 segments showed >20% corridor encroachments), which has served to reduce the effective width of the valley and floodplain in all but two reaches (Guernsey Brook T6.1-S3.01, and the mainstem between Guernsey Brook and the West Branch (at Lower Michigan Rd.), T6.2; Fig. 11). Berms and elevated roads within the river corridor increase the depth of flood flows, and thus also increase stream power.

Significant deposition, particularly delta and backwater deposits, create the potential for more shallow depths during moderate flows due to the mid-channel deposits and the wider channel that results from the backwater conditions. Stream power is reduced in these areas, leading to further deposition. Moderate to heavy deposition was noted in the uppermost and most downstream portions of the mainstem as well as each of the tributaries assessed in Phase 2 (Fig. 11). Gravel removal has been common practice throughout the assessed reaches of the Tweed (pers. comm., Frederick Nicholson, VT ANR-RMP Stream Alteration Engineer), and also contributes to the potential for more shallow depths during high flows due to the over-widened channel that typically results from dredging, gravel mining, and bar scalping. Stream dynamics related to this practice are complex, however, and it is also important to recognize that headcutting up and downstream of bar scalping sites has likely contributed to channel incision in flood flows, particularly in the lower portions of the Tweed, where natural grade controls are less frequent and bed materials are relatively finer-grained (see Appendix 5 for more information on bar scalping impacts).

Stormwater inputs were documented in Phase 2 fieldwork throughout the study area, but were particularly concentrated in the southern (upstream) portion of the Project area where development impacts are high. Cumulatively, direct stormwater inputs to the stream can significantly increase peak discharge during floods, which typically results in an increase in flow depths and stream power.

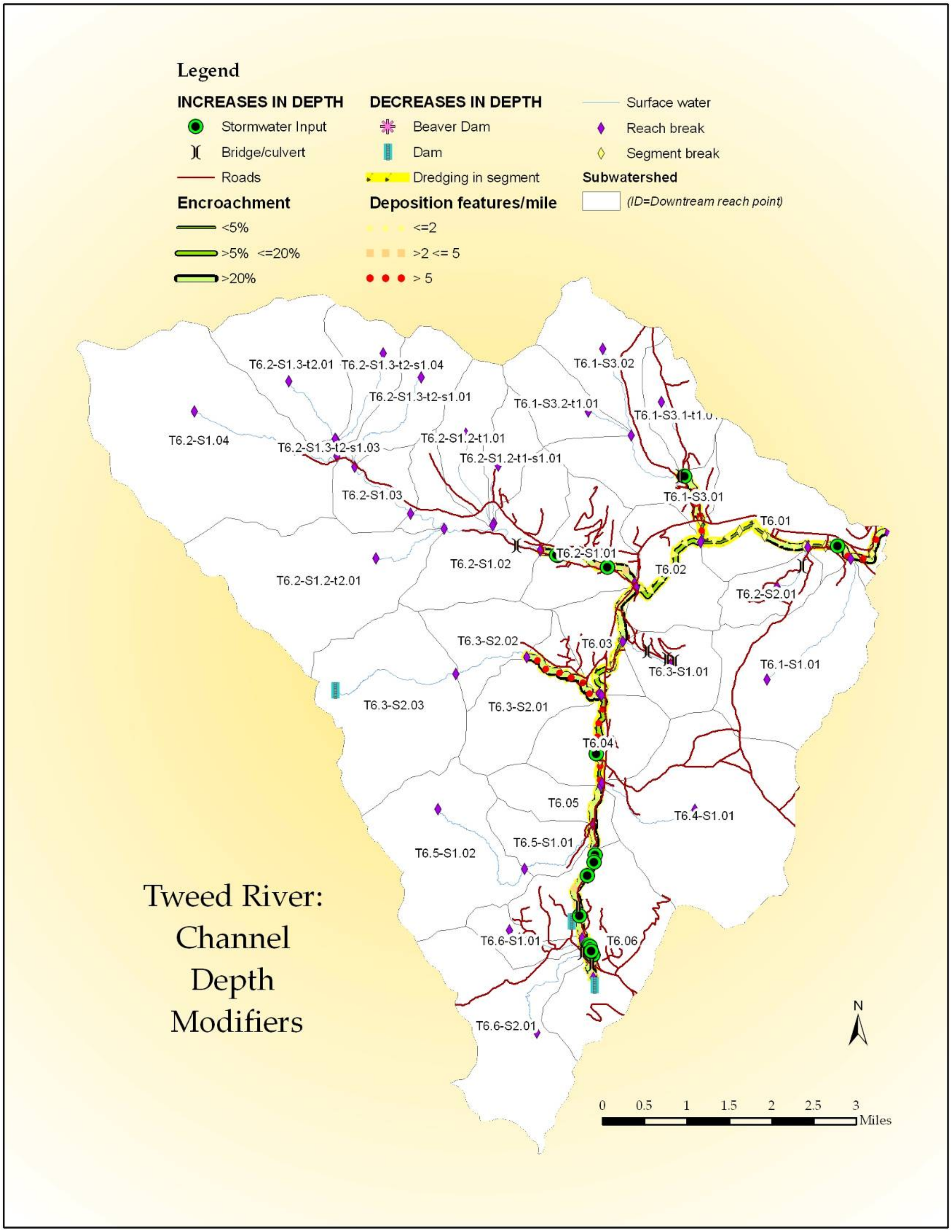


Figure 11. Reach-scale stressors: Channel depth modifiers map for the Tweed River watershed.

5.1.3c Boundary condition and riparian modifiers

Stream boundaries include bed and banks, and are also affected by 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.

Bed materials were coarse in all reaches assessed along the Tweed and its tributaries, although the majority of reaches included for Phase 2 assessment were dominated by gravel with cobble materials predominant only higher in the watershed. Upper bank materials are often more easily erodible in flood flows than the bed and lower banks, with sand and gravel the predominant upper bank materials on both banks in 15 of the 19 segments assessed in Phase 2 (sand dominated the upper portion of the left bank on three of the remaining four segments; Appendix 3). Bank erosion was noted extensively throughout the watershed, particularly in areas where riparian buffers lacked significant vegetation. Downstream reaches of the river are pinned against a steep valley wall above the right bank, and the buffer is generally forested on the steep walls. Heavy erosion was noted along much of the developed areas and hayfields on the left bank in these areas, where buffer vegetation was greatly reduced in extent compared with the right bank, which is primarily forested (Fig. 12). The only segments indicating erosion on >20% of the right bank on the mainstem were in segment T6.01A (which has extensive evidence of heavy historical use, with two breeched sluice dams and old bridge abutments) and segments B and C of Reach T6.03 and reach T6.04, where the dominant and subdominant land use in the riparian corridor were residential and vegetated buffer widths dropped. It is clear that the presence of wooded buffers greatly aids the stability of the banks in the Tweed corridor planning area. Minor to locally extensive areas of hard bank and riprap revetments have been placed throughout the watershed to limit erosion in areas of development and agricultural use where these buffers are lacking (Fig.12), exacerbating some of the channel slope and depth modifications discussed in sections 5.1.3a and 5.1.3b above.

Historically, log drives were used on the West Branch to transport logs from the Bayonne and Michigan Camps (Fig. 3) to the railroad along the Tweed, and there are strong indications that the stream has been “snagged” there and elsewhere in the watershed as well. This removal of woody debris has reduced sediment storage and channel roughness throughout the assessed reaches of the watershed, contributing to the episodic movement of “sediment slugs” toward downstream reaches in high flows and the concentration of gravel downstream, as well as the presence of plane bed features frequently noted in these reaches during Phase 2 assessment. With this reduction of sediment storage higher in the watershed and highly erodible sand and gravel present in the upper banks of virtually all reaches assessed on the Tweed, bank erosion and fine sediment deposition have also contributed to ongoing concerns for infrastructure and property protection, as well as habitat quality, on the mainstem White and the Tweed (USDA-FS 2001; WRP 2007).

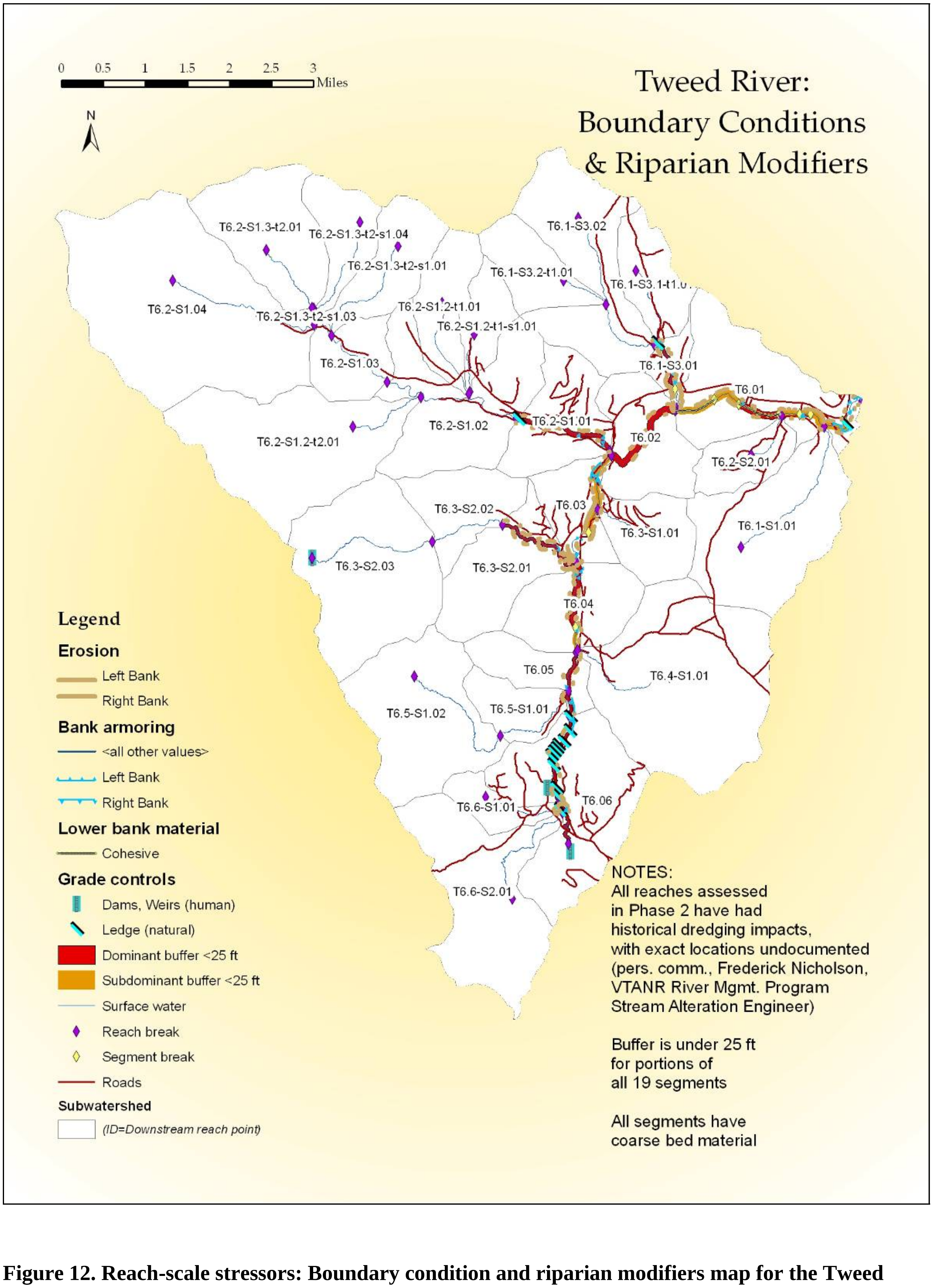


Figure 12. Reach-scale stressors: Boundary condition and riparian modifiers map for the Tweed river watershed.

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. 13). 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 ANR 2007).

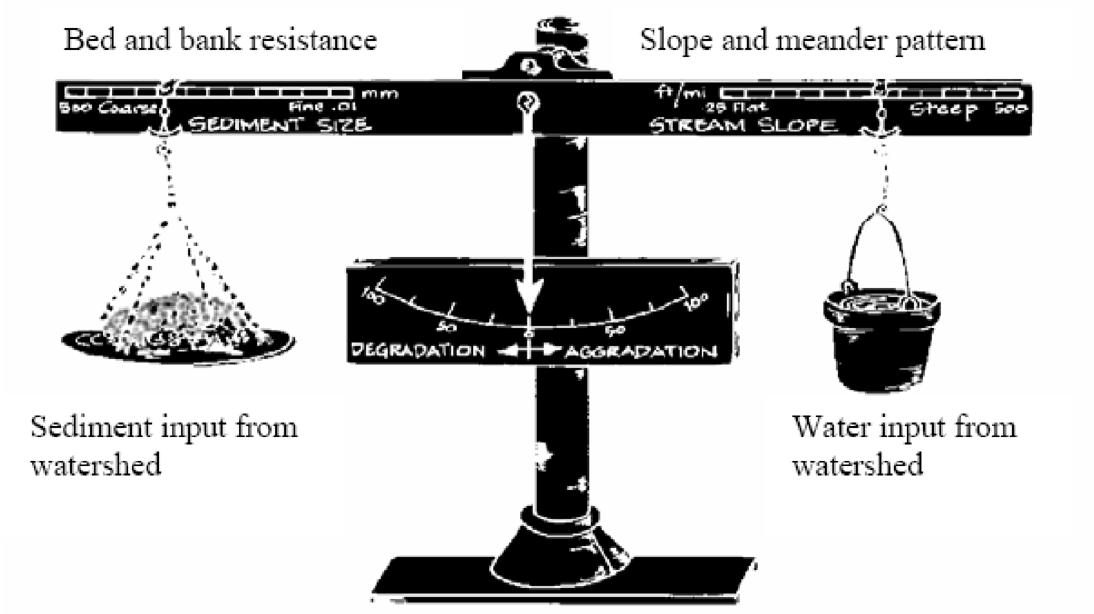


Figure 13. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955).

Phase 1 designates a "reference type" for all reaches, and except for T6.06, the most upstream reach, Tweed mainstem reaches in the Project area were generally C-type riffle-pool systems (based primarily on natural valley confinement and valley slope; see Section 3.3). Only the most downstream reach (reach T6.01) of the Tweed mainstem would be characterized by a gravel bed substrate (a C4 stream type) under reference conditions; the remainder would be characteristically cobble (C3 stream type). Reach T6.06 would be a plane bed system due to a series of ledge grade controls and bedrock outcrops.

The C channel type is typically found in unconfined valleys, displays a meandering nature, and uses floodplains for sediment storage and dissipation of stream power. Under reference conditions, the sediment regime of the mainstem Tweed would be one in which all reaches below T6.06 would provide for coarse particle equilibrium (in = out: 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) and fine sediment deposition at annual flood flows (Coarse Equilibrium and Fine Deposition regime, Table 5; VT ANR 2007, pp. 34–36).

Phase 1 analysis indicated that reference conditions for two of the three tributary reaches assessed in Phase 2, plus reach T6.06 on the mainstem Tweed, would be a B-type step-pool system; the first reach of the West Branch (reach T6.02-S1.01) was designated a B-type planebed system. All of these reaches would be characterized by cobble substrates under reference conditions. B-type streams with these characteristics would typically demonstrate a Transport sediment regime, contributing minor amounts of sediments of various sizes to downstream reaches.

Table 5. Reference sediment regime parameters for Tweed River corridor planning project reaches.

Sediment regime	Natural valley types	Pertinent reference stream types	Applicable Tweed Project reaches
Transport	NC, SC, NW Valley slope >2%	B3, B4	T6.06, T6.01-S3.01, T6.02-S1.01, T6.03-S2.01
Coarse equilibrium (in = out) & fine deposition	NW, BD, VB Valley slope <2%	C3, C4	T6.01, T6.02, T6.03, T6.04, T6.05

NC, Narrowly confined; SC, Semiconfined; NW,Narrow; BD, Broad; VB, Very Broad

Sediment regime departure is determined based on a number of parameters measured in Phase 2 assessments (VT ANR 2007b, pp. 34–36), as summarized in Table 5. 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 6. Pertinent data for characterizing Tweed River corridor planning Project area 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">A, B, G, or F</td></tr>
<tr><td rowspan="2">Coarse equilibrium & fine deposition</td><td colspan="2">Bc, C, E, or D</td></tr>
<tr><td colspan="3">Valley type = BD or VB</td></tr>
<tr><td>Confined storage & transport</td><td rowspan="4">Incision ≥1.3</td><td colspan="3">Valley type = NC or SC</td></tr>
<tr><td>Unconfined storage & 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 storage & transport, coarse deposition</td><td>Bank armoring or straightening <50%</td></tr>
<tr><td colspan="2">Channel evolution stage = IV</td></tr>
</table>

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. Phase 2 work assessed all reaches in the Tweed River Corridor Planning Project area as being at Stage III of channel evolution, with the exception of Reach T6.05 which was in Stage II (Table 7). Schumm (1977 and 1984) has described five stages of channel evolution (Fig. 14) for reaches such as those found in the Project area, where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time, paraphrased from the SGA protocols (VT ANR 2006, Appendix C) as follows:

I. Stable — in regime, reference to good condition. Insignificant to minimal adjustment; planform is moderate 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.

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.

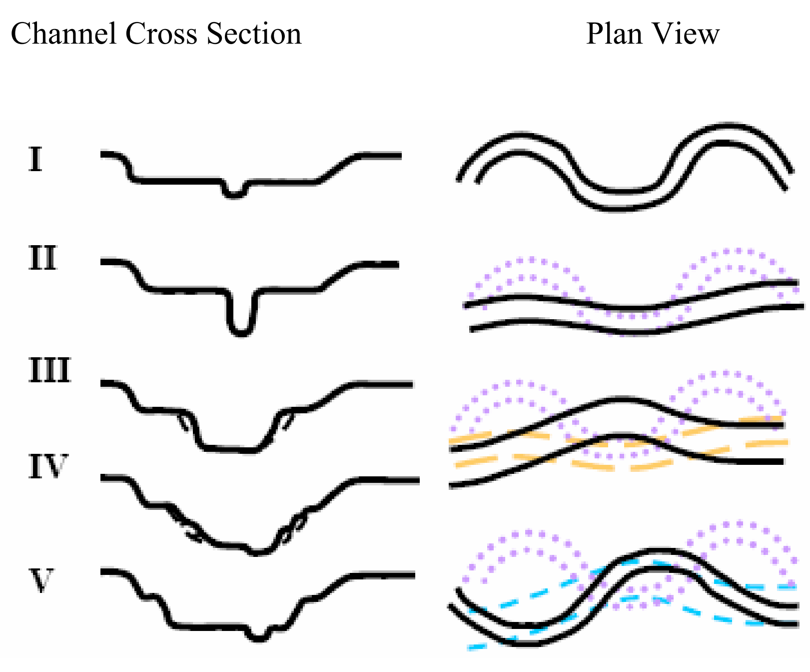
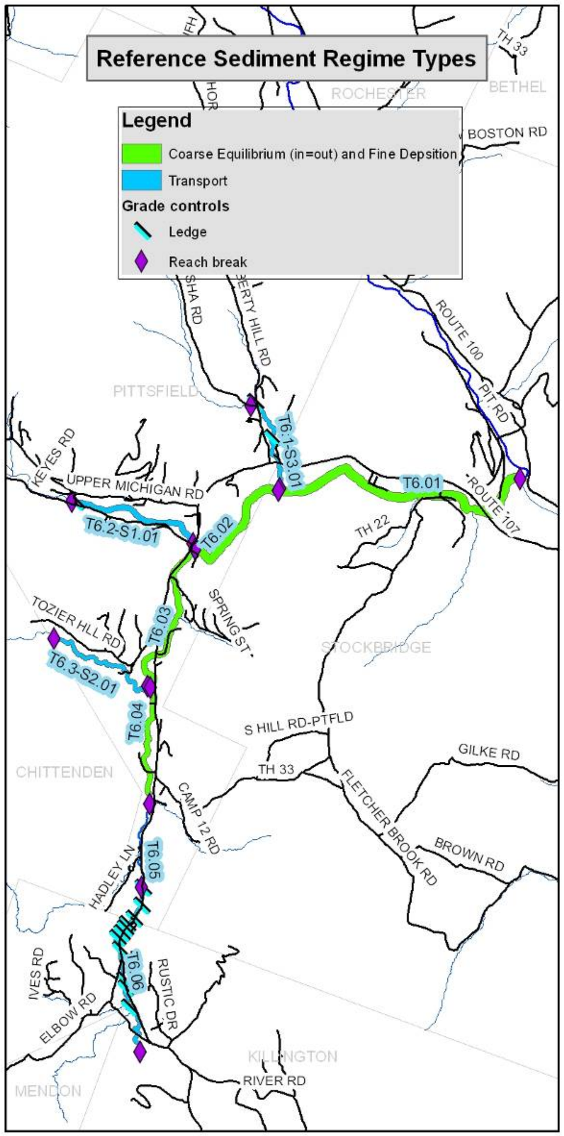


Figure 14. Channel evolution process showing channel downcutting or incision in Stage II (cross section), widening through Stages III and IV, and floodplain reestablishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a flood-driven process taking place over decades (VT ANR 2007a).

Phase 2 measurements found a high degree of historical incision (downcutting) throughout much of the Tweed corridor planning Project area, indicating little to no access of the river to historical floodplains in most reaches in conjunction with extensive straightening and channelization that have served to increase stream power. Only segments on the upper reaches of the Tweed mainstem (including segment T6.03C upstream) were characterized by cobble substrates; all other segments were classed with gravel substrates, including the tributary reaches assessed in Phase 2 (the most downstream reaches of each of those tributaries). Of the segments assessed in Phase 2, 10 of 19 were classed as plane bed rather than riffle-pool or step-pool systems, generally indicative (except in steep gradient or bedrock-controlled areas) of substantial deposition of relatively finer-grained (small cobble, gravel, and sand) particles which serves to reduce channel bed roughness and thus further increase stream power and transport capacity. The reference sediment regime has been converted to one in which all reaches of the mainstem Tweed function as transport reaches, with coarse deposition (including coarse gravel) occurring primarily when stream power is reduced or sediment load exceeds the carrying capacity of the stream. All of the mainstem reaches have been converted to Fine Source and Transport & Coarse Deposition reaches (Fig. 15; Table 7).

Phase 2 assessment of the predicted reference Transport reaches indicated that only T6.06 in the upper portion of the mainstem was characterized with a cobble substrate; the tributary reaches all exhibited gravel substrates, indicating substantial deposition of finer-grained particles. Despite increased stormwater inputs and a series of ledge grade controls and bedrock outcrops that might increase transport, Phase 2 assessment still found substantial sediment deposition in reach T6.06. With increased stream power prevalent in much of the Project area, it appears that sediments are being recruited from upstream reaches and the tributaries as downstream reaches along the mainstem attempt to reestablish equilibrium. With primary channel-forming processes usually occurring on an annual or biannual basis during high flows, coarse bedload sediments can take a good deal of time to move through the stream network and be restricted from such movement by constraints such as undersized structures and bedrock constrictions, and the larger sediments may only be energized in high flow events exceeding these annual events. In the meantime, it appears that gravel and small cobble movement has deposited in entrenched and overwidened areas of the Tweed watershed in lower flows, contributing to plane bed formation and “fining” of the sediment size moving through these channels and often exacerbating the heightened stream power at higher flows.



Tweed River Sediment Regime Departure

The map on the left is based primarily on the relationship of the river to its valley type and valley slope. This Phase 1 assessment identified downstream reaches on the Tweed mainstem as gravel bottom, C type streams. These reference type streams utilize access to their floodplains as a primary means to store sediment and nutrients within the watershed, and the reference sediment regime is generally a 'Coarse Equilibrium (in = out) & Fine Deposition' type. Tributary reaches and upstream mainstem reaches in the Project area were identifed as cobble bottom, B type streams. Reference streams of this type would exhibit a Transport sediment regime.

Due to changes in hydrology and sediment storage and transport within the watershed (largely related to encroachment impacts magnified by a legacy of historic deforestation), exisiting stream types and dynamics identified in Phase 2 rapid field assessments (map at right) indicate that all but two reaches within the Tweed River Corridor Planning Project area have been converted to 'Fine Source and Transport & Coarse Deposition' sediment regimes.This means that most sediment entering the stream is either being transported through without being deposited,or is being dropped out when the load reaches a point the river cannot carry (or at channel constrictions such as old abutments and dam remains).

Although important ledge grade controls have limited downcutting in both downstream and upstream portions of the watershed, much of the stream channel in the Tweed Project area has incised sufficiently to prevent access to historical floodplains. Channel evolutionwill likely entail widening channels and lateral migration until the stream is able to rebalance the power of the water in the channel with the amount of sediment being moved. Efforts to constrain the river and curtail these processes will futher aggravate the impacts of increased flows and sediment tranport on downstream reaches. Hence, it will be important to identify areas where sediment and nutrients can be stored within the watershed.

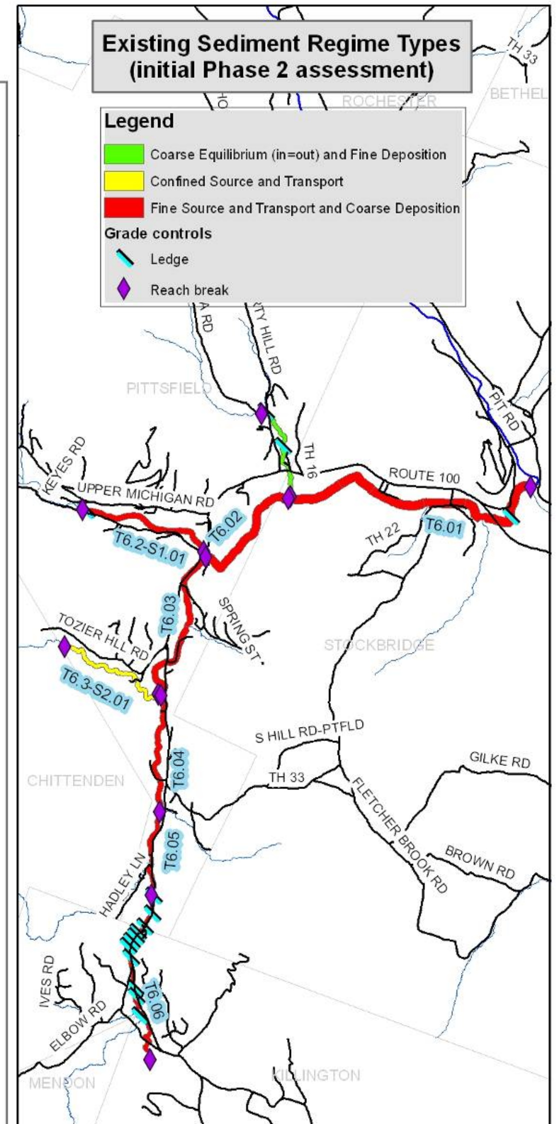


Figure 15. Sediment regime departure in the Tweed River corridor planning Project area.

Table 7. Sediment regime characterization criteria for Tweed River corridor planning Project area reaches (see Table 6 above for color coding and brief description of sediment regimes).

Reach/Segment (Sediment Regime)	Incision Ratio	Natural Valley Type (existing type in parentheses)	Straightening and Bank armor (% range)	Channel Evolution Stage and Geomorphic Condition	Existing Stream Type
Tweed mainstem					
T6.01A (FSTCD)	2.6	VB (SC)	>50 >20	III Fair	F4
T6.01B (FSTCD)	1.9	VB (BD)	20–50 5–20	III Fair	C4
T6.01C (FSTCD)	2.0	VB (VB)	>50 5–20	III Poor	F4
T6.01D (FSTCD)	1.4	VB (SC)	>50 <5	III Fair	C4
T6.01E (FSTCD)	1.9	VB (BD)	>50 <5	III Fair	C4
T6.01F (FSTCD)	2.0	VB (BD)	>50 <5	III Fair	C4
T6.01G (FSTCD)	1.6	VB (BD)	>50 <5	III Poor	F4
T6.02 (FSTCD)	1.6	VB (VB)	>50 <5	III Fair	C4
T6.03A (FSTCD)	2.0	VB (VB)	>50 5–20	III Poor	F4
T6.03B (FSTCD)	2.9	VB (VB)	>50 <5	III Fair	F4
T6.03C (FSTCD)	2.7	VB (BD)	20–50 5–20	III Fair	F3
T6.04A (FSTCD)	1.9	VB (BD)	20–50 <5	III Poor	B4
T6.04B (FSTCD)	1.8	VB (BD)	>50 <5	II Fair	B3
T6.05 (FSTCD)	1.8	BD (NW)	20–50 5–20	III Fair	C3
T6.06 (FSTCD)	2.7	NW (SC)	>50 5–20	III Poor	B3

Reach/Segment (Sediment Regime)	Incision Ratio	Natural Valley Type (existing type in parentheses)	Straightening and Bank armor (% range)	Channel Evolution Stage and Geomorphic Condition	Existing Stream Type
Guernsey Brook					
T6.1-S3.01A (CEFD)	1.3	VB (VB)	>50 <5	III Fair	B4
T6.1-S3.01B (CEFD)	1.3	NW (NW)	>50 <5	III Fair	B4
West Branch Tweed					
T6.2-S1.01	2.3	BD (BD)	>50 <5	III Poor	B3a
Townsend Brook					
T6.3-S2.01 (CST)	2.2	NW	>50 <5	III Poor	F4

Townsend Brook (T6.03-S2.01) was characterized with a Confined Source and Transport sediment regime, although substantial deposition (>5 deposition features/mile) noted in Phase 2 was somewhat anomalous for a sediment regime of this type. Generally a Confined Source and Transport sediment regime is characteristic of streams in narrow valley settings such as Townsend Brook when disturbances to equilibrium conditions trigger incision, subsequent rejuvenation processes, and, frequently, mass wasting and gully formation in steep valley walls with unconsolidated geologic materials (VT ANR RCPG 2007, p.34). Such reaches usually store very little of these sediments due to enhanced stream power deriving from valley confinement and relatively steep gradients, and the elevated deposition may indicate gravel deposition in overwidened areas. It appears that Townsend Brook could currently be characterized more as a Fine Source and Transport & Coarse Deposition regime due to the substantial amounts of deposition occurring in the reach.

Phase 1 analysis indicated a B-type plane bed system for reference conditions on the West Branch, and a C-type plane bed on reach T6.05 on the Tweed mainstem. The plane bed features noted in Phase 1 windshield surveys were more likely indicative of adjustment processes, including substantial deposition, than of reference conditions, which are plane-bed primarily in streams with bedrock or ledge-controlled beds or steeper gradients and narrower confinements. In fact, the valley confinement indicated in Phase 1 analysis for T6.05 was Broad, but was changed to Narrow in Phase 2 field assessment due to Rte. 100 road encroachment. On the West Branch, valley slope is 2.1% (typical C-type streams have a valley slope <2%, while typical B-types range from 2% to 4% slope). Berming, encroachment, and straightening in this reach due to both the historical impacts of the railroad (Fig 3) and current road and development impacts in the corridor have served to narrow the valley significantly, and Phase 2 identified this reach with a stream-type departure (even from a B-type stream that might not be the true reference) to an F-type stream (Fig. 17, Section 5.2), indicating an overwidened channel in an entrenched setting with little access to floodplain. The important point is that under true reference conditions, it is likely that this reach would have significant access to floodplain in a broad valley and exhibit a Coarse Equilibrium and Fine Deposition regime, while the existing sediment regime is Fine Source and Transport & Coarse Deposition. The Phase 1 reference plane-bed assessment for both of these reaches was revised based on the Phase 2 observations.

The field-assessed reach on Guernsey Brook (T6.01-S3.01) was segmented, in large part because of the situation of the stream in a much broader valley, with access to a broader floodplain, in the lowest quarter-mile of the stream before it enters the mainstem. Incision ratios (a primary delimiting criteria for sediment regime classification, VT ANR RCPG 2007, pp.35–36; Table 6) were limited on both segments, in part due to ledge grade controls in the upstream segment that serve to limit further bed degradation. Both segments within the reach were thus somewhat anomalous in terms of sediment regime classification, but further delimiting criteria, including Stage III channel evolution, extensive straightening, and limited amounts of bank armoring documented in both segments during Phase 2 assessment, indicate that initial Phase 2 assessment of a Coarse Equilibrium and Fine Deposition sediment regime for these segments might also be characterized as a Fine Source and Transport & Coarse Deposition regime for both segments. The existing sediment regime currently noted in the reach may thus be more sensitive to changes in watershed inputs than indicated by the current equilibrium conditions in the upstream segment in particular, where higher gradients and ledge grade controls make bank materials more erodible than the bed and increase the likelihood of downstream transport of finer sediment loads. These dynamics increase the sensitivity of the downstream segment as well, increasing the value of floodplain access and meander development as a means of permitting fine deposition that would otherwise contribute to elevated loads of finer-grained washload sediments that appear to be moving long distances within and out of this watershed under the current sediment regime.

Natural lateral constraints to channel evolution occur in the form of bedrock and ledge outcrops on both mainstem and tributary reaches in the Tweed corridor planning area, but the most significant constraints to channel evolution in the Project area are associated with human-built encroachments of both a historical and contemporary nature (Fig. 16). The magnitude of these constraints in upstream reaches, in combination with the naturally narrow valleys present in the higher elevation reaches of the watershed, places a particularly high value on the downstream reaches of the Tweed mainstem as attenuation assets (Table 8) and places a high priority on protecting these functions in areas that do not currently have lateral constraints that conflict with channel evolution processes such as widening and lateral migration (often evidenced as erosion and, in the types of geologic materials present here, sudden channel avulsions or catastrophic changes in channel location during floods).

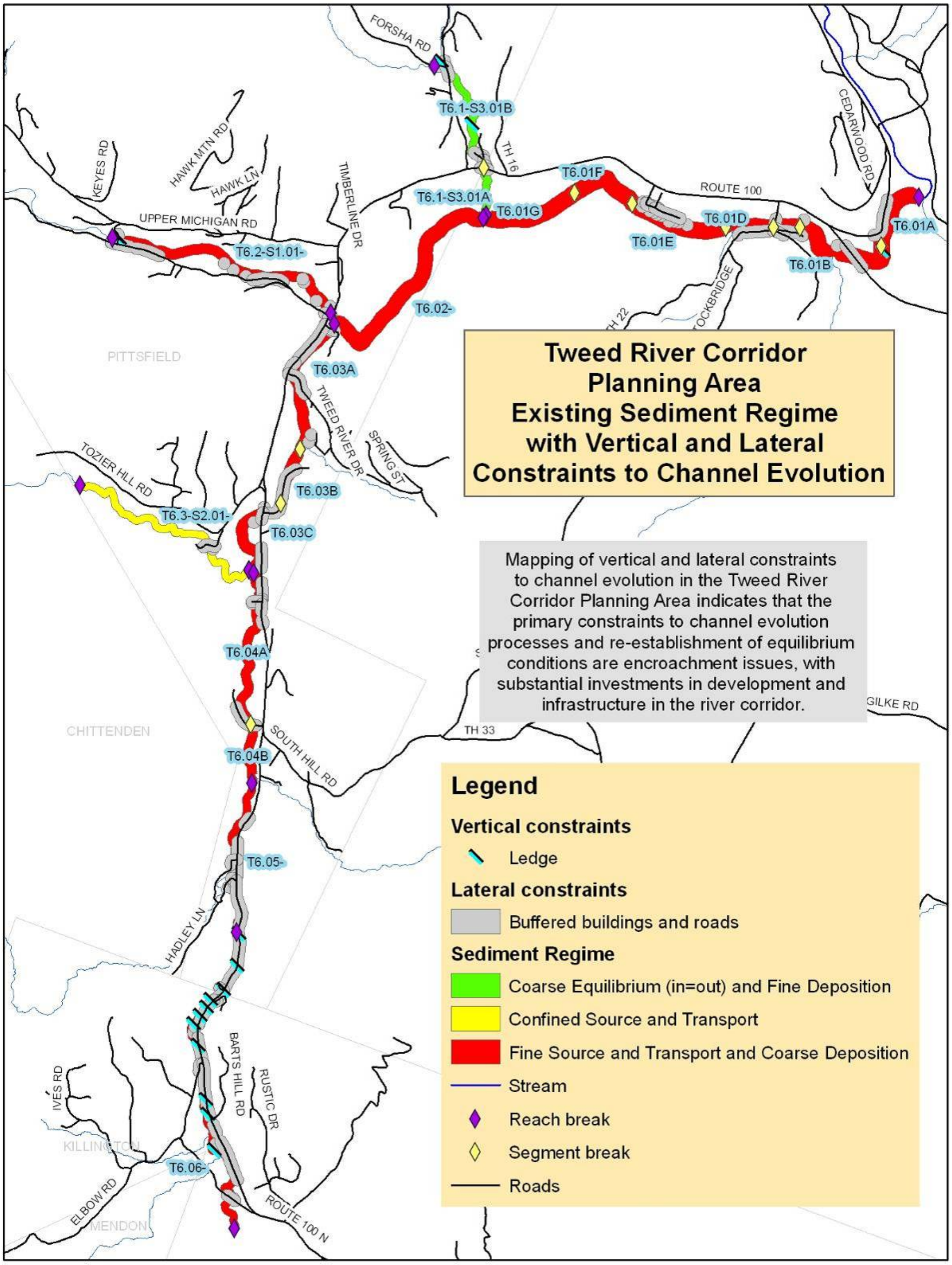


Figure 16. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution in the Tweed River corridor planning Project area.

Table 8. Tweed River corridor planning Project area Departure Analysis Table, indicating where river segments are constrained from adjustment, converted to transport streams, and have or may someday have potential for attenuating flow and sediment loads.

Tweed corridor Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
Tweed River mainstem							
T6.01A		Human: roads, development, structures Natural: bedrock outcrops (in conjunction w/ Rte. 100)		X	X	X	X
T6.01B	Natural: waterfalls	Human: agriculture, roads (bridge) Natural: bedrock		X	X		X
T6.01C		Human: development, roads, agriculture		X	X	X	Limited
T6.01D		Human: roads, agriculture		X	X	X	X
T6.01E		Human: development, roads Natural: bedrock		X	X		Limited
T6.01F		Human: roads, development, agriculture		X	X	X	X
T6.01G		Human: agriculture, development Natural:		X	X		X

Tweed corridor Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
		bedrock					
T6.02-0		Human: roads, development (upstream end), agriculture Natural: bedrock		X	X		X
T6.03A		Human: roads, development, agriculture		X	X		encroached
T6.03B		Human: roads, development; agriculture?		X	X		limited
T6.03C		Human: roads, development		X	X	X	limited
T6.04A		Human: roads, development		X	X	X	limited
T6.04B		Human: roads, development; agriculture?		X	X	X	limited
T6.05-0		Human: roads, development		X	X		limited
T6.06-0	Natural: ledge	Human: roads, development	X				
Guernsey Brook							
T6.1-S3.01A		Human: agriculture, development		X	X	X	X
T6.1-S3.01B	Natural: ledge	Human: roads, development	X			X	

Tweed corridor Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
West Branch Tweed River							
T6.2-S1.01	Natural: Ledge (upstream)	Human: development, roads, agriculture		X	X	X	Limited (midstream), important
Townsend Brook							
T6.3-S2.01		Human: roads, development, agriculture	X			X	limited (bottom)

To summarize, the existing sediment regime in the Tweed Project area features limited floodplain access and increased stream power with significant deposition currently occurring even in typical Transport reaches. Erosion, widening, and lateral migration are active processes in most reaches and segments as channel evolution proceeds and these streams attempt to rebuild meanders and floodplains to reestablish equilibrium between this increased stream power and the sediment loads being carried by it. Currently, deposition is primarily occurring when sediment load exceeds carrying capacity, though channel geometry changes sufficiently to decrease stream power in stream segments throughout the Project area as well; this appears to be enhancing "fining" of sediment deposits in overwidened and entrenched portions of the stream channel. The combination of increased stream power and sediment transport in the Project area raises the following issues on the Tweed and assessed tributaries.

1. Bed materials are somewhat resilient to further degradation, and banks thus appear to be generally more easily erodible and susceptible to accelerated levels of erosion as part of a process of channel evolution, as the stream attempts to regain equilibrium;

2. With gravel a common dominant bed material, maintenance of banks through continued channelization can still increase the likelihood of further bed incision (including potential headcuts, only one of which was identified in Phase 2 work) that would further limit access to floodplain and initiate more channel adjustments. Ledge grade controls present in several areas of the watershed provide important checks to limit the vertical extent and upstream migration of further incision.

3. Lack of access to floodplain and extensive channel straightening means that the bulk of sediment deposition impact is being transferred to downstream reaches: coarser bed loads are moving in sediment "slugs" with apparent discontinuities (e.g., reach T6.04) in transport of larger materials to downstream reaches, and finer washload sediments are being transported further downstream, often over long distances at high flows.

4. Deposition is occurring whenever stream power is reduced, and will likely continue to accumulate quickly in these areas (building on the further decrease of stream power caused by that deposition), increasing the likelihood of channel avulsions in erodible materials along the river corridor.

5. Lack of access to floodplains and meanders for sediment storage means that nutrients are being transported downstream and out of the Tweed River watershed.

6. Deposition of fine sediments is amplified at lower flows in overwidenened channels, with potential negative habitat quality impacts for Tweed and White River fisheries in particular (USDA-FS 2001)

The primary constrictions (and thus sources of sediment transport discontinuity) evidenced in Phase 2 assessment were at undersized bridges and culverts. Dredging and bar scalping have been practiced extensively in the Project area as well, and it is possible that significant deposition may be occurring at overwidened channels resulting when wider, shallower channel geometry has decreased stream power sufficiently to facilitate sediment deposition and rapid refilling of pools and excavations (see Appendix 5).

Given the: a) extensive degree of encroachment throughout the Project area; b) maintenance of highly-valued agricultural resources along the river corridor in the lower reaches of the mainstem in particular; and c) legacy of historical impacts from the railroad (Fig. 3), restoration of floodplain access will be a critical but highly challenging component in reestablishing equilibrium conditions along the Tweed and its tributaries. Identification of attenuation assets (Table 8) to accommodate high flows and sediment deposition would include areas where the river can be allowed to reestablish meanders (rather than being channelized) as well as access the floodplain (which can help not only sediment storage but nutrient retention as well, as evidenced by the fertility of alluvial soils). Although some prospects exist in most reaches of the Project area, opportunities are likely limited in the upper reaches of the mainstem Tweed (upstream of the West Branch confluence (Lower Michigan Rd.), including reach T6.03 up) and along the West Branch due to road and development encroachments (Fig. 16; Table 8). The downstream segment (T6.01-S3.01A) of Guernsey Brook and all the downstream reaches on the mainstem Tweed are particularly important to consider in terms of attenuation assets (Table 8).

5.2 SENSITIVITY ANALYSIS

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain the sediment regime departure currently existing in Tweed River corridor planning Project area. 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 ANR 2007 Protocols, 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.

Alteration of sediment and flow regimes have converted all Project area reaches to transport reaches, and erodible boundary conditions (particularly on banks) and high levels of current aggradation in most reaches are indicative of high to extreme sensitivity in all reaches and segments (Fig. 17). Stream type departures (indicating a change from the reference-type channels indicated by Phase 1 analysis) were indicated for 9 of 19 river segments assessed in Phase 2, converting all but one of these to F (highly entrenched and overwidened) stream types. Segment T6.04B indicated a C to B stream type departure (moderately entrenched). This is indicative of the loss of floodplain access, with attendant increased stream power impacts, that is a major contribution to elevated stream sensitivity.

Although the lack of floodplain access has currently converted Project area reaches to a transport regime, the high sediment load and high sensitivity of the reaches indicate good possibilities for success of passive geomorphic projects, which would allow the river to utilize its own energy and watershed inputs to reestablish its meanders, floodplains, and self maintaining equilibrium conditions over time. It should be noted, however, that given the erodible banks of the river and relatively coarse bed materials, continued planform change in these areas will likely entail elevated erosion. Providing ample room for these processes to occur will be a critical aspect of restoration efforts. Efforts to curtail these processes through bank armoring or similar efforts will arrest these evolution processes (although this is likely to be temporary) and could dramatically delay reestablishment of equilibrium conditions.

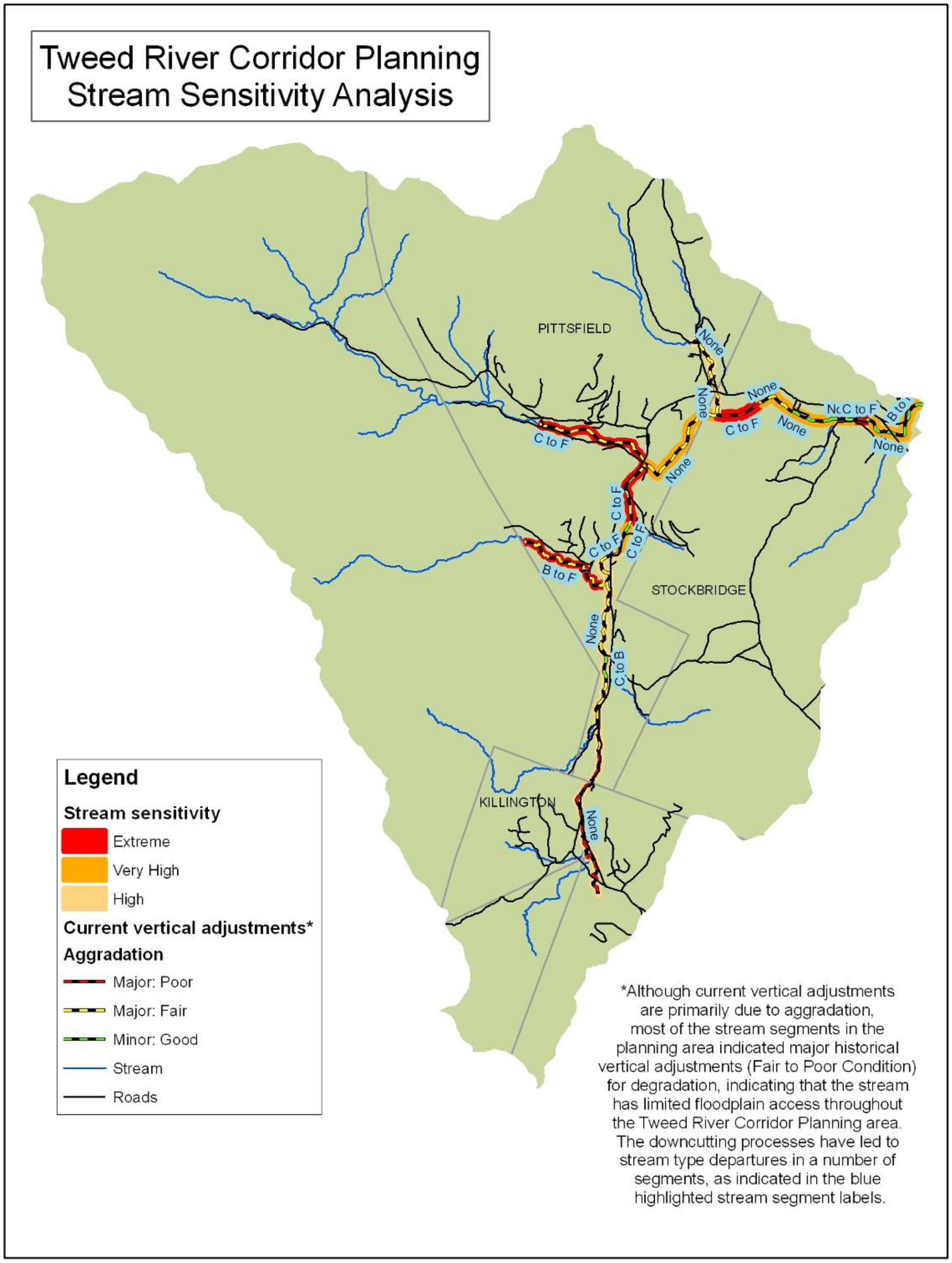


Figure 17. Sensitivity analysis: Stream sensitivity and current adjustment map for the Upper White River Corridor Project planning area.

6.0 PRELIMINARY PROJECT IDENTIFICATION

The preceding departure and sensitivity analysis provides the watershed and reach-scale background to inform prioritization and selection of projects in a manner that maximizes their effectiveness and reduces the likelihood of failure, specifically by assessing underlying causes of channel instability. With the information from these maps and tables, a stepwise process has been conducted to identify the following actions, in order of priority, in a manner designed to facilitate restoration of the stream to equilibrium conditions (VT ANR RCPG 2007, Ch. 6; chapter number is included here with the step):

6.1. Protecting river corridors

6.2. Planting stream buffers

6.3. Stabilizing stream banks

6.4. Arresting headcuts and nick points

6.5. Removing berms and other constraints to flood and sediment load attenuation

6.6. Removing/replacing structures (e.g., undersized culverts, constrictions, low dams)

6.7. Restoring incised reaches

6.8. Restoring aggraded reaches

As indicated in Section 5.2 of this report, the high to extreme sensitivity of all reaches in the Tweed River Project area indicates that passive geomorphic projects, particularly given the high sediment load of the Tweed and its tributaries, is generally an appropriate management alternative in the Project area. Encroachment issues are commonplace, however, placing a particularly high priority, throughout the Project area, on the first item identified in the stepwise procedure. Planting stream buffers should also receive a high priority, as there appears to be a strong relationship in the Project area between extent of vegetated cover and erosion impacts (see Section 5.1.3c, Boundary Conditions and Riparian Modifiers). The third item, stabilization of stream banks, is generally not recommended due to vertical instability in all reaches and continuing widening in channel evolution processes, increasing the likelihood of failure of such efforts, as well as escalating maintenance costs. This recommendation needs to be carefully assessed with regard to site-specific recommendations and critical infrastructure. It should be stressed again, however, that the current conversion of all Tweed River Project area reach sediment regimes to transport types means that further armoring of banks or bed will likely intensify downstream deposition and flooding impacts.

Bed materials are somewhat resilient to erosion, although one headcut was documented in Phase 2, and the gravel materials aggrading in many reaches are likely to be more sensitive than the cobble sediments that would characterize these reaches under reference conditions. The deeply incised nature of the Tweed and the assessed reaches of its tributaries makes Step 6.4 an item to be regularly assessed, as further downcutting of the channel could initiate further channel adjustments and delay establishment of equilibrium conditions.

6.1 REACH DESCRIPTIONS—PRELIMINARY PROJECT IDENTIFICATION

With these overarching considerations, preliminary project identification for the Tweed River Project area is presented on a reach-by-reach basis in the following pages. "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 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). WRP project areas along the river in the first (furthest downstream) reach and along the nearby portions of the Upper White are also indicated. Background imagery for the reach maps is from the National Agricultural Imagery Program (NAIP), primarily dated 2003. NAIP imagery from 2006 (which is a preliminary release and has not undergone rigorous quality assurance procedures) was used for Tweed mainstem reaches T6.03 and T6.04 (to include recent development impacts that were not present in 2003) and T6.01-S3.01 (Guernsey Brook), where cloud cover in the 2003 photography obscured much of the river corridor area.

6.1.1 Preliminary project identification: Reach T6.01—Tweed River mainstem, White River confluence to Guernsey Brook confluence

Reach T6.01 is the furthest downstream reach within the Project area, extending roughly 14,000 ft (2.6 mi) from just above the confluence with the White River in Stockbridge upstream to the Guernsey Brook confluence (Fig. 18). This gravel-dominated reach was divided into seven segments based on differences in stream type, corridor encroachments, planform and slope, banks and buffers, and depositional features. The majority of the reach has experienced extensive historic straightening (see Fig. 3 in Section 3.2, depicting the effective pinning of the river against the valley wall by the Lumber Railroad) and has a low to moderate sinuosity; riprap is common in the downstream portions of the reach. Erosion is prevalent, even in areas where riprap is present, and is moderate to extensive in segments C, E, and G, where vegetated buffers are minimal or lacking along agricultural lands in the corridor.

The reach map and Projects and Practices Table have been divided into two sections due to the length of the reach and extensive segmentation. The reach map in Fig. 18 covers segments T6.01A–D, and is followed by the narrative summaries and the Projects and Practices Table for these segments. The reach map (Fig. 19), narrative summaries, and Projects and Practices Table for segments T6.01E–G follow subsequently.

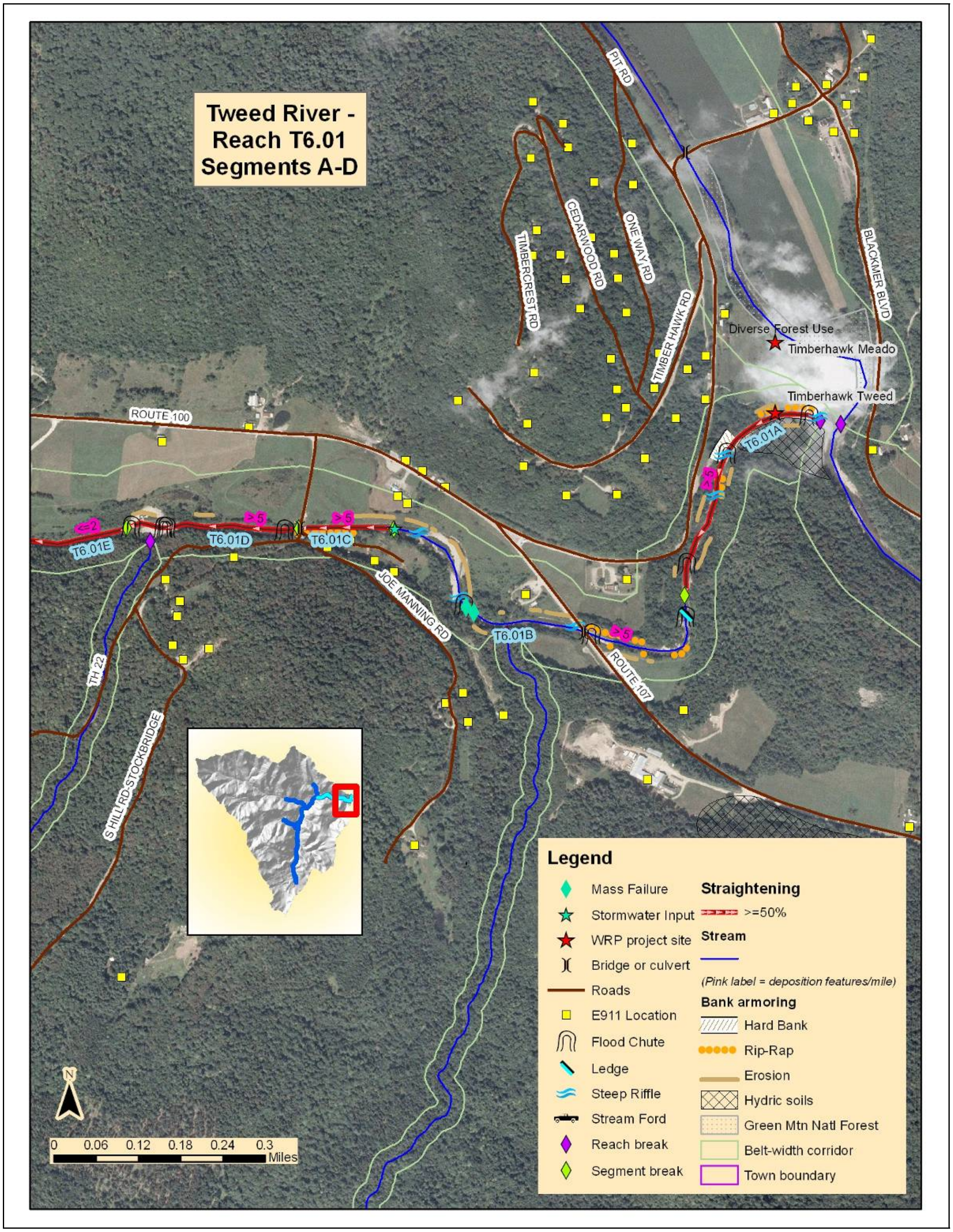


Figure 18. Tweed River reach T6.01, segments A–D.

Segment T6.01A, covering 1415 ft (0.27 mi) from the White River confluence to a popular swimming hole and bedrock outcrop on the upstream end, shows signs of significant historical impacts featuring two breeched sluice dams and additional old stone abutments and walls (none of which were identified in Phase 2 assessment as significant current constrictions or grade controls). Phase 2 measurements showed a stream type departure from a Bc channel to a deeply entrenched and overwidened F channel, with an incision ratio of 2.7 indicating lack of floodplain access and extensive bank armoring and erosion as indicators of increased stream power impacts. A semiconfined valley setting is the result of a significant narrowing of valley width by the encroachment of Rte. 100 along the left bank in conjunction with steep valley walls on the right bank, indicating that this segment will likely need to be managed toward a Bc type stream for equilibrium conditions rather than the C type (with Very Broad confinement) originally assigned in the Phase 1 assessment. Bank and buffer vegetation was generally good except in areas where Rte. 100 encroaches heavily on the left bank. Numerous deposition features and multiple flood chutes were indicative of significant aggradation and planform change, although Phase 2 scores indicated only "minor" current adjustments in this segment. Movement of sediment "slugs" through upstream portions of the river suggest that these adjustments may be likely to increase over time, exacerbating erosion impacts in particular, and strongly suggest that even the relatively limited opportunities to attenuate flow and sediment impacts in this segment are important to protect. The WRP implemented the Timberhawk Tweed project in this segment, planting a 400-ft buffer and installing instream fish habitat enhancement structures as part of the project.

Segment T6.01B includes roughly 3150 ft (0.6 mi) from the swimming hole continuing upstream past the Rte. 107 bridge to a stormwater input behind the Stockbridge post office. The Broad valley confinement is wider here than downstream, but still sufficiently narrowed by encroachment from both Rtes. 100 and 107 to change the Phase 1 Very Broad confinement assessment. Phase 2 measurements indicate that the stream channel remains a C riffle pool system, likely due to the presence of ledge grade controls in the reach, although an incision ratio of 1.9 still indicates significant loss of floodplain access. Heavy erosion, particularly along hayfields on the left bank where bank and buffer vegetation was reduced or lacking, and three mass failures were contributing sediment to the substantial deposition documented in the reach. Flood chutes located near channel constrictions at the Rte. 107 bridge and downstream bedrock outcrops were indicative of planform change occurring in conjunction with the significant aggradation.

Segment T6.01C is a short reach extending 850 ft (0.16 mi) from behind the Stockbridge post office to the upstream end of the South Hill Rd. bridge. Despite a Very Broad valley confinement type, an incision ratio of 2.0 again indicates loss of floodplain access, and Phase 2 assessment indicated a stream departure from a reference C type to an entrenched F-type stream. There is significant erosion along much of the left bank at the edge of agricultural fields lacking any woody buffer vegetation. The right bank corridor is dominated by residential development, again lacking substantial woody vegetation in the riparian buffer zone, and the bank has been extensively armored on that side. Significant widening and aggradation were documented in the reach, and limited planform change within the reach appears to be manifesting as elevated levels of erosion on the left bank, since nearly half of the right bank is armored.

Segment T6.01D extends roughly 1400 ft (0.27 mi) from the South Hill Rd. bridge to a large area of aggradation just above a small tributary confluence on the right bank. Road encroachment from South Hill Rd. on the right bank and Rte. 100 on the flanks of the left bank valley has narrowed the valley and floodplain width, and an overwidened channel (with a high width:depth ratio of 35) now exists in a semi-confined setting due to the ratio of this overwidened channel to the narrowed valley. A relatively low incision ratio of 1.4 and retention of access to floodplain may be related to rapid channel evolution featuring high erodibility of the banks in comparison with the bed and lack of constraints to evolution (Phase 2 noted indications that the segment was more armored in the past). Although field assessment did not note an alluvial fan, delta deposits, or tributary rejuvenation from Brown Brook on the upstream end of this segment, substantial deposition at the base of this tributary appears to be augmenting the function of this segment as a highly valuable sediment attenuation asset for upstream reaches in the watershed (Fig. 18). The segment is dominated by the White's hayfields on the left bank, with minimal woody vegetation in a 5- to 25-ft buffer on that bank.

Table 9. Tweed River Reach T6.01A–D, Projects and Practices Table, used throughout the stepwise project identification process (VT ANR RCPG 2007, Ch. 6 step numbers) to catalogue projects, indicate a priority for each project, and list the next steps suggested in developing the project.

River segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.01A (1,2,3)	Protect river corridor	High	Low	Y	Limited but important opportunities (Timberhawk/tennis courts—educational signage; RB hydric)
T6.01A (4)	Plant stream buffer	High	Low	Y	Primarily augmentation. Further measures need watershed strategies (>5 yrs)
T6.01B (1,2,3)	Protect river corridor	High	High	Y	Limited but important opportunities – ag lands
T6.01B (4)	Plant stream buffer/fencing?	High	High	Y	Low cost, very high sensitivity, grade controls = elevated bank impacts Further measures need watershed strategies (>5 yr): reduction of stream power (includes Rte. 107 bridge – replacement impacts land uses in corridor)

River segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.01C (1,2,3)	Protect river corridor	High	High	Y	RB already developed
T6.01C (4)	Plant stream buffer/fencing?	High	High	Y	Low cost: extreme - sensitivity, high erosion Further measures need watershed strategies (>5 yr): reduction of stream power (includes S. Hill bridge constriction—replacement impacts land uses in corridor)
T6.01D (1,2,3)	Protect river corridor	High	High	Y	Ag lands; valuable attenuation asset
T6.01D (4)	Plant stream buffer/fencing?	High	High	Y	Low cost: very high sensitivity, high erosion Further measures need watershed strategies, but segment may play vital role in those strategies

Segment T6.01E continues upstream 2665 ft (0.5 mi), past the White farm fields to the upstream end of a development dubbed “the A-frame village”, which includes a number of units within the extent of the recently abandoned floodplain (Fig. 19). The stream is still maintained against the valley wall in this portion of the reach, and an incision ratio of 1.9 indicates loss of floodplain access related to the increased stream power of channelization and straightening. Road and development encroachment have helped change the valley confinement from Very Broad to Broad, and the residential land use (as well as some areas of agricultural lands) contributes to the minimal to absent vegetated buffers documented on the left bank of the segment during Phase 2 assessment. The steep slopes above the right bank are forested, with reference buffer conditions, and overall erosion levels in the segment appear low. Lack of distinct depositional features in the segment was surprising given the significant aggradation in the reach overall, as well as assessment scores that indicate the segment is aggrading. Plane bed features were noted throughout the segment (with the exception of bedrock-formed scour pools), leaving questions as to whether the segment has been dredged. Dredging and bar scalping have been practiced extensively in the Tweed watershed, but exact locations are undocumented (pers. comm., Frederick Nicholson, VT River Mgmt. Program Stream Alteration Engineer).

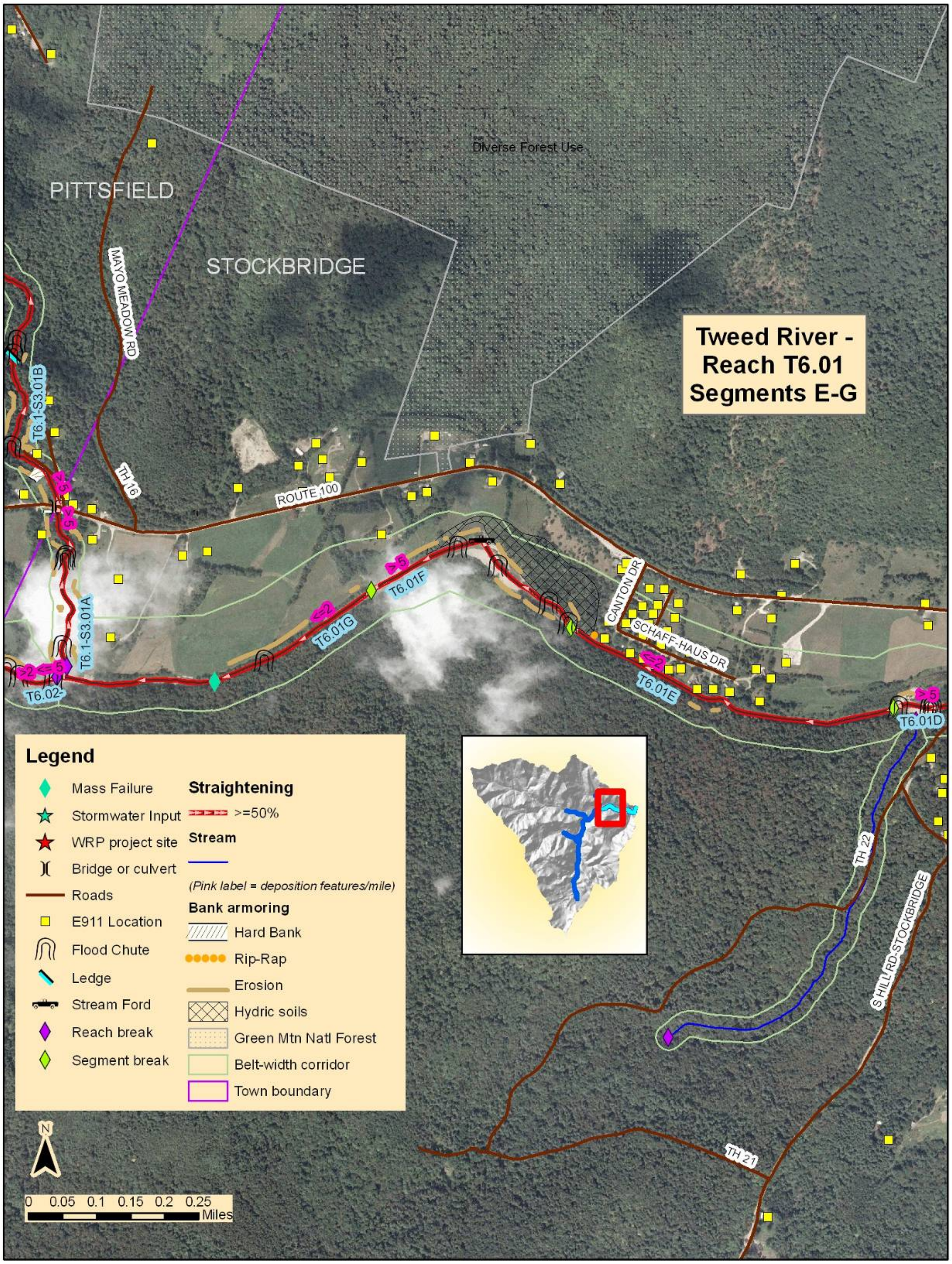


Figure 19. Tweed River reach T6.01, segments E–G.

Segment T6.01F extends roughly 2115 ft (0.4 mi) from upstream of the A-frame village to a point where the right valley wall begins to pinch the stream corridor. Although the valley is relatively wide in this portion of the reach, an overwidened channel in conjunction with road and development encroachments that narrow the valley width yield a confinement ratio indicating a Broad valley rather than the reference Very Broad type. This segment marks the first area upstream of the confluence with the White where the Tweed mainstem departs from the right valley wall to any significant extent. During 2006 Phase 2 assessments, a stream ford was being constructed midsegment to access forest lands across the river, and water diversions, channel braiding, and slackwater pools were noted due to the movement of gravel and cobbles for construction. Despite an incision ratio of 2.0, Phase 2 measurements still show a C-type stream with access (though diminished) to floodplain. Heavy erosion was noted on both banks, along with significant aggradation. Channel measurements indicated major overwidening (width/depth ratio of 41.8), and plane bed features were dominant in the reach, with sedimented riffles and multiple flood chutes forming in areas of aggradation. Minimal bank cover (1–25% bank canopy) on both banks was noted, with residential and agricultural land use on the left bank contributing to lack of buffers (0–25 ft) as well. A combination of pasture and forest land on the right bank reduced buffer widths (to 26–50 ft) on that side as well.

Segment T6.01G, the most upstream segment of the reach, covers 2660 ft (0.5 mi) from the point where the valley wall begins to pinch the stream corridor up to the confluence of Guernsey Brook. The stream is back against the valley wall in this segment, and encroachment is again significant enough to change the valley confinement type from Very Broad to Broad. An incision ratio of 1.6 may indicate less recent degradation than in other downstream segments in the reach, with bedrock noted as a dominant material on the right bank, but no channel-spanning grade controls were recorded. The relatively low incision ratio indicates that the recently abandoned floodplain may be accessed more easily in this section of the reach than in some of the other segments. Phase 2 measurements indicated a stream type departure from a C to an F type stream, however, indicating an entrenched and overwidened stream segment that has lost significant access to floodplain. Heavy erosion on the left bank indicates where the majority of widening is occurring, and all distinct depositional features noted in the segment were side bars. A mass failure mid-segment contributes to heavy overall aggradation and plane bed features noted in the segment. Although no headcuts were noted in Phase 2 fieldwork, the high sediment load of fine materials being contributed by the mass failure and tributary rejuvenation from Guernsey Brook are likely to quickly “wash out” distinct signs of degradation.

Table 10. Tweed River Reach T6.01E-G Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.01E (4)	Plant stream buffer	High	Low	Y	Very high sensitivity, minor current adjustments Further measures need watershed strategies (>5 yr)
T6.01F (1,2,3)	Protect river corridor	High	High	Y	Ag lands: attenuation asset
T6.01F (4)	Plant stream buffer/fencing?	High	High	Y	Low cost: very high sensitivity, major current adjustments Further measures need watershed strategies (>5 yr)
T6.01G (1,2,3)	Protect river corridor	High	High	Y	Ag lands: attenuation asset
T6.01G (4)	Plant stream buffer/ fencing?	High	Low	Y	Low cost: extreme sensitivity, high erosion Further measures need watershed strategies first: reduction of stream power

6.1.2 Preliminary project identification: Reach T6.02—Tweed River mainstem, Guernsey Brook confluence to West Branch confluence

Reach T6.02 comprises 6195 ft (1.2 mi) of the mainstem Tweed between the Guernsey Brook confluence and the confluence of the West Branch of the Tweed (Fig. 20), and marks the historic extent of the Lumber Railroad along the mainstem, as the railroad continued along the West Branch upstream of this reach. The reach was not segmented during Phase 2 assessment. As with the rest of the river along the old Railroad, this reach is extensively straightened and maintained against the valley wall for much of its length. Impacts of increased stream power due to channelization are evidenced as historical downcutting (incision ratio 1.6) followed by current aggradation, with widening and planform adjustments that feature moderate to extensive areas of bank erosion that are more prevalent on the left bank. Corridor encroachments have a moderate impact but are concentrated in the upstream portion of the reach in Pittsfield village, beginning with outbuildings below the Stanley Tool plant facilities. Phase 2 assessment thus indicated that the Very Broad valley confinement has not been significantly altered except in the short portion of the stream below the confluence of the West Branch, where channelization and the valley wall combine to force the stream into a pair of right angle turns and encroachments are in close proximity to the stream. Despite loss of some floodplain function indicated by the incision ratio, the stream in this reach still accesses sufficient floodplain to function as a C-type stream, with riffle-pool features and a gravel-dominated substrate. A series of flood chutes just upstream of the Guernsey Brook confluence were indicative of planform adjustment and likely indicate the importance of this area as a potential attenuation asset. Buffer vegetation was generally adequate to good, with some developed areas along the left bank lacking vegetated buffers (<25 ft) in the upstream portion of the reach.

Table 11. Tweed River Reach T6.02 Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.02 (1,2,3)	Protect river corridor	High	High	Y	Ag lands: attenuation assets—particularly upstream of Guernsey Brook confluence
T6.02 (4)	Plant stream buffer/fencing?	High	High	Y	Upstream; low cost: very high sensitivity, major current adjustments Further measures need watershed strategies (>5 yr)

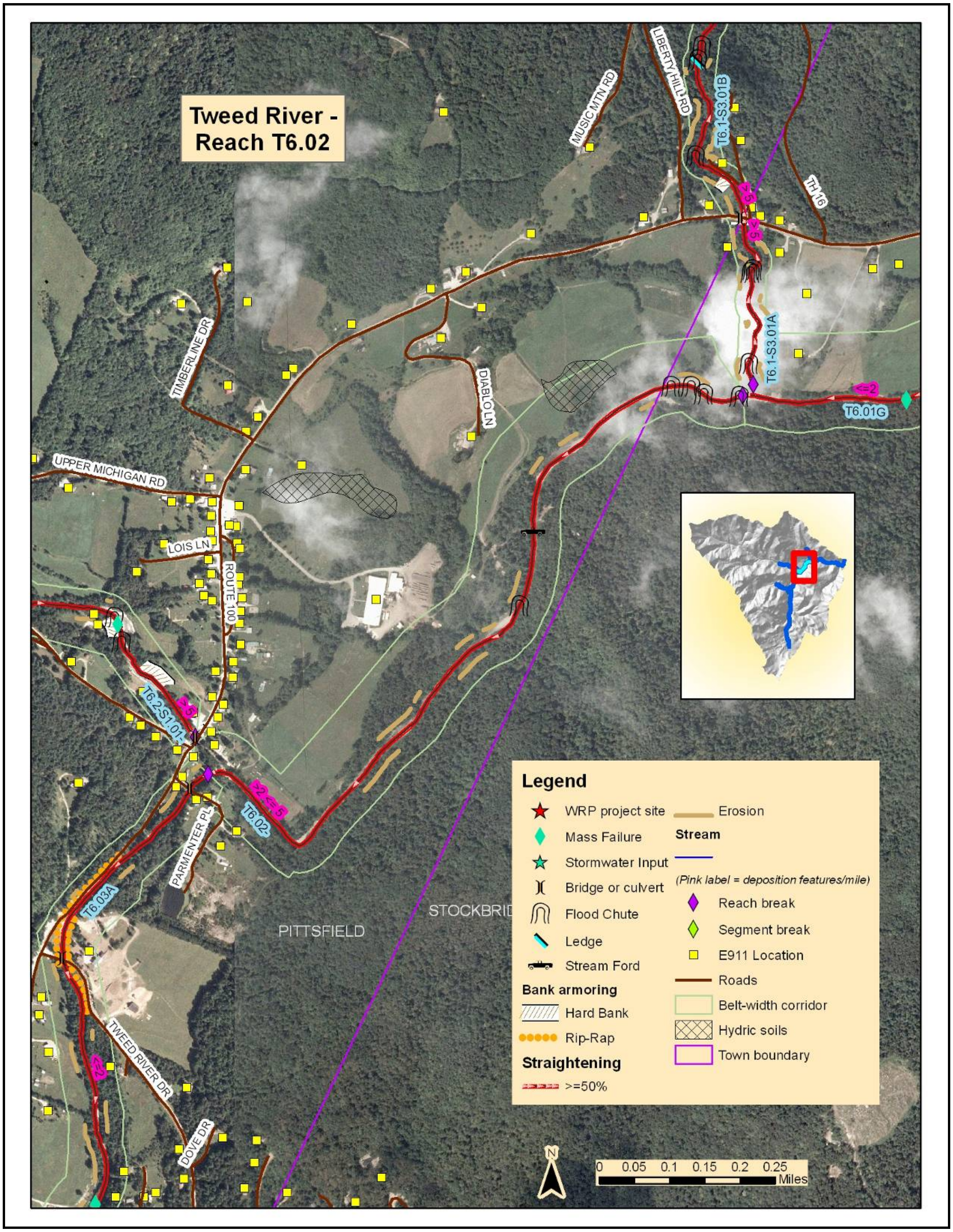


Figure 20. Tweed River reach T6.02.

6.1.3 Preliminary project identification: Reach T6.03—Tweed River mainstem, West Branch confluence (Pittsfield village) to Townsend Brook confluence

Reach T6.03 covers roughly 8350 ft (1.6 mi) of the mainstem Tweed between the West Branch confluence in Pittsfield village and the confluence of Townsend Brook (Fig. 21). This is the first reach upstream of the historic extent of the Lumber Railroad, and it was broken into three segments during Phase 2 based on differences in flow status, slope, and planform. The two downstream segments are extensively straightened and encroachment is prevalent through all portions of the reach. Road and development encroachment is sufficient to change the valley confinement type from Very Broad to Broad in T6.03C, the furthest upstream segment, and effectively bottlenecks the river between the base of Tweed River Drive and the left bank valley wall in segment T6.03A (Fig. 21). Historical maps (Fig. 3) indicate that the Tweed River Drive encroachment is a long-standing confinement that forces the river across the valley to the opposite wall but it appears likely that the road approach to Route 100 has been relocated farther south, further restricting potential access of the river to former floodplain. Development in the floodplain in the area of Parmenter Place just downstream of this area has increased but appears on historical maps dating to 1917 as well (Fig. 3) and would likely be at risk if the river were to access this floodplain (Fig. 21).

The three segments appeared to be evidencing different stages of channel evolution, with downstream segment T6.03A still in between the downcutting processes that dominate Stage II and the subsequent widening and aggradation processes that evolve during stage III. The upstream segments were further along in stage III, with sediment slugs contributing to heavier current aggradation in T6.03C. Multiple flood chutes below the confluence of Townsend Brook in segment T6.03C and multiple mass failures on Townsend Brook indicate that tributary rejuvenation is contributing significant amounts of sediment in this section of the river that are being moved downstream in high flows (Fig. 21). All three segments were noted as highly entrenched F-type streams in the Phase 2 assessment, a stream type departure from the expected reference C-type channels, and high incision ratios of 2.0 in T6.03A, 2.9 in T6.03B, and 2.7 in T6.03C were noted. The combination of deep incision, overwidened channels, extensive erosion along both banks, and the presence of a long portion of windrowed stone along the banks in segment T6.03A indicate that historical dredging practices may have been prevalent in this portion of the mainstem (dredging has been noted historically in many portions of the Project area, with exact locations undocumented; pers. comm., Frederick Nicholson, VT ANR-RMP Stream Alteration Engineer, November 2007). The combination of these factors indicates that this area may play an important role as an attenuation asset, and it is likely that under current conditions this portion of the watershed marks an area where passive or active project implementation might be reasonably expected to achieve relatively rapid results in comparison with downstream sections where results are likely to be more dependent on previous remediation of upstream impacts before channel evolution processes begin to move toward equilibrium conditions. Opportunities are significantly constrained by existing development, however, and will require careful review for implementation options; midportions of the reach will likely offer the best opportunities.

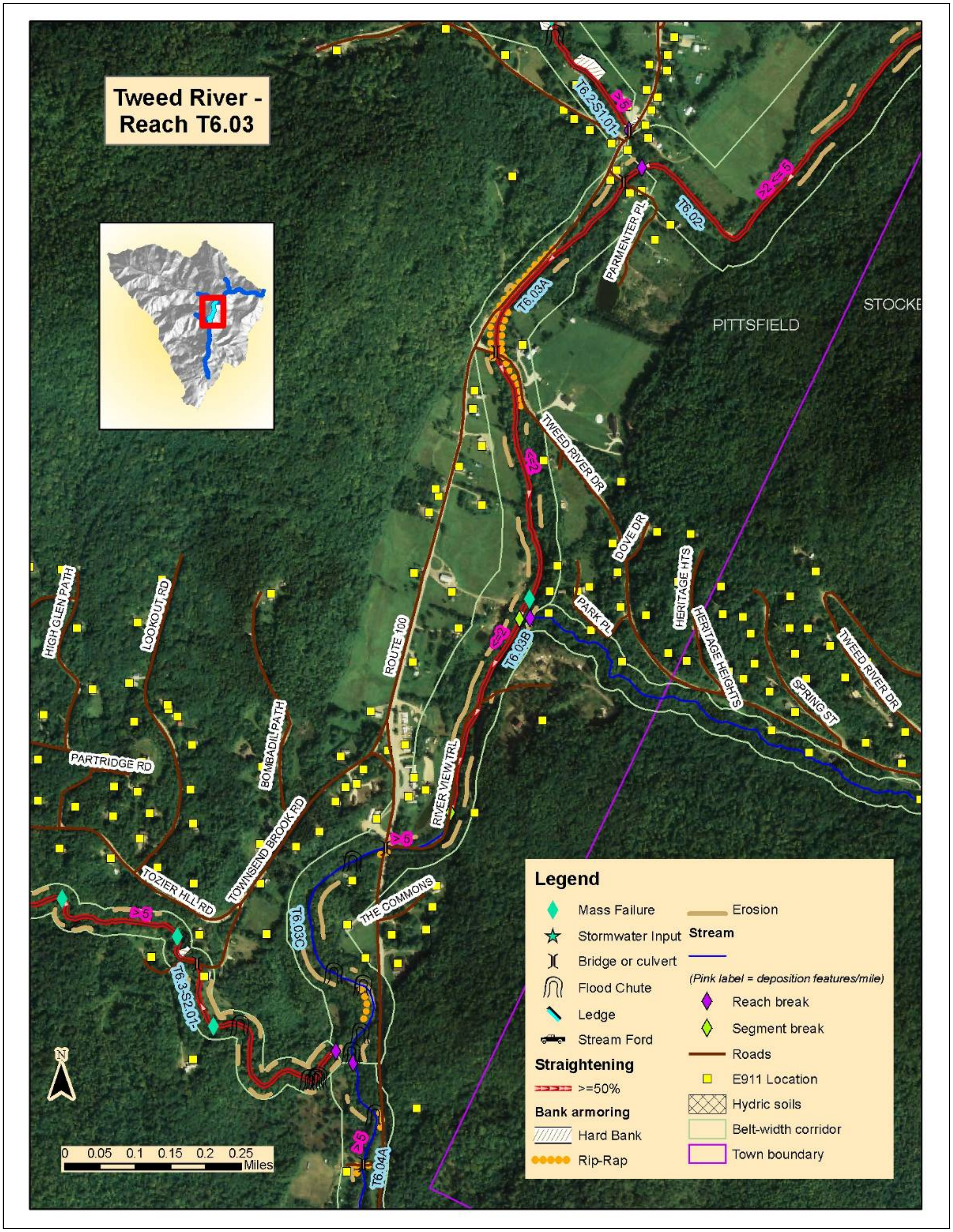


Figure 21. Tweed River reach T6.03 (NAIP 2006 background imagery).

Segment T6.03A, marked by extensive encroachment and a right angle turn in the river at the base of the West Branch in Pittsfield village, was the longest of the three segments into which the reach was split in Phase 2, comprising roughly 3926 ft (0.74 mi) at the downstream end of the reach. Dominant buffers in segment T6.03A were less than 25 ft on the left bank and 26–50 ft on the right bank. Although downcutting was a dominant current adjustment process in the segment, no active headcuts were documented during fieldwork. This portion of the stream lacks any natural grade controls, however, and boundary materials are highly erodible on both bed and banks. With substantial tributary rejuvenation being noted from further upstream at Townsend Brook, it appears likely that the lack of headcuts may be due to high bed load sensitivity and rapid “washing out” of these indicators of incision. A substantial portion of the banks are armored in the midsection of the segment near Tweed River Drive. Three bridges in this segment were all noted as floodprone constrictions, but only the upstream two were noted in Phase 2 fieldwork as channel constrictions with evidence of geomorphic incompatibilities contributing to deposition above the structures and scour both above and below. It should be noted, however, that the bridge (at Parmenter Place) showing no signs of geomorphic incompatibilities was replaced in 1995 and measures roughly 85% of the reference channel width and 70% of the overwidened channel width documented in Phase 2. Information on whether sediment was removed at the time of the replacement was unavailable. Replacement of the older bridges upstream would need to be evaluated carefully for possible impacts to development within the corridor due to the possibility of channel bed elevation changes and/or lateral bank instability.

Table 12.Tweed River Segment T6.03A Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.03A (4)	Plant stream buffer/fencing	Low	Low	Y	Opportunities limited due to encroachment; low cost: extreme sensitivity, major current adjustments
T6.03A (34)	High-priority river corridor protection at downstream reach; restore incised reach with bed forms and floodplain features in equilibrium with increased stream power	Low	High	Y	Opportunities limited due to encroachment, may become more feasible with repeated conflicts Should be tied to watershed strategies

Segment T6.03B was the shortest of the three segments delineated in this reach during Phase 2, covering roughly 1565 ft (0.30 mi) in the midportion of the reach. This segment is straightened along its entire length and showed extensive erosion along both banks. Dominant buffer widths were <25 ft on the left bank. On the right bank, the steep valley wall against which the river is pinned is largely wooded, but dominant buffer widths were recorded at 50–100 ft, largely due to encroachment from a road leading to a number of house lots that have been developed on this valley wall between 2003 and 2006 (Fig. 22).

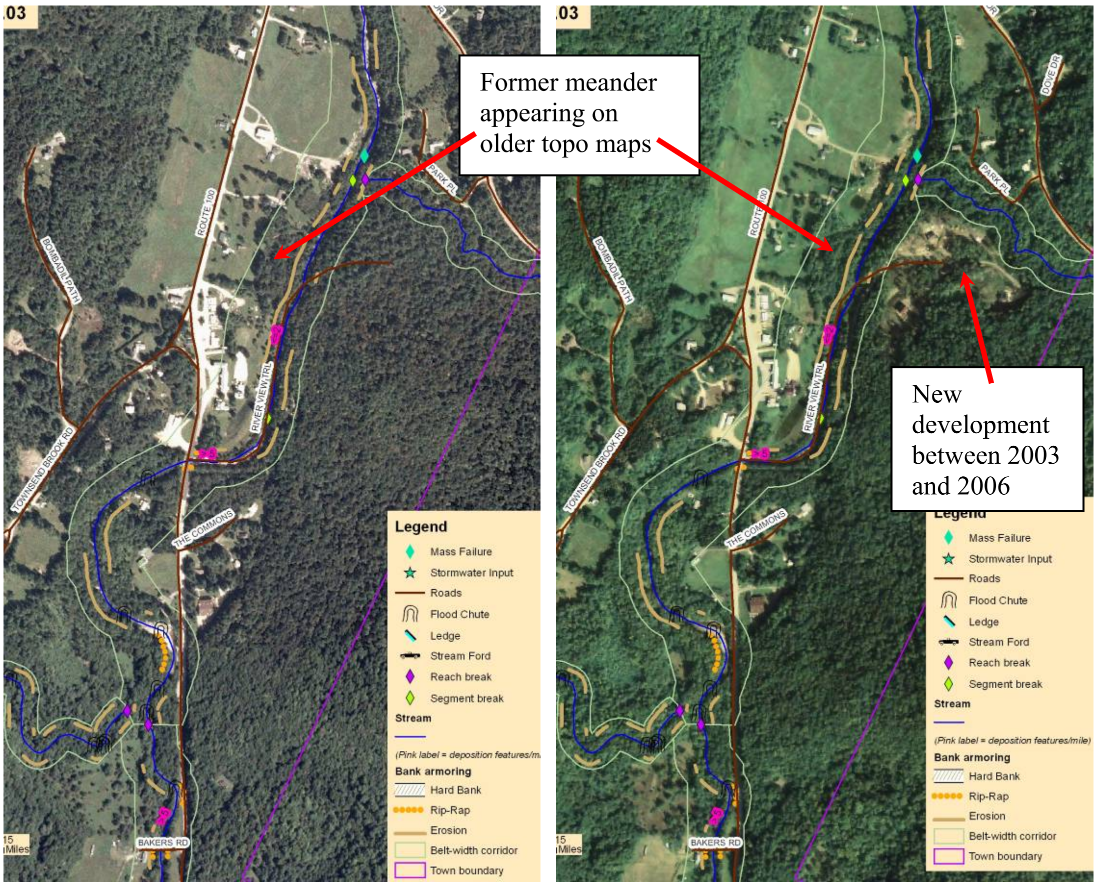


Figure 22. Aerial photography from 2003 (left) and 2006 (right) indicates new development on the steep valley wall southeast of the confluence of the Tweed mainstem and an unnamed tributary in the upper right corner of these photos. Phase 2 field notes and older topographic maps (Fig. 31) indicate a former island and meander just west of this location. Restoring this meander could provide sediment attenuation and help diffuse increased stream power contributing to lateral bank instability in this area.

Field notes from Phase 2 assessment indicated that the segment was unusual in exhibiting good riffle-pool features and a relatively low width/depth ratio (25.3) despite being highly entrenched and incised, with a C- to F-type stream departure denoting the change from reference conditions. Further field notes indicated that topographic maps showed an island with active stream channels on either side of it downstream of the Clearwater Tavern in this segment, but that one of the channels was abandoned and functioning only as a flood chute despite rain within a week prior to the assessment (Fig. 22). An F-type stream is usually overwidened in addition to being entrenched, and it is possible that the low width/depth ratio may be related to the abandonment of the former channel. While it is difficult to determine without documentation, the prospect that this area has been dredged or actively straightened in the past appears to be a distinct possibility. The segment was noted as having no sediment storage in bars (depositional features that might be expected under reference conditions in a segment of this length), and the increased stream power of a narrower and deeper single channel would contribute to the eroded riffle types and extensive erosion documented in the segment during the Phase 2 assessment. With substantial deposition and tributary rejuvenation upstream of this segment (Fig. 9), the riffle-pool features documented may indicate rapid “washing out” of headcuts and nickpoints resulting from increased stream power, with rapidly shifting depositional features now in evidence. The extensive erosion in the segment and the presence of a mass failure just below the confluence of the tributary at the beginning of the next stream segment downstream indicate that reaccessing the former meander off the left bank could help diffuse stream power that may eventually contribute to lateral bank instability below the road leading to the new development above Riverview Trail on the right bank. Encroachment makes such a project unlikely at the current time, however.

Table 13. Tweed River Segment T6.03B Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.03B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited but important, may become more feasible with repeated conflicts
T6.03B (4)	Plant stream buffer	Low	Low	Y	Opportunities limited due to encroachment; low cost: very high sensitivity, major current adjustments
T6.03B (32)	Restore incised reach to abandoned channel	High	High	Y	May need to address hydraulic changes

Segment T6.03C represents the upstream 2858 ft (0.54 mi) of the reach and extends just upstream of the confluence with Townsend Brook. The river exhibits a more meandering nature in this segment than in the downstream portions of the reach, but appears to be maintained in position in relation to Rte. 100, several houses perched on the banks of the river, the Rte. 100 bridge at the south end of Pittsfield village, and River View Trail (Fig. 21). Buffer widths are diminished to a dominant 26–50 ft width on the right bank, primarily due to road and development encroachments, making planting conditions difficult. These encroachments and their relationship to the valley walls currently present strong lateral constraints to channel evolution or the possibility of reestablishing equilibrium conditions in this portion of the river. Significant deposition in the reach indicates that this section of the river could play a role as an attenuation asset, but these possibilities are currently unlikely due to these constraints. The Rte. 100 bridge was noted as both a floodprone and channel-width constriction not aligned well with the river, with both deposition and scour noted above and below the structure, and contributes to the maintenance of the river against opposite valley walls upstream and downstream of the structure. With the deposition noted and considerable encroachments near the structure, outflanking of this bridge under flood conditions is of significant concern, but replacement of the structure would need to be considered carefully for the possibility of channel bed elevation changes and/or lateral bank instability.

Table 14. Tweed River Segment T6.03C Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.03C (1,2,3)	Protect river corridor	High	High	Y	Opportunities currently unlikely, may become more feasible with repeated conflicts
T6.03C (4)	Plant stream buffer	Low	Low	Y	Opportunities limited due to encroachment; low cost: high sensitivity, major current adjustments
T6.03C (34)	High-priority river corridor protection at downstream reach. Restore incised reach with bed forms and floodplain features in equilibrium with increased stream power	High	High	Y	Upstream portion and downstream of bridge; opportunities limited due to encroachment, may become more feasible with repeated conflicts

6.1.4 Preliminary project identification: Reach T6.04—Tweed River mainstem, Townsend Brook confluence to Johnson Brook confluence

Tweed mainstem reach T6.04 extends roughly 6156 ft (1.17 mi) from the Townsend Brook confluence to just upstream of the Johnson Brook confluence (Fig. 23). The reach was divided into two segments during Phase 2 assessment, with downstream segment T6.04A indicated in stage III channel evolution evidenced by widening, aggradation, and planform change following historic incision. Upstream segment T6.04B was assessed to be in stage II, with fewer indications of channel evolution processes evident. Both segments were noted as B-type streams, a departure from the reference C stream type for both segments.

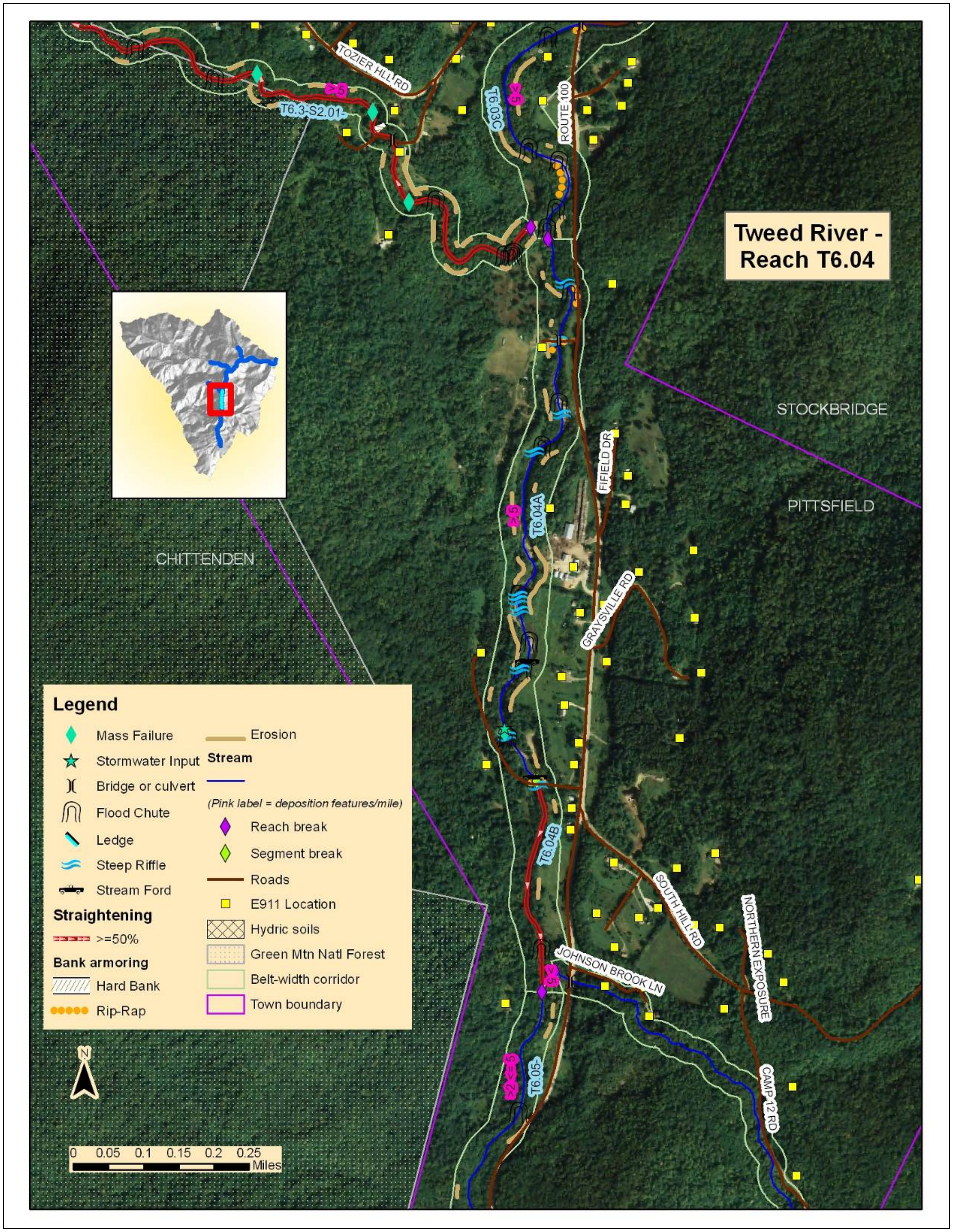


Figure 23. Tweed River reach T6.04 (NAIP 2006 background imagery).

Segment T6.04A comprises roughly 4500 ft (0.85 mi) in the downstream portion of the reach, extending to just below the bridge at Stonewood Crossing (across the Tweed from the base of South Hill Rd.; Fig. 23). The segment is characterized by a patchwork of former small fields and pasture, now largely converted to commercial (dominated by Colton Enterprises firewood processing and kiln drying operations) and residential areas with lawns and clearings intermixed with wooded lands along the narrowing upper reaches of the Tweed valley. Historical maps dating to 1893 (http://docs.unh.edu/VT/rutl93ne.jpg) indicate that the river has been maintained in a straightened condition alongside Rte. 100 for more than 100 years, and a B- to C-type stream departure resulting from historic incision points out that the stream is now moderately entrenched. Dominant buffer widths on the right bank ranged from 26–50 ft, with a subdominant buffer width of <25 ft in some of the residential and field areas, and extensive erosion noted on both banks was prominent in areas lacking buffers. Encroachment levels of a moderate 5–20% of the segment were noted on each of the banks, but these encroachments are placed and spaced in a manner that makes project implementation challenging. Significant deposition in the segment was marked by numerous very steep riffles (nine steep riffles and eight flood chutes were documented in the segment) and two stream fords contribute to decreases in stream power that augment the depositional processes occurring in the segment. The bridge at Baker's Road (near the southwest corner of the Stockbridge town boundary; Fig. 23) was noted as both a floodprone and channel constriction, with deposition above and scour below the structure; the effective width for sediment transport is reduced (from a structure width of 32 ft) to 25 ft (roughly 50% of the channel width) by the angle of alignment with the stream. With significant hydrologic changes from stormwater inputs and substantial amounts of ledge and bedrock grade controls further upstream, this segment appears to have the potential to play a vital role as an attenuation asset relatively high in the watershed but is currently limited for such possibilities by corridor encroachments.

Table 15. Tweed River Segment T6.04A Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.04A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited by encroachment; valuable attenuation asset relatively high in the watershed
T6.04A (4)	Plant stream buffer	High	High	Y	Primarily low cost: high sensitivity, major current adjustments
T6.04A (24)	Replace structure	High	High	Y	Erosion/avulsion hazard and replacement appears consistent with evolution processes
T6.04A (34)	High-priority river corridor protection	High	High	Y	Throughout segment; opportunities limited due

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
	at downstream reach. Restore incised reach with bedforms and floodplain features in equilibrium with increased stream power				to encroachment, may become more feasible with repeated erosion/flooding conflicts

Segment T6.04B continues upstream from Stonewood Crossing (across from the base of South Hill Rd.; Fig 23), covering roughly 1600 ft (0.30 mi) to the reach break just above the Johnson Brook confluence. Similar to the downstream portion of this reach, this segment appears to have been maintained in a highly straightened condition for more than 100 years and now evidences significant loss of floodplain access reflected in a B- to C-type stream departure. Unlike the downstream segment, however, this portion of the stream shows less channel evolution in terms of planform adjustment in particular, with very little meander development evident. The segment was thus characterized as being in Stage II channel evolution, and a plane bed form despite significant boulder and cobble stream-bed components both reflects and contributes to the impacts of elevated stream power in this segment, further contributing to the transfer of hydrologic and sediment transport impacts to downstream portions of the watershed. Due to relatively low levels of encroachment, this segment appears to have potential as an attenuation asset, but the stream is moderately entrenched and the valley is narrowed by the presence of Rte. 100 and development just upstream of Stonewood Crossing in particular. Although the segment may have potential for an active restoration project, such a project is not currently recommended due to the high cost of implementation, increase of flood hazard risk downstream, and a relatively low yield of accessible floodplain.

Dominant buffers in segment T6.04B were <25 ft on the right bank but generally >100 ft on the left bank. Moderate levels of erosion (5–20% of the reach) were noted on the right bank, with low levels (<5%) noted on the left bank; encroachments were noted in <5% of the corridor in this segment. The bridge at Stonewood Crossing was noted as both a floodprone and channel constriction sized at roughly 50% of the Phase 2 bankfull width measurements, with deposition above the structure and scour below. Although some geomorphic inventory data was available for this structure at the time of this report, it is recommended that the data from the Bridge and Culvert Survey done on this structure be assembled for its value in contributing to town capital expenditures planning, as well as a fuller comprehension of the role this constriction plays in stream dynamics and fish and wildlife habitat provisions.

Table 16. Tweed River Segment T6.04B Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.04B (1,2,3)	Protect river corridor	High	High	Y	Attenuation asset relatively high in the watershed
T6.04B (4)	Plant stream buffer	High	High	Y	Primarily low cost: high sensitivity, major current adjustments
T6.04B (24)	Replace structure	High	High	Y	Erosion/avulsion hazard and replacement appears consistent with evolution processes
T6.04B (34)	Defer action on restoring incised reach	High	Low	Y	Possible active restoration, but likely yield of floodplain low and downstream flood hazards increase

6.1.5 Preliminary project identification: Reach T6.05—Tweed River mainstem, Johnson Brook confluence to roughly 1500 ft upstream of Hadley Ln. and 300 ft downstream of 232 Rte. 100 (Pittsfield historic marker for "old dance hall")

Reach T6.05 includes 4425 ft (0.84 mi) of the Tweed mainstem upstream of the Johnson Brook confluence (Fig. 24) and marks a significant transition in valley confinement, passing from the Broad valley type of reach T6.04 to a Narrow confinement type. Rte. 100 runs right along the stream for much of the reach, and this encroachment narrows the valley sufficiently to change the Broad valley confinement type that the reach would have under reference conditions. As in reach T6.04, historical maps indicate that the stream has been maintained in this straightened condition by the presence of the road for more than 100 years, and roughly 20% of the right bank is riprapped. Unlike reach T6.04, however, the narrow stream in this reach retains sufficient access to floodplain to be classed as a C-type stream due to a lower degree of entrenchment (a higher entrenchment ratio, i.e., floodprone width/bankfull width, of 3.4 in contrast to 2.0 in segment T6.04A and 1.8 in T6.04B). In addition, the downstream portion of the reach is farther from the road, and some meander development or retention is evident; the reach was characterized as straightened in just under half (49.9%) of its extent, in contrast with the 15 of 19 stream segments assessed in Phase 2 that were characterized as >50% straightened. Encroachment was noted in >20% of the reach, largely due to the presence of Rte. 100, since levels of development along the river were lower than in many other portions of the mainstem. Dominant buffers in reach T6.05 were <25 ft on the right bank, and a subdominant class of <25-ft buffers was noted on the left bank as well.

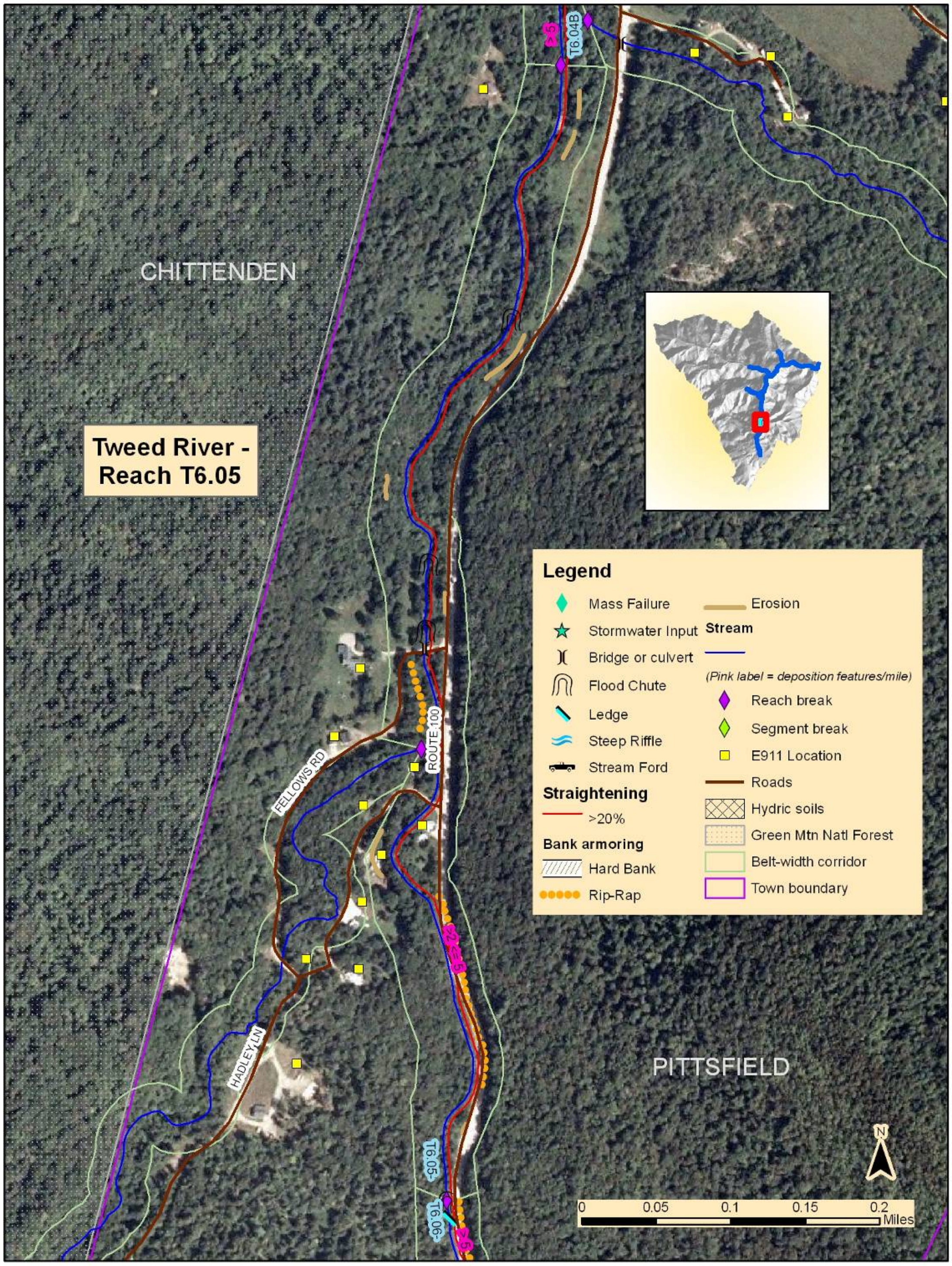


Figure 24. Tweed River reach T6.05 (NAIP 2003 background imagery).

Three bridges are present on the stream in reach T6.05, but geomorphic inventory data for these structures was not available at the time of this report; it is highly recommended that this data be assembled for its value to town and state infrastructure planning as well as fuller comprehension of the role these structures play in current stream dynamics and provision of fish and wildlife habitat. Although none were noted as channel constrictions during Phase 2 assessment; erosion was noted up and downstream of the bridge accessing a private residence at the downstream end of the reach. The bridge at Fellows Rd. is sized at roughly 85% of channel bankfull width measured in Phase 2 and 78% of reference channel width. Indications of historic dredging were noted during Phase 2 assessment, although exact locations were undocumented. Planform change was noted as the major current adjustment process, with multiple flood chutes and single island and midchannel bars documented in the Phase 2 assessment and tributary rejuvenation noted as contributing to the depositional processes in the reach. Nine stormwater inputs and numerous ledge grade controls in the next upstream reach are contributing to significant increases in stream power in this reach as well; efforts to address these impacts are discussed further in the project identification for Reach T6.06 in Section 6.1.6.

Table 17. Tweed River Segment T6.05 Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.05 (1,2,3)	Protect river corridor	High	Low	Y	Opportunities limited by encroachment, particularly Rte. 100; available floodplain significantly limited by this encroachment
T6.05 (4)	Plant stream buffer	High	Low	Y	Primarily low cost: high sensitivity, major current adjustments
T6.05 (20)	Collect and assemble data from geomorphic Bridge and Culvert Survey	High	High	Y	Data not available at time of this report; none of the structures recorded as constrictions, so very little information available
T6.05 (31)	Reduce upstream hydrologic impacts (watershed strategies)	High	High	Y	Stormwater mitigation, Better Backroads, or similar guidelines

6.1.6 Preliminary project identification: Reach T6.06—Tweed River mainstem, Pittsfield historic marker for "old dance hall" (1500 ft above Hadley Ln., 300 ft below 232 Rte. 100) to golf course pond above Trailside Lodge (Coffeehouse Rd.)

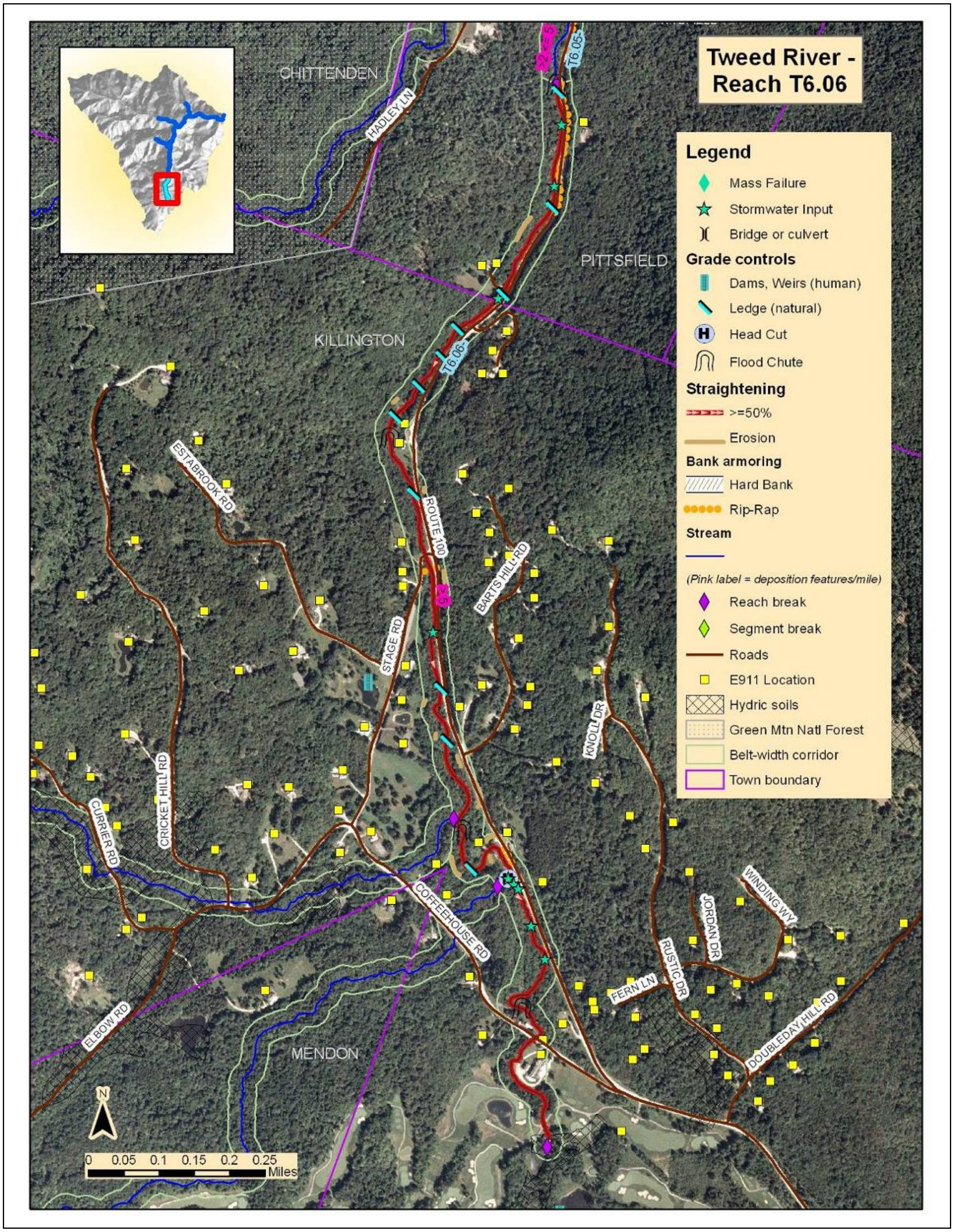


Figure 25. Tweed River reach T6.06 (NAIP 2003 background imagery).

Reach T6.06 was the most upstream reach of the Tweed mainstem assessed in Phase 2 and covers roughly 9875 ft (1.87 mi), ending at a small pond in the Green Mountain National Golf Course (Fig. 25). The reach was characterized by extensive development in the riparian corridor, straightening along Rte. 100 for most of the reach, and exposed bedrock with 12 ledge grade controls documented in the reach. This reach was further characterized as a B-type step-pool system dominated by cobble substrates under both reference and current conditions, but Phase 2 assessment noted that many of the pools were filling with sediments of various sizes. "Urban" land use accounted for >40% of the corridor land use, and encroachment was noted along >20% of the reach. Buffers reflected this level of development, with the right bank buffer having dominant and subdominant widths of <25 ft and 26–50 ft, respectively, and the left bank buffer having dominant and subdominant widths of 26–50 ft and <25 ft, respectively. With bedrock so prominent in the reach, banks are likely to be more erodible than the bed, and channel avulsions are an increased risk in flood conditions. Vegetated buffers can help mitigate these impacts and attenuate the impacts of increased stream power on downstream reaches in high flows. Directing stormwater outlets to well vegetated surfaces, reduction of direct inputs to the stream where possible, maintenance of vegetated buffers (shrubs can sometimes be established in surprisingly difficult conditions), and similar efforts would also help. The Better Backroads (http://www.vt.nrcs.usda.gov/rc&d/bbcoverpage.html) program has assisted communities in developing design and implementation guidelines for such efforts.

An incision ratio of 2.73 (height of recently abandoned floodplain/maximum channel depth) indicates that although the stream is only moderately entrenched, maintaining some access to a narrow floodplain in floods, recent downcutting processes have contributed to restriction of access to floodplains formerly accessible in high flows. Field notes from the Phase 2 assessment noted that the Middle Brook tributary, the most upstream tributary to enter the Tweed mainstem near the Mendon town line and Coffeehouse Rd., had a higher flow volume than the mainstem, and that a headcut had formed on the mainstem at the confluence with this tributary. With increased hydrologic inputs from five stormwater inputs in a relatively short section of the stream upstream of this point, a pond at the head of the reach, no grade controls upstream of this point, and Rte. 100 closely encroaching on the stream in this area, it is recommended that this headcut be assessed for the possibility of upstream migration and potential impacts (including impacts to both infrastructure and private property, as well as further loss of access to floodplain) of such migration in a high-water event. In addition, there are two bridges in this reach lacking geomorphic inventory data that would indicate possible impacts to the structures, as well as the role these structures are playing in current stream dynamics; it is highly recommended that this data be assembled.

Table 18. Tweed River Segment T6.06 Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.06 (4)	Plant stream buffer	High	Low	Y	Primarily low cost: high sensitivity, major current adjustments, difficult planting conditions; would help mitigate impacts of potential channel avulsions
T6.06 (15)	Arrest headcut	High	High	Y	Needs further assessment of potential impacts
T6.06 (20)	Collect and assemble data from geomorphic Bridge and Culvert Survey	High	High	Y	Data not available at time of this report; structures not recorded as constrictions, so little information available
T6.06 (34)	High priority river corridor protection at downstream reach. Restore incised reach with bed forms and floodplain features in equilibrium with increased stream power	High	High	Y	Throughout segment, opportunities limited due to encroachment, may become more feasible with repeated erosion/flooding conflicts

6.1.7 Preliminary project identification: Reach T6.01-S3.01—Guernsey Brook, Tweed mainstem confluence to unnamed tributary confluence at Forsha Rd. and Liberty Hill Rd.

Reach T6.01-S3.01 is the most downstream reach of Guernsey Brook, extending roughly 5090 ft (0.96 mi) from its confluence with the mainstem Tweed near the Stockbridge/Pittsfield town line to just upstream of the confluence with an unnamed tributary above the intersection of Forsha Rd. and Liberty Hill Rd. (Fig. 26). The reach was divided into two segments during Phase 2 assessment due to differences in valley width, planform, and slope. Although both segments were characterized as B-type streams, downstream segment T6.1-S3.01A was characterized with a Very Broad confinement type in the valley downstream of Rte. 100, while upstream segment T6.1-

S3.01B was characterized by a Narrow valley confinement ratio of valley width to channel width.

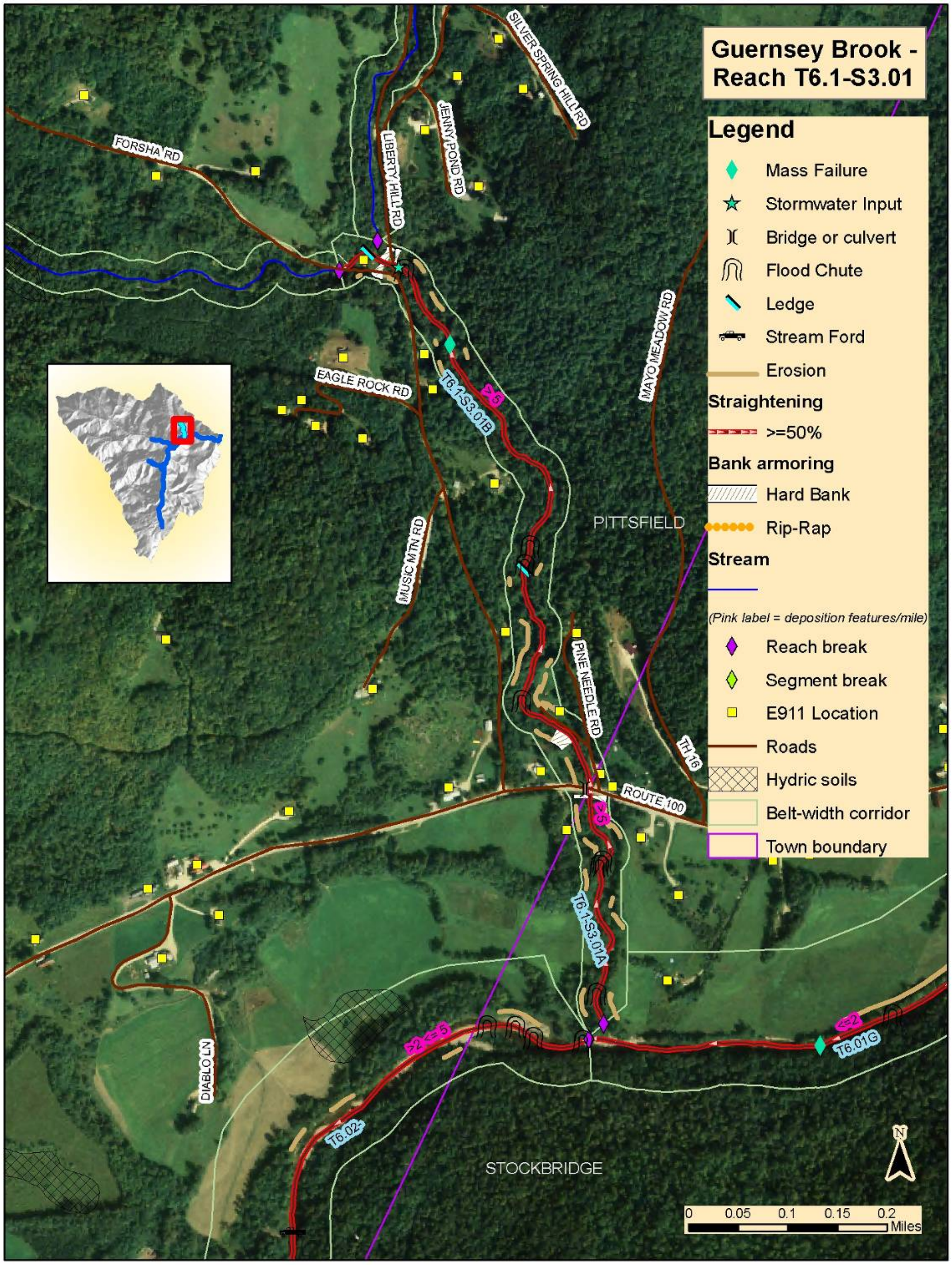


Figure 26. Guernsey Brook reach T6.1-S3.01 (NAIP 2006 background imagery).

Segment T6.1-S3.01A consists of roughly 1380 ft (0.26 mi) of Guernsey Brook downstream of Rte. 100 (Fig. 26). Historical maps from 1893 (Fig. 3) indicate that the stream may have meandered farther to the west toward the town line, and it appears likely that this portion of the Brook has been straightened through the valuable agricultural lands along the Tweed mainstem riparian corridor. Because Phase 1 assessment included this segment with the upstream portions of the reach, the overall reach was assessed as a B-type stream under reference conditions. The Very Broad valley confinement in this portion of the reach suggests that this portion of the stream may be a C-type stream that has departed from its reference conditions and is now moderately entrenched due to historic incision, although this assessment was not established during Phase 2 fieldwork. Encroachment levels of <5% along this portion of the stream indicate that development conflicts are relatively low, and dominant buffers exceeding 100 ft in width on both banks appear to be critical to the stability of the very highly erodible soils in this area. Dominant vegetation in the buffer on both sides of the stream was herbaceous, however, with subdominant deciduous tree buffers, and the actual bank canopy on both banks was noted as <25%. The left bank had a subdominant buffer width of 26–50 ft noted in the Phase 2 assessment. Erosion was noted along >20% of the banks on both sides of the stream, indicative of channel evolution stage III widening and lateral migration noted in the segment, which reinforces the need for the vegetated buffers to reduce impacts of erosion. This erosion and several flood chutes noted in the Phase 2 assessment indicate attempts of the stream to reestablish meander patterns (planform change) and diffuse stream power through access to a broader floodplain. Maintenance and augmentation of the existing buffers can help these processes to proceed while simultaneously reducing the loss of soils and nutrients in this area, allowing this stream segment to play a vital role in attenuating sediment and hydrologic inputs to the mainstem. In such a scenario, finer sediments are retained and deposited in the floodplain (contributing to fertility) along this segment, while coarser sediments are allowed to proceed further downstream as part of the bed load that will be important in reestablishing equilibrium conditions along the Tweed mainstem. Limiting further development along the base of Guernsey Brook also plays a critical role in allowing this area to fulfill its extremely valuable role in watershed dynamics.

The Rte. 100 culvert in this segment is sized at 42% of the Phase 1 predicted channel width based on regional hydraulic curves and subwatershed basin size. The effective width of the structure is reduced due to the alignment of the structure with the stream, and sediment deposition was noted downstream of the structure, but the structure was not noted as a floodprone constriction. Hard bank armoring and erosion within a short distance up and downstream of the structure, however, indicate effects of elevated stream power in this area. A 9-ft culvert in the segment is undersized as well, presenting both floodprone and channel constrictions, and deposition was noted both above and below the structure, in addition to scour below. Channel avulsions at this point should be considered likely in high-water events, and maintenance of well vegetated buffers would be critical to the stability of the surrounding area. Replacement of this structure could help reduce erosion and restore sediment transport capabilities.

Table 19. Guernsey Brook Segment T6.1-S3.01A Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
T6.1-S3.01A (1,2,3)	Protect river corridor	High	High	Y	Extremely valuable attenuation asset
T6.1-S3.01A (4)	Plant stream buffer; maintenance and augmentation of existing buffers/fencing?	High	High	Y	Primarily augmentation, mixed cost: high sensitivity, major current adjustments, but maintenance of existing buffers would increase survival rate of higher-value stock
T6.1-S3.01A (20)	Collect and assemble data from geomorphic Bridge and Culvert Survey	High	High	Y	Structures recorded as constrictions, so some information available but full data not available at time of this report
T6.1-S3.01A (34)	Potential restoration/protection project	High	High	Y	Information gathering: Passive may be cheapest and best alternative if corridor protection is possible; active floodplain/meander restoration might be combined with 9-ft culvert replacement but would need cost/benefit analysis of floodplain gains vs. engineering costs; maintenance of existing buffers critical, augmentation desirable

Segment T6.1-S3.01B extends roughly 3710 ft (0.70 mi) upstream of the Rte. 100 bridge to just upstream of the confluence with an unnamed tributary above the junction of Liberty Hill Rd. and Forsha Rd. The segment contains two sets of ledge grade controls, one in the midstream section of the segment and one at the head of the reach, that help explain the limited incision ratios in the reach overall (incision ratios of 1.26 in the downstream segment and 1.25 in this segment). Phase 2 fieldwork indicated a B-type stream with boulder and cobble step-pool features being replaced by plane bed features due to significant aggradation; the Phase 2 cross-section data characterized the segment as having a gravel stream bed. This portion of Guernsey Brook sits in a narrower valley than the downstream segment, and constraints of road encroachment on both sides of the downstream portion of the segment were not noted in fieldwork as sufficient to change the valley confinement classification of Narrow. Encroachment levels exceed 20% of the reach overall, concentrated in the upper and lower portions of the segment, and the channel has been maintained in a straightened condition along >50% of its length. Although the dominant corridor land cover is forest on both sides of the stream, subdominant corridor land use was noted as residential on both sides as well. These developed areas and the road encroachments are the primary areas where buffer widths contribute to a subdominant class of <25 ft on both sides of the stream; dominant buffer widths exceed 100 ft on both sides. Two culverts in the segment were noted as both floodprone and channel width constrictions, with scour noted below each of the structures and effective width for sediment transport reduced by the angle of alignment to the stream in both instances. Neither structure had deposition above, and only one was noted as having deposition below the structure. Dredging was noted as likely within this segment, with exact locations undocumented, so it is difficult to know what role or timetable these practices may have had in the surprising lack of deposition upstream of these structures. One mass failure was documented in the reach downstream of the Liberty Hill Rd. and Forsha Rd. intersection, and multiple flood chutes and erosion levels of >20% of the left bank and 5–20% of the right bank indicate channel widening and lateral migration in this portion of the stream. With ledge and bedrock present in the stream bed, banks are likely to be more susceptible to erosion in many areas, and there is increased risk of channel avulsions and bank failure in high-water events, increasing the importance of corridor protection in areas that do not currently have constraints on channel evolution. At the same time, coarse sediment contributions from this portion of the watershed may be important to reestablish equilibrium conditions in the incised reaches along the Tweed mainstem. Because of the extent of floodplain loss in downstream reaches, this evolution will likely require an extended period of time (>5 yrs), during which the movement of coarse sediment through the stream channel is apt to increase lateral migration in particular as the stream flow interacts with shifting sediment deposits.

Table 20. Guernsey Brook Segment T6.1-S3.01B Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and other Project Notes
T6.1-S3.01B (1,2,3)	Protect river corridor	High	Low	Y	Attenuation asset; FEH avoidance
T6.1-S3.01B	Plant stream buffers/fencing?	High	High	Y	Low cost: high sensitivity, major current adjustments

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and other Project Notes
(4)					
T6.1-S3.01B (20)	Replace structures	High	High	Y	Important to maintain sediment continuity for flood hazard reduction and contribution of coarse sediments for watershed dynamics
T6.1-S3.01B (42)	Reduce watershed stressors	High	High	Y	Reach aggrading but likely being driven by tributary rejuvenation from this area; likely to need >5 yrs to equilibrate

6.1.8 Preliminary project identification: Reach T6.2-S1.01—West Branch of the Tweed, confluence with the Tweed mainstem (Pittsfield village) to Crossover Rd.

Reach T6.2-S1.01 is the most downstream reach of the West Branch of the Tweed and covers roughly 6790 ft (1.29 mi), extending from the confluence with the Tweed mainstem in Pittsfield to just upstream of Crossover Rd., which connects Upper and Lower Michigan Roads (Fig. 27). The reach was not segmented during Phase 2 assessment. Similar to the downstream reaches of the Tweed mainstem, this lowest reach of the West Branch was locked into place by the presence of the Lumber Railroad along the left bank, which had its terminus just above the upstream reach break of T6.2-S1.01 (Fig. 3), in conjunction with Lower Michigan Rd. on the opposite bank. The double right-angle bend of the Tweed mainstem just downstream of the confluence with this reach accommodated a freight yard at the end of a rail spur in Pittsfield village, and the West Branch was bermed and snagged to increase the depth and power of the stream in order to move lumber down to this yard from the Michigan and Bayonne Lumber Camps located further up the West Branch (Fig. 3). The 1927 flood caused enough damage to railroad beds to contribute to the eventual closing of all rail lines that were formerly located along the White and its tributaries above Bethel, and the Lumber Railroad was not rebuilt after that time (Johnson 1928). Phase 2 assessment in 2006 indicated berms along only 4% of the reach, but the legacy of berming is still incorporated into the elevated road beds on either side of the mainstem and windrowed stone is evident along midstream portions of the right bank below the Lower Michigan Rd. in particular. The stream in this reach was noted as an entrenched (entrenchment ratio 1.17, incision ratio 2.30) and overwidened F-type channel with plane bed features. With significant development along the reach in addition to the berms and roads, encroachment levels exceed 20% of the reach, and dominant buffer widths on the right bank were <25 ft; subdominant buffer widths were 26–50 ft on the right bank and <25 ft on the left bank.

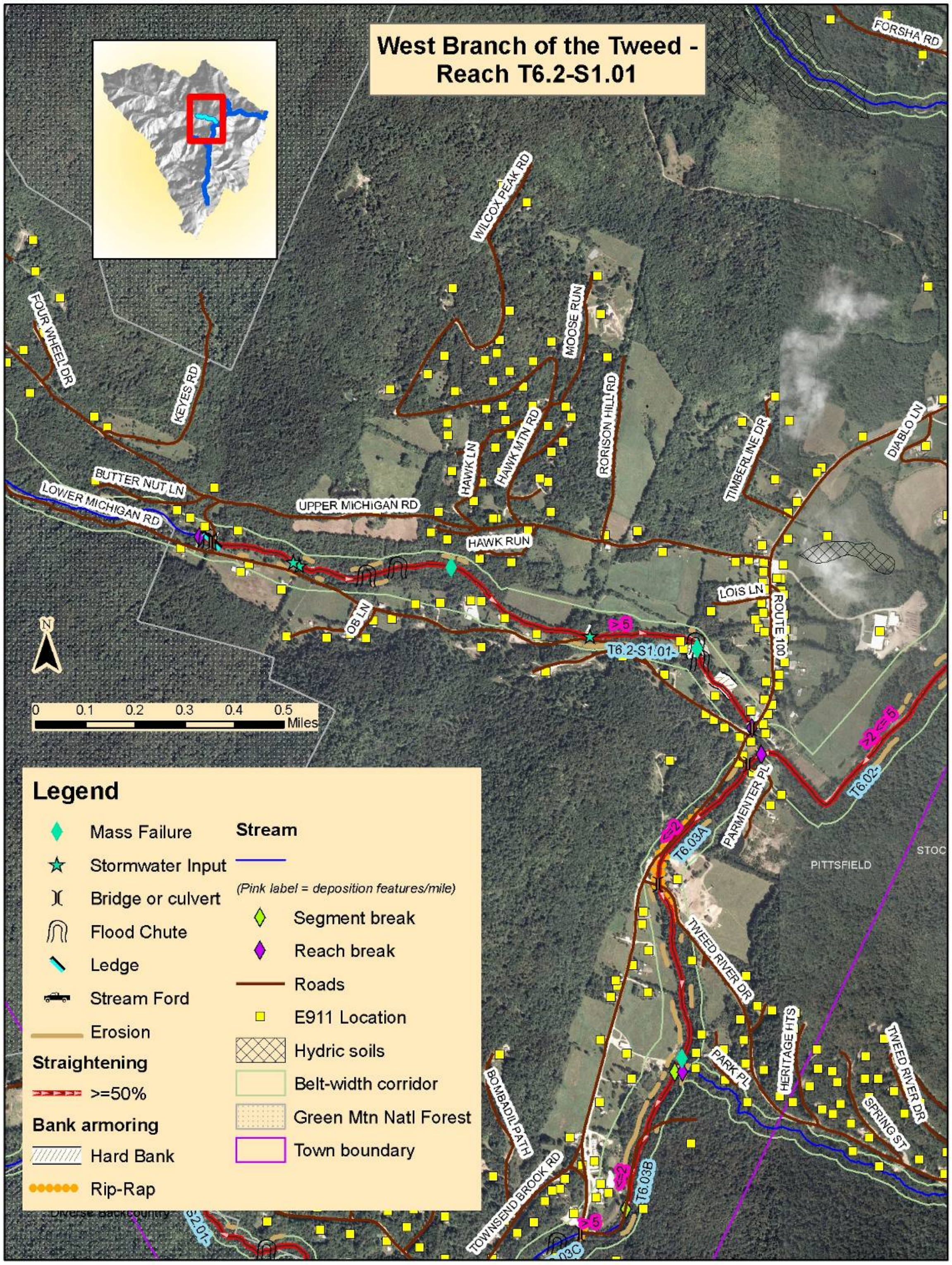


Figure 27. West Branch of the Tweed reach T6.2-S1.01 (NAIP 2003 background imagery).

The extensive straightening of Reach T6.2-S1.01 permitted Pittsfield village to occupy an alluvial fan that forms the floodplain between the West Branch and the Tweed mainstem (Fig. 3; Fig 27). This extensive development makes it unlikely that channelization of this reach will be significantly reduced, and dramatically increases the potential value of planting full-width buffers on the left bank of midportions of the reach above the village for flood hazard mitigation in particular. Despite the extreme sensitivity, widening, and lateral migration documented in the reach, the value of these plantings for protection of the village in a high-water event would suggest that investment in higher-value planting stock, and the extra time and planting techniques that would establish the stock more quickly, would be well spent in the portions of such a buffer that are set back from the stream.

During 2007 Phase 2 assessment, this reach was assessed at stage III channel evolution, with widening, lateral migration, and aggradation on each bank evident along the 5–20% of the reach with evidence of bank erosion, two mass failures, four flood chutes, and multiple depositional midchannel bars. Two bridges in the reach were noted as both floodprone and channel-width constrictions, with evidence of sediment deposition both upstream and downstream of both structures. Similar to the dynamics along Guernsey Brook, it appears that the erosion and mass failures evident in this reach are contributing coarse sediments important to reestablishing equilibrium conditions in the overall watershed. It is thus important to maintain sediment continuity through these structures to permit these bed load sediments to be transported in high flows. Unlike Guernsey Brook, however, there is only one grade control at the upstream end of this reach, and possible replacement of these structures would need to be evaluated carefully for changes in bed elevation (migration of headcuts in particular) and possible impacts to infrastructure and private property, as well as further loss of floodplain access due to downcutting. Replacement was thus not recommended at this time. It should be noted, however, that dredging or similar removal of these sediments also increases these same risks, and any of these options would need to be evaluated carefully with a view to the damages likely to be caused by outflanking these structures, which is a scenario that would be more consistent with the channel evolution dynamics present in the reach.

Table 21. West Branch of the Tweed Reach T6.2-S1.01 Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and other Project Notes
T6.2-S1.01 (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited but important, esp. midreach; attenuation asset, flood hazard avoidance
T6.2-S1.01 (4)	Plant stream buffers/fencing?	High	High	Y	Mixed cost: extreme sensitivity, major current adjustments; important for

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and other Project Notes
					flood hazard mitigation
T6.1-S1.01 (34)	High priority river corridor protection at downstream reach, Restore incised reach with bed forms and floodplain features in equilibrium with increased stream power	High	High	Y	Best opportunities currently midreach; opportunities limited due to encroachment, may become more feasible with repeated erosion/flooding conflicts; need careful evaluation regarding flood risks to village

6.1.9 Preliminary project identification: Reach T6.03-S2.01—Townsend Brook, confluence with the Tweed mainstem (south of Pittsfield village) to Pittsfield/Chittenden town line

Reach T6.03-S2.01 comprises the most downstream reach of Townsend Brook and extends roughly 6580 ft (1.25 mi) from the confluence with the Tweed mainstem at the south end of Pittsfield village to where the valley becomes extremely narrow, roughly 200 ft as the crow flies, or 500 ft along the stream from the Pittsfield/Chittenden town line (Fig. 27). Reference conditions for the reach would indicate a B-type step-pool system with a cobble substrate, but Phase 2 fieldwork identified an entrenched (entrenchment ratio 1.16, incision ratio 2.28) F-type stream with gravel-dominated substrate and significant sedimentation of pools in the reach. The subwatershed is largely undeveloped off the right bank of the stream, with much of the land included within the boundaries of the Green Mountain National Forest, but the area off the left bank has been extensively developed. Tozier Hill Rd. parallels the stream along the upstream two-thirds of the reach, and encroachment was noted along >20% of the reach length. Although dominant buffers on the left bank exceed 100 ft, a patchwork of clearings associated with developed areas and four mass failures along the reach have limited dominant buffer widths on the right bank to 26–50 ft and subdominant buffer widths on the left bank to <25 ft; buffers of 51–100 ft were dominant on the right bank. The reach was assessed at stage III channel evolution with the four mass failures, numerous midchannel and island bars, seven flood chutes, and erosion along >20% of the left bank and 5–20% of the right bank all indicating the widening, lateral migration, and planform change associated with that stage of channel evolution.

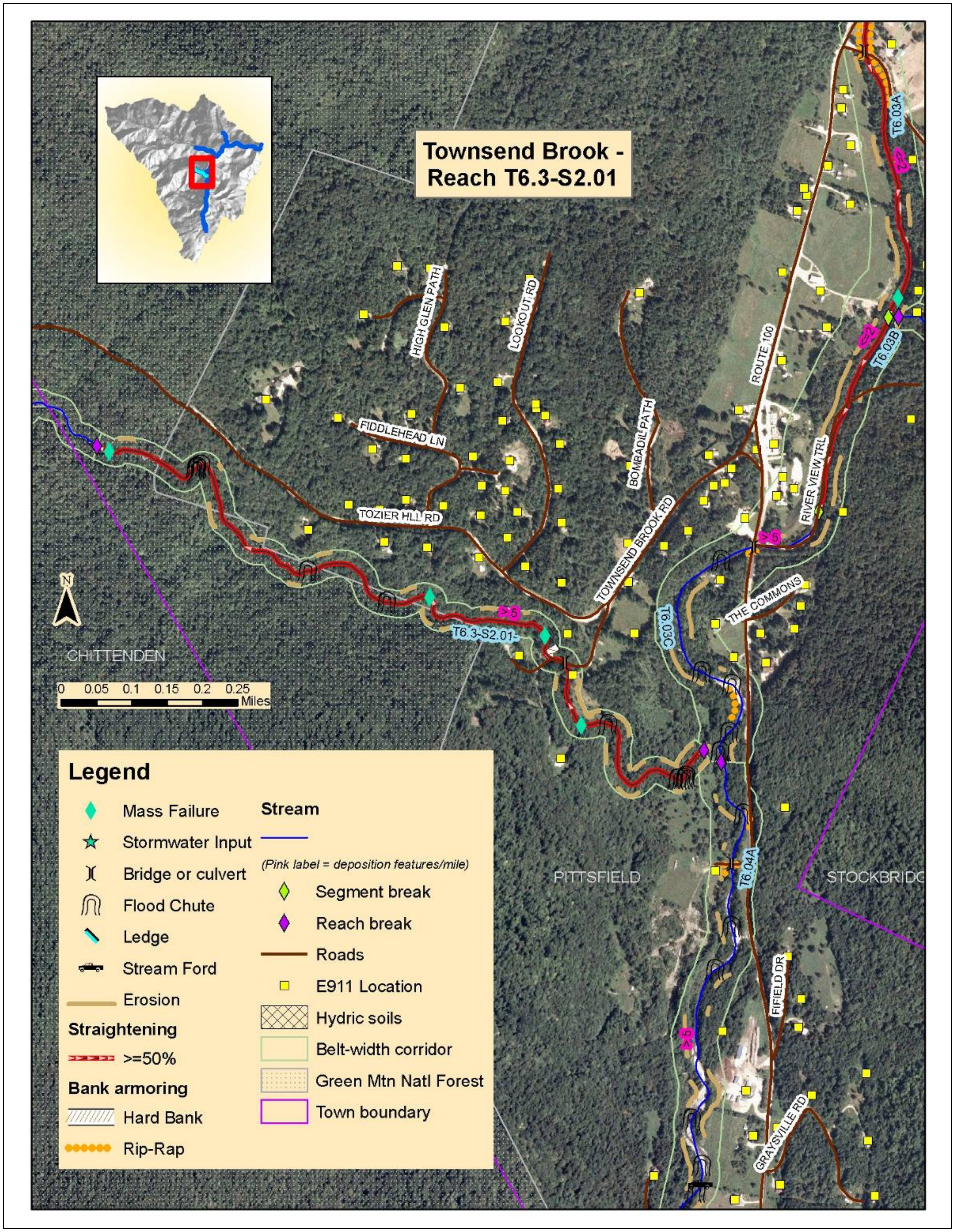


Figure 28. Townsend Brook reach T6.3-S2.01 (NAIP 2003 background imagery).

The bridge at Townsend Brook Rd. in reach T6.3-S2.01 is sized at roughly 62% of channel width and was noted as both a floodprone and channel-width constriction, with evidence of upstream deposition obstructing the inlet, scour below the structure, and the angle of alignment to the stream reducing the effective width of the structure for flow and sediment transport. Similar to the situation on West Branch reach T6.2-S1.01, there are no natural grade controls on this reach and it appears that sediment is being recruited from this tributary to attempt to reestablish equilibrium conditions in the deeply incised reaches along the mainstem of the Tweed. It is important to watershed dynamics to have sediment transport continuity between this tributary and downstream reaches, but structure replacement will need to be evaluated carefully for potential changes in bed elevation (migration of headcuts in particular), possible impacts to infrastructure and private property, and loss of already limited floodplain access due to downcutting. It is possible that outflanking of this structure in a high-water event may be less costly and more consistent with current stream dynamics, and that downstream dynamics may require >5 yrs to equilibrate; replacement was not recommended at this time. Indications are that this reach has been dredged historically, with exact locations undocumented (pers. comm. Frederick Nicholson, VT ANR-RMP Stream Alteration Engineer), and it should be noted that extreme sensitivity of this reach means that migration of headcuts and loss of floodplain access are highly probable when gravel is removed from the streambed of this reach. Under the current sediment regime, gravel removal will mean that more sediment will be recruited from further upstream in an attempt to reestablish equilibrium between the resulting heightened stream power and the sediment being moved by that water.

Table 22. Townsend Brook T6.3-S2.01 Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and other Project Notes
T6.3-S2.01 (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited but important, primarily downstream of Townsend Brook Rd.; attenuation asset, flood hazard avoidance
T6.3-S2.01 (4)	Plant stream buffers/fencing?	High	High	Y	Low cost: extreme sensitivity, major current adjustments; important for flood hazard mitigation
T6.3-S2.01 (36)	Potential protection/restoration project	High	High	Y	Information gathering for passive project downstream of Townsend Brook Rd.

6.2 PROJECT PRIORITIZATION

Reaches selected for inclusion in the Tweed River corridor planning Project area 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. Lower investments associated with this approach are desirable considering an inherent degree of uncertainty in the success of engineered approaches in an active system, and the Tweed watershed can be characterized as an active, high-sediment-load system. With some exceptions, stream sensitivity in this watershed generally changes along a downstream to upstream gradient, with extremely sensitive reaches located primarily in the most downstream portions, very high sensitivity in midwatershed reaches, and high sensitivity in the upstream portions. While this suggests that downstream reaches would be the quickest to equilibrate in response to protection and restoration efforts, the dynamics in the Tweed watershed indicate that watershed inputs originating in upstream reaches are important drivers of downstream dynamics, and addressing these inputs will be important to the success of downstream efforts.

Currently, a primary issue in the Tweed watershed is the significant increase in stream power resulting from long-term impacts of extensive straightening and consequent loss of floodplain access. Extensive straightening has encouraged subsequent development in many historic floodplains, and this fact has combined with steep narrow valleys that naturally limit the width of higher-elevation floodplains in the Tweed watershed to exacerbate a situation in which key attenuation assets are a rapidly dwindling resource. With continued significant development pressures, high priority is recommended for protection of these assets and use of belt-width corridors as a basis for reducing flood hazards and land-use conflicts. The FEH corridor (corridors indicated on reach maps in this report) approach being developed by the State of Vermont River Management Program offers a science-based refinement and added measure of protection over corridors that are based only on a predefined width or similar method and can be implemented through a variety of approaches (VT ANR, 2007a). While the political processes involved with such an approach might appear to fall outside the typical domain of project emphasis for the WRP, development of outreach materials and presentations including this information appear to be a fruitful avenue for further exploration.

Regardless of the methods for implementation chosen, the key attenuation assets available to provide significant amounts of floodplain access in this watershed are concentrated in the downstream reaches below reach T6.03 (Pittsfield village), including the floodplain below Rte. 100 on the downstream end of Guernsey Brook. Due to the extremely erodible materials present along the banks of the streams in this area, ample buffer establishment will be critical to permitting these functions without continuing to lose large amounts of fine sediments and valuable nutrients. Because watershed inputs originating in upstream reaches are such important drivers of downstream dynamics in this watershed, it is also important to protect and utilize the smaller portions of floodplains and corridors (for meander development) that still exist in upstream reaches, lending further importance to a town-based approach for the planning necessary to protect these assets. While scattered development, combined with the extensive encroachment of Rte. 100, has already impaired the ability to do this in long stretches of the corridor, it is conceivable that further opportunities may arise with repeated erosion conflicts and flooding impacts; this increases the importance of the downstream floodplains to attenuate these discharges in the meantime.

As part of the need to address upstream drivers of watershed dynamics, efforts to reduce or attenuate increased direct hydrologic inputs to the stream from stormwater inputs in reach T6.06, as well as addressing these issues in development and transportation planning throughout the watershed, will help with avoidance and mitigation of flood hazards and will permit the movement of coarser sediments into downstream reaches to begin to come into balance with increased stream power. Although the river in this portion of the watershed appears small in low flows, the narrow valley and extensive encroachment of Rte.100 combine with the numerous bedrock outcrops in this area to transfer the bulk of increased flow impacts to downstream reaches. Stormwater management to ensure percolation and distribution over well vegetated surfaces, and maintenance (and establishment where they are lacking) of woody buffers, can help mitigate these impacts. Buffer maintenance and establishment can play a similarly important role for flood hazard mitigation, as can reduction of stream power above Pittsfield village, where extensive encroachments along the West Branch (reach T6.2-S1.01) following the straightening of the stream during the days of the Lumber Railroad have severely restricted possibilities for floodplain access and meander development.

Current significant increases in hydrologic inputs are primarily concentrated in the upstream portion of the mainstem, but in the wider watershed a primary objective is ensuring sediment continuity so that bed load sediments can work their way through the stream network and contribute to the rebuilding of floodplains and meanders. Deposition of coarse bedload sediments will be vital to the reestablishment of meanders, pools, and a variety of stream features that are currently not well distributed in the watershed. Coarse sediments are largely being recruited from the tributaries; extremely erodible bank materials of the mainstem downstream reaches and portions of the upstream and tributary reaches are primarily contributing fine sediments (gravel, sand, and silt) that are dropping out when stream power is significantly decreased or are being transported large distances downstream. This dynamic increases the export of nutrients out of the watershed and contributes to filling of pools and plane bed formation, which eliminates the habitat variety needed by fish and the insects and macroinvertebrates that form an important part of the food chain critical to the vital fisheries resources of the Tweed and greater White River watershed. Sediment regime departure analysis (see Section 5.1.4 of this report, especially Fig. 9) currently indicates significant deposition in reach T6.04 on the mainstem Tweed, and bridges in that reach have been identified as constrictions restricting sediment transport to reaches farther downstream. Replacement with structures of adequate size to permit transport of both sediment and water in high flows would benefit these dynamics (sizing guidelines and recommendations are currently being developed by a number of cooperating partners, including VT Fish & Wildlife, VT Agency of Transportation, Better Backroads, and other organizations, and are expected to be released in 2008). While this is true of many structures and stream dynamics in the Tweed watershed, other structures might require temporary grade controls or similar measures to prevent adverse impacts to stream dynamics, private property, and infrastructure. These would benefit from cost/benefit analysis or capital budgeting and prioritization, particularly in situations in which outflanking of structures might be more consistent with stream dynamics than replacing them, and it is highly recommended that this information be obtained where it is not currently available.

With these considerations as a general backdrop, Table 23 lists potential projects in the Tweed River corridor planning Project area in recommended order of priority. Project prioritization should be considered preliminary and will need to be adjusted based on further information and community interest. Buffer establishment and augmentation would be an important component of many of these projects, although planting conditions will be difficult in areas of extensive road encroachment. Buffer establishment and/or augmentation could be conducted independent of other project implementation in most instances. Maps of the potential project areas follow the table and are referenced in the table.

Table 23. Potential project prioritization for the Tweed River corridor planning Project area

Tweed River Corridor Planning 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	All	Extensive straightening and frequent loss of floodplain access, escalating erosion conflicts due to adjustments	FEH and belt-width-based corridor planning, protection of attenuation assets	Feasible, high priority; delineation process largely developed Develop-ment pressures in watershed likely to continue, upstream impacts affect success of projects	Flood hazard reduction, fisheries protection, prime farmland protection, viewshed preserva-tion	Develop-ment of outreach and educational materials; policy development and implementa-tion	Depends on options chosen; see VT ANR Municipal Guide to Fluvial Erosion Hazard Mitigation (Literature Cited section of this report)	Towns of Killington, Pittsfield, and Stockbridge; WRP; GMNF; TRORC; RRPC; VT ANR-RMP

Tweed River Corridor Planning 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	Numerous	Downstream reaches incised, sediment discontinuities reducing movement of larger bedload sediments to help rebuild meanders and floodplain access	Collect and assemble geomorphic data for bridges and culverts where missing; develop and disseminate sizing recommendations and/or requirements for private installations and help towns with inventory, prioritization, and capital budgeting	Feasible, high priority; geomorphic survey protocols already developed, some data already available; sizing recs expected 2008; some towns may have model inventories and budgeting	Flood hazard reduction; fisheries protection	Data collection and assembling; replacement costs where appropriate		Towns of Stockbridge, Pittsfield, and Killington; WRP; GMNF; TRORC; RRPC; VT ANR-RMP; VT F&W, VTrans

Tweed River Corridor Planning 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
3	T6.02 (downstream) Fair to Very High (Fig. 29)	Still has floodplain access, relatively high in watershed	Passive; protect corridor; augment and establish buffers	Feasible, high watershed priority; hydric soils, lower productivity, existing buffers decent	Flood hazard mitigation	Easement transactions	Land use conversion minimal; commitment to easements	Landowners, CREP, VT River Conservancy or other organizations
4	T6.1-S3.01A Fair to High (Fig. 29)	Straightened, moderately entrenched; buffers decent but might need augmentation	Passive: protect corridor, ensure that structures permit sediment continuity	Feasible, high priority; development conflicts still low	Farmland protection, high visibility	Easement transactions	Land use conversion minimal; commitment to easements	Landowners, VT River Conservancy or other organizations

Tweed River Corridor Planning 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	T6.01G Poor to Extreme T6.01F Fair to Very High T6.01D Fair to Very High (Fig. 30)	Attenuation assets; low incision ratio of 1.6 in segment G indicates that abandoned floodplain may become accessible; floodplain already accessible in segments F & D	Passive: protect corridor; establish buffer with low-cost stock	Feasible, high priority; linked to upstream dynamics, particularly sediment transport continuity; important to attenuate discharges during equilibra-tion	Farmland protection, flood hazard mitigation, high visibility	Easement transactions, compensa-tion on ag lands	Management easements along corridor, full-width buffers	CREP, EQIP, VT River Conservancy, VLT, VTrans

Tweed River Corridor Planning 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
6	T6.04A Poor to High T6.04B Fair to High (Fig. 31)	Departure from C to B stream type in both segments, high aggradation currently; sediment continuity important to downstream dynamics	Replace undersized structures, assess uses and dynamics at stream fords	Feasible but expensive; high priority for watershed dynamics		VTrans database estimate of $344 K for Baker's Rd. bridge; Stonewood Crossing data unavailable at time of this report		Town of Pittsfield, landowners at stream fords
7	T6.2-S.1.01 Poor to Extreme (Fig. 32)	Departure from C to F stream type, extensive encroachment limits stream evolution capabilities	Buffer establishment midreach primarily for flood hazard mitigation above Pittsfield village	Feasible; high reach priority but lower watershed priority	Flood hazard mitigation	Planting stock	Buffer establishment	Ag landowners, CREP

Tweed River Corridor Planning 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	T6.01A Fair to Very High T6.01B Fair to Very High (Fig. 33)	Attenuation assets for mitigation of upstream impacts during adjustments; T6.01A mostly at base of reach for value to White mainstem	Protect corridor	Feasible, but lower priority for watershed dynamics	Popular waterfalls between A & B; recreational facilities and access point at Timber-hawk offer educational possibilities (signage)	Easement transactions, policy implementa-tion	Buffer establishment; commitments to easements or planning designations	Ag landowners, CREP, EQIP, Timberhawk owners association, VT River Conservancy
9	T6.3-S2.01 Poor to Extreme (Fig. 34)	Attenuation asset, tributary rejuvenation for mainstem: sediment load moving downstream	Protect corridor; could be included with belt-width or FEH planning but may need to be wider at base	Feasible; may need administra-tive adjustment of corridor	Flood hazard avoidance	Policy implementati on	Conversion minimal; commitments to easements or planning designations	Town of Pittsfield, VT ANR-RMP

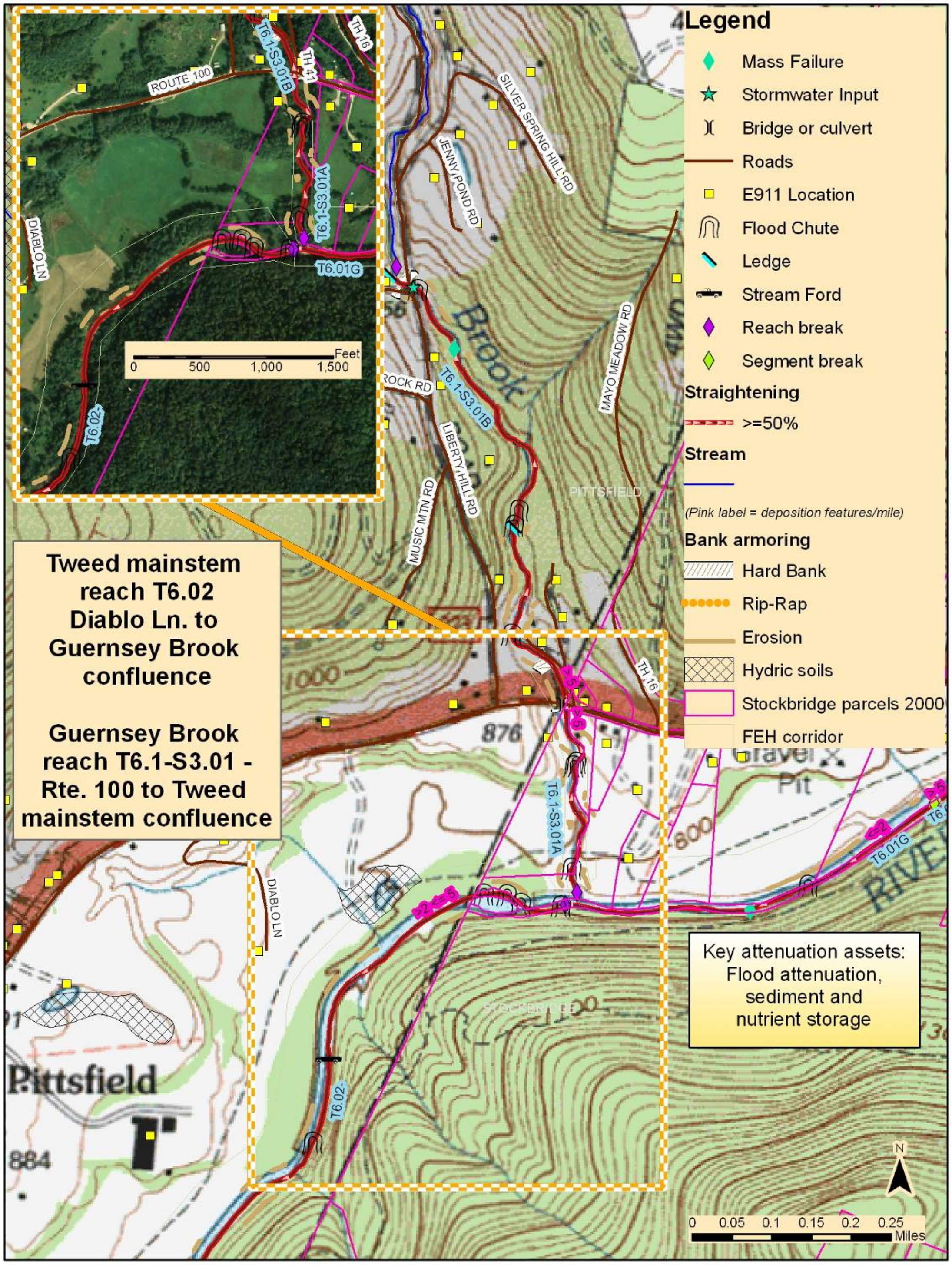


Figure 29. Project prioritization: Tweed mainstem reach T6.02 and Guernsey Brook reach T6.1-S3.01, Pittsfield/Stockbridge town line.

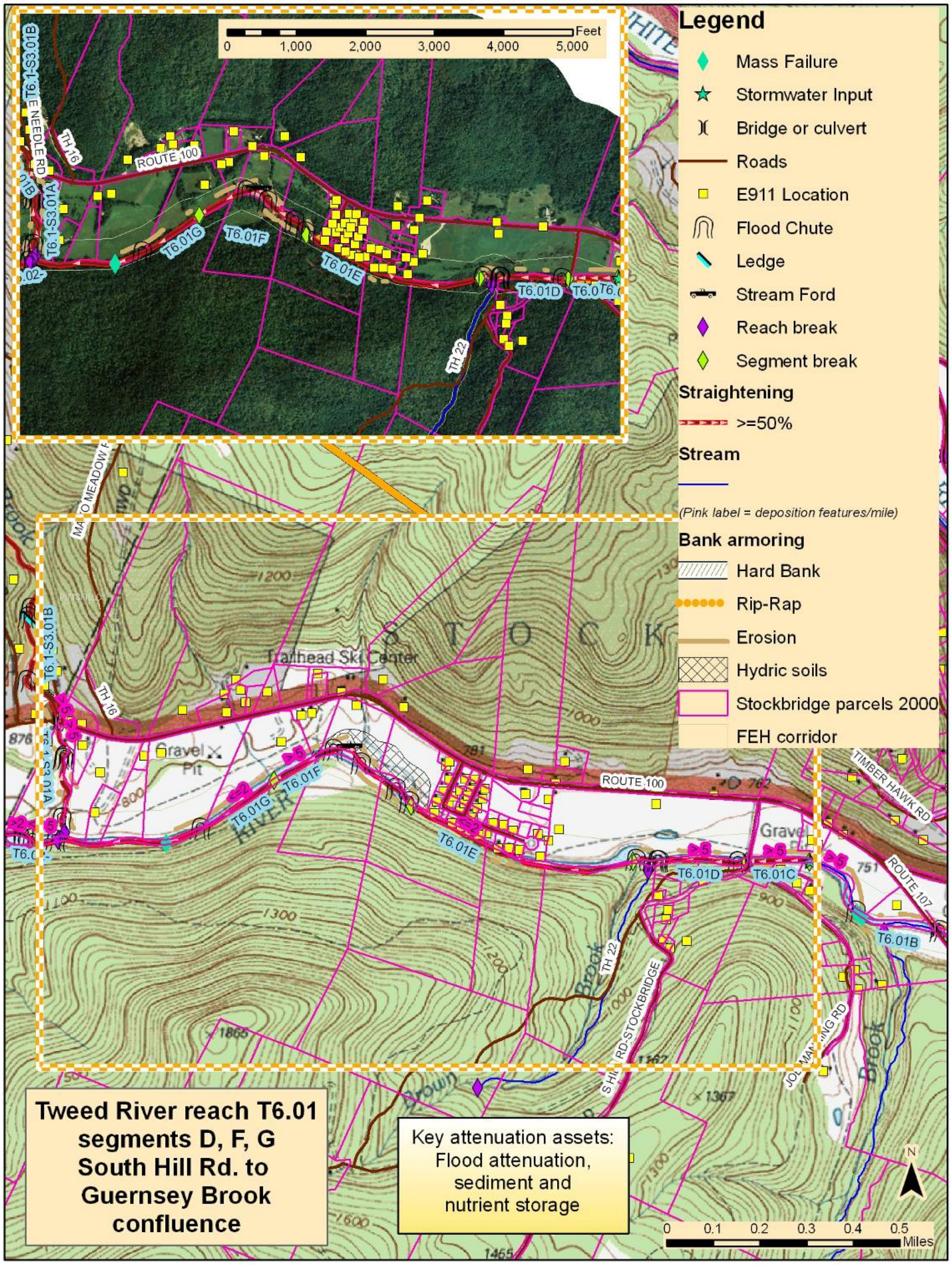


Figure 30. Project prioritization: Tweed mainstem reach T6.01, South Hill Rd. to Guernsey Brook.

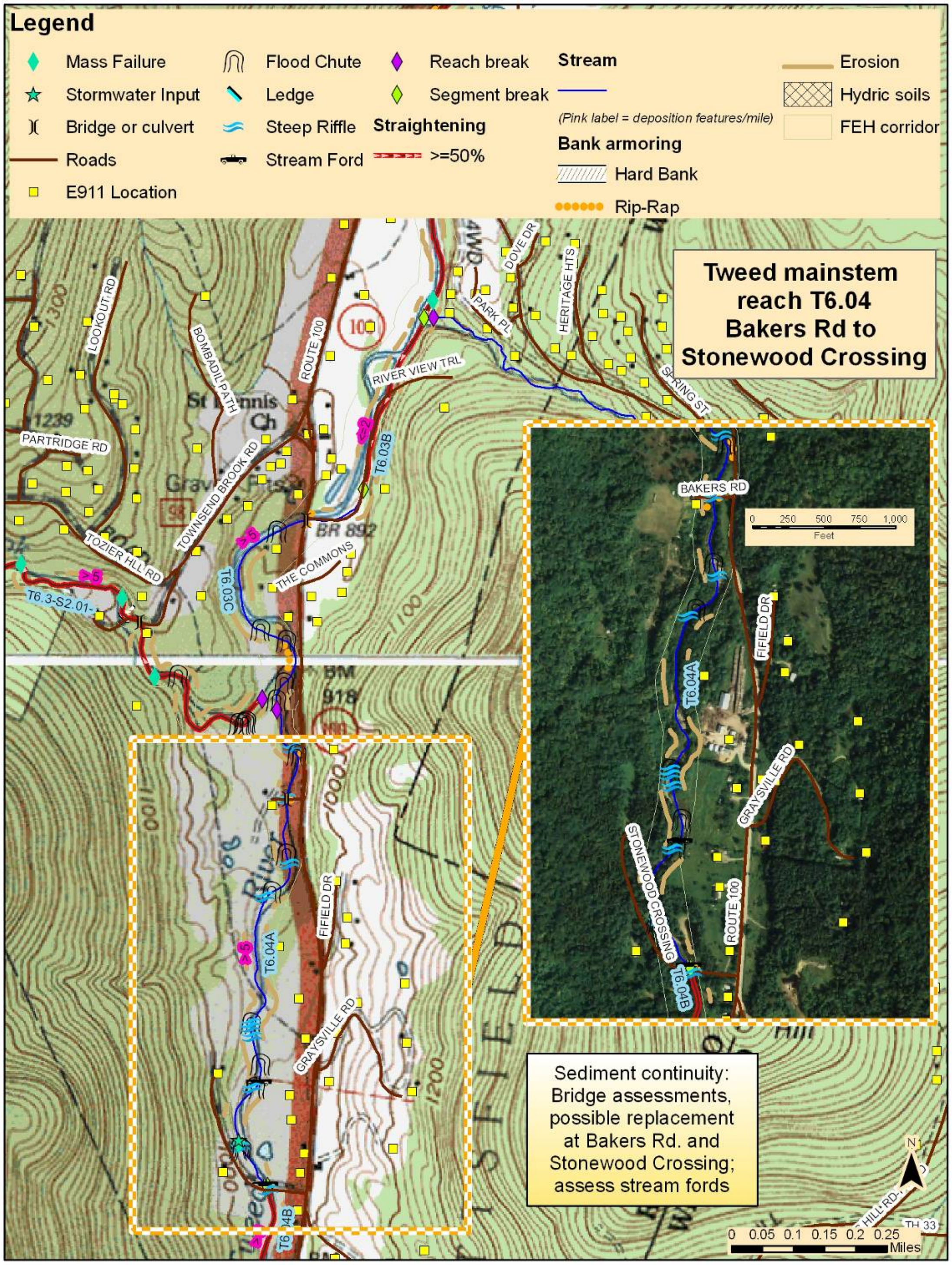


Figure 31. Project prioritization: Tweed mainstem reach T6.04, Bakers Rd. to Stonewood Crossing.

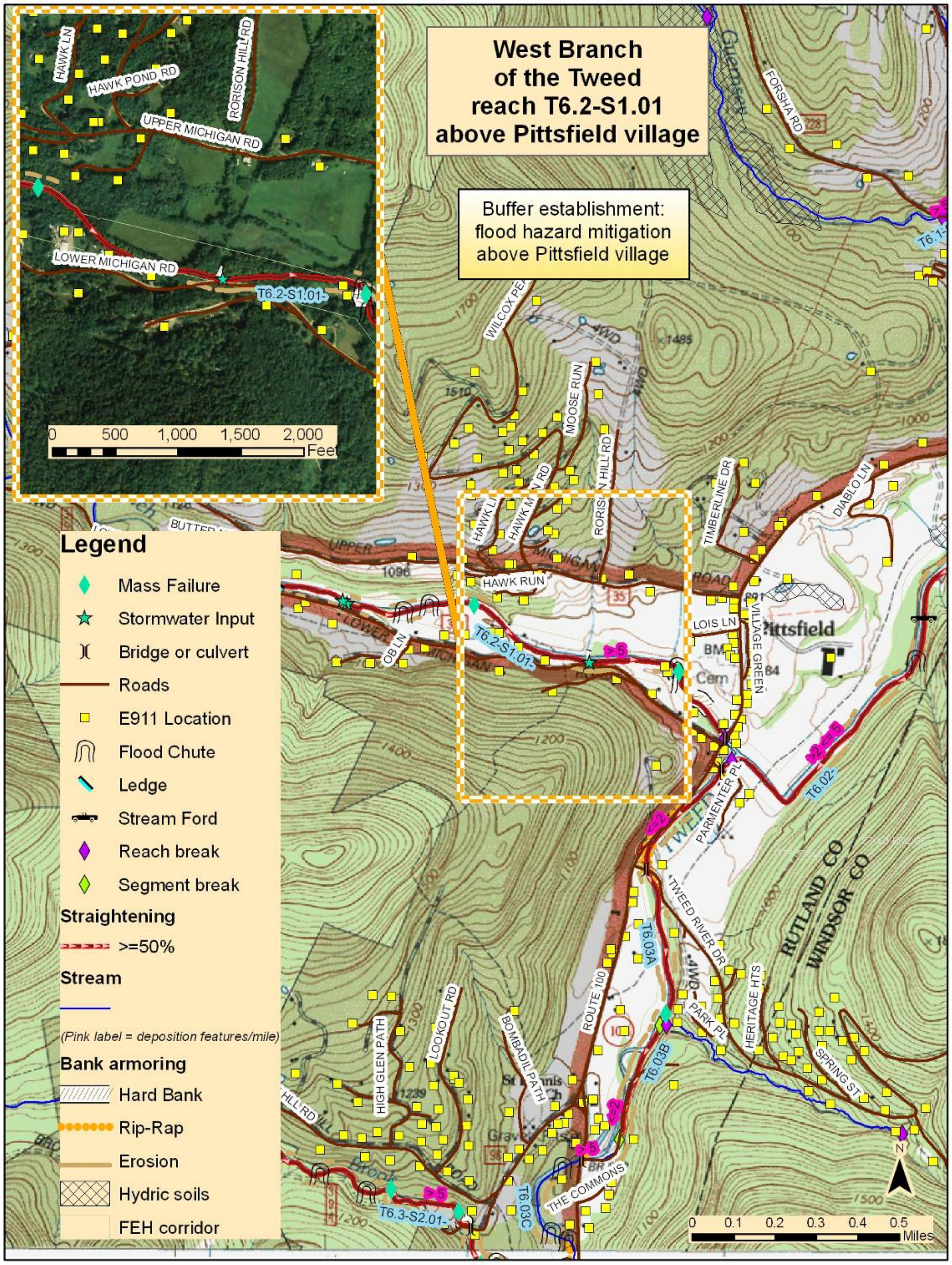


Figure 32. West Branch of the Tweed reach T6.2-S1.01 above Pittsfield village.

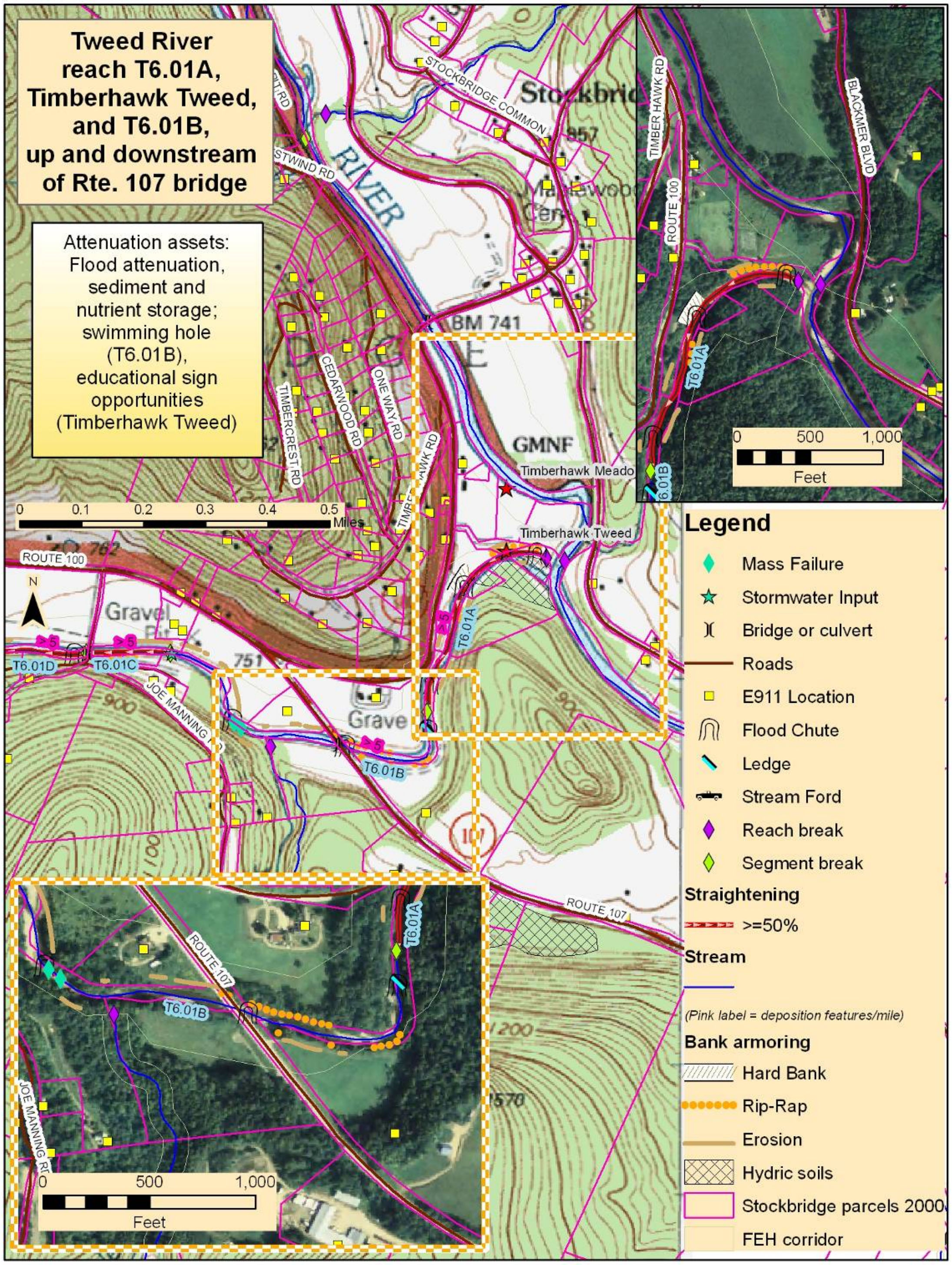


Figure 33. Project prioritization: Tweed mainstem reach T6.01, White River confluence to upstream of Rte. 107 bridge.

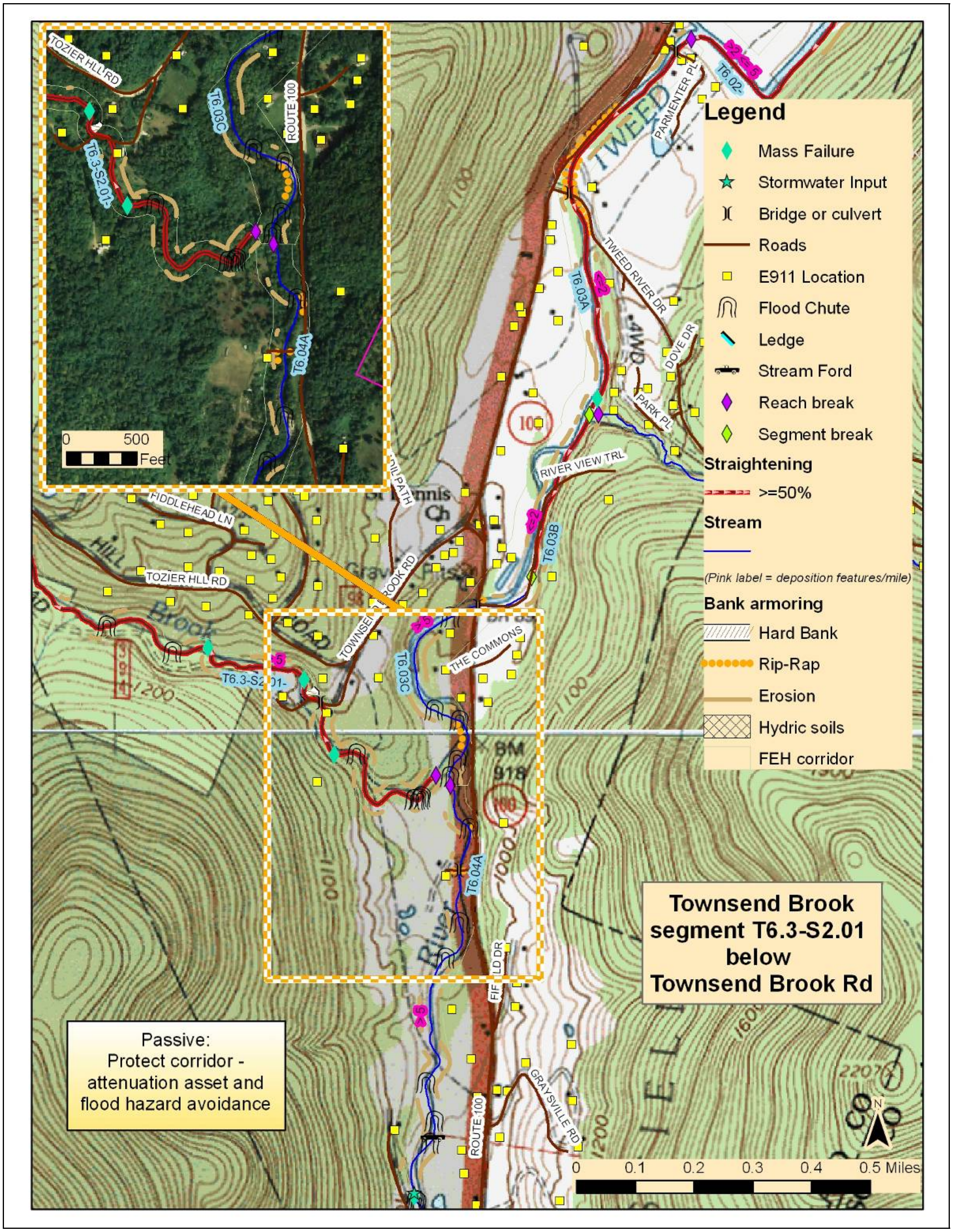


Figure 34. Project prioritization: Townsend Brook reach T6.3-S2.01, below Townsend Brook Rd. to Tweed mainstem confluence.

7.0 PROJECT AND PROGRAM RECOMMENDATIONS

7.1 FEDERAL, STATE, AND MUNICIPAL ACTIONS

Several strategies can be used by federal and state agencies and municipalities to reduce human conflicts with the river. The first strategy, planning and zoning to minimize future encroachment, includes tools such as corridor-based zoning ordinances, participation in the National Flood Insurance Program, and FEH mapping.

The National Flood Insurance Program (NFIP) was created by Congress through the National Flood Insurance Act of 1968. It enables property owners in participating communities to purchase insurance protection against flood-related losses. The insurance provides an alternative to disaster assistance by covering damage repairs to buildings and their contents. Participation in the NFIP is based on an agreement between the Federal Government and local communities that states that the Federal Government will make flood insurance available if a community adopts and enforces a floodplain management ordinance to reduce flood risks to new construction in special flood hazard areas (SFHAs). The SFHAs and other risk premium zones that affect participating communities are depicted on flood insurance rate maps (FIRMs). The Mitigation Division of the Federal Emergency Management Agency (FEMA) manages the NFIP and oversees the floodplain management and mapping components of the Program (http://www.fema.gov/business/nfip/index.shtm). The maps on which determinations are based are currently undergoing updates through the “Map Modernization” program, which will convert the FIRMs to a digital format that can be more easily overlaid with other maps through Geographic Information Systems (GIS) and similar technologies. These map updates were the result of a review process in Windsor and Rutland counties in 2007, which included the area covered in this plan in Stockbridge, Pittsfield, and Killington (still listed as Sherburne). The current status of these FIRM updates is now being made available online as part of the map modernization program (http://www.floodmaps.fema.gov/fhm/scripts/ST_srch.asp?state=VT). At the time of this report, the new FIRMs had undergone review and become effective in Stockbridge in September 2007, with additional data being sought for a Letter of Map Change. Pittsfield and Sherburne (Killington) updates will become effective in August 2008.

FEH mapping offers a science-based approach that uses the geomorphic data collected in Phases 1 and 2 to rate erosion hazards in the zone along the river. Flash flooding is more common in Vermont than inundation flooding, particularly in watersheds such as those assessed in this plan within the Tweed River watershed, where (1) there is a high degree of straightening and streams are now undergoing planform change, (2) historic floodplain access has been limited, and (3) bank materials are highly erodible. The FEH approach is highly recommended for all three towns within the Project area for its more refined delineation of belt-width corridors and added measure of protection, particularly given the degree of development pressure in evidence within the watershed. Model ordinances, guidance documents, and information about both the NFIP and FEH programs in Vermont are available through the VT ANR-RMP (http://www.vtwaterquality.org/rivers/htm/rv_floodhazard.htm).The Association of State Floodplain Managers also offers information about additional measures a community can take to manage floodplains with "No Adverse Impact" to existing development (http://www.floods.org/home/default.asp).

The Tweed River corridor planning Project area is strongly affected by the dynamics of sediment transport, and it is highly recommended that the towns within this area undertake a thorough bridge and culvert inventory and assessment and base capital budget planning and prioritization on the results of these assessments. Many areas of northern New England have seen an increase in intense, localized "microburst" storms over the last several years, and this is likely to be an increasingly important matter for town planning. The VT Department of Fish & Wildlife and other partners have been working on sizing recommendations to ensure sediment and flow transport in high-water events as a means of improving habitat for aquatic organisms, but these recommendations will also play an important role in helping stream dynamics move toward equilibrium conditions and reduce flood hazards in this watershed. The VT ANR-RMP is also currently developing tools to help communities use bridge and culvert assessment results in budget planning and prioritization, and the Green Mountain National Forest is currently in the process of planning Integrated Resource Projects in this area and have noted road, sediment, and culvert issues in their preliminary planning (pers. comm., GMNF Integrated Resources Project community meeting, Hancock Town Hall, Feb. 2008).

7.2 STORMWATER MANAGEMENT

Although the Tweed River watershed may not appear to be an "urban" setting, the watershed is highly developed in a localized, dispersed settlement pattern. Stormwater management should be considered for rural areas, because hydrology and sediment regimes can be altered by direct input from field ditching, as well as disturbed or impervious surfaces such as driveways, roof tops, and road construction and maintenance, as noted in this report. State and municipal permitting and guidelines have been developed for managing roadwork, and the Vermont Better Backroads Program offers assistance to towns, including on-site technical assistance, project funds for addressing erosion problems, and a manual of cost-effective procedures for reducing the impact of roads on water resources (http://www.vt.nrcs.usda.gov/rc&d/bbcoverpage.html).

7.3 INDIVIDUAL OR MULTIPLE LANDOWNER INITIATIVES

This plan encourages coordination of landowner and municipal efforts to approach restoration with an eye to watershed-scale dynamics. While previous efforts have often focused on individual properties within the river corridor, and will continue to need to do so in watersheds such as the Tweed, it is important in project consideration to expand this focus to incorporate upstream and downstream impacts. This plan aims to facilitate such coordination in a way that can help landowners understand the part their properties play within the context of the watershed. The WRP (http://www.whiteriverpartnership.org/) has played a leading role in coordinating such efforts in this area of the state and continues to build on its track record of community outreach, partnerships, and implementation of protection and restoration strategies, and has frequently partnered with

Green Mountain National Forest personnel, and more recently with the Vermont River Conservancy (http://www.vermontriverconservancy.org/), on important projects within the watershed.

7.3.1 Short-term

The following short-term actions are recommended in this preliminary Tweed River Corridor Plan:

- Review of the draft plan by WRP, VT ANR-RMP, and other interested parties during May 2008
- Draft revision to incorporate feedback
- In conjunction with WRP, development of an educational and outreach brochure incorporating a bulleted approach of key ideas from this corridor plan for outreach efforts with individual landowners as well as town officials and planning agencies
- A public meeting to introduce key findings of the corridor plan to the community with WRP, Redstart, Conservation Reserve Enhancement Program (CREP) and VT ANR-RMP personnel in attendance
- Follow-up meetings with individual landowners (on downstream reaches in particular) and personnel from CREP and VT ANR-RMP
- Review of the FEH zones mapped in conjunction with this project and coordination between VT ANR-RMP Fluvial Erosion Hazard Program Coordinator Kari Dolan, Redstart Consulting (contracted to develop the corridors in conjunction with this Project), and WRP
- Discussion of the FEH corridor idea with interested parties including Two Rivers Ottauquechee Regional Commission (TRORC), Rutland Regional Planning Commission (RRPC), and the towns of Stockbridge, Pittsfield, and Killington regarding options for incorporation of these zones into the town planning process
- Incorporation of desired information into TRORC’s and RRPC’s predisaster mitigation plans and subsequent support of those plans
- Development of a bridge and culvert inventory and prioritization process in conjunction with the VT ANR-RMP and the towns of Stockbridge, Pittsfield, and Killington and other interested parties
- Consideration of a set of sizing recommendations or permitting requirements for private installations of culverts and bridges to be incorporated into the town planning process

7.3.2 Long-term

With most of the Tweed River corridor planning Project area in Stage III of channel evolution, indications are that streams will be overwidening and starting to migrate laterally in efforts to reestablish functional floodplains. This is likely to aggravate erosion problems in particular, and situations calling for bank stabilization and channelization as short-term remedies are likely to arise. Restoration plans should be consistent with the objective of returning streams to dynamic equilibrium while taking into account human and capital constraints. In some cases, land use conflicts along the river corridor may make reinforcing current stream banks a priority. However, key issues for long-term stability in the watershed will include identification and protection of attenuation assets that allow for floodplain access, reestablishment of river meander patterns, and continuity of sediment transport that will be needed to facilitate these processes. Flood hazard mitigation for downstream reaches in this watershed will be highly dependent on the reduction of stream power in upstream reaches. An alternatives analysis of four restoration and protection approaches is listed below:

No action allows the stream to return to its dynamic equilibrium with no human aid or involvement. Using this strategy often postpones land use conflicts rather than resolving them, which may increase costs and limit management options in the future. For this reason, a no action management plan is recommended only in regions where conflicts are few to none.

Continued channelization involves the sustained maintenance of historically straightened streams and frequently involves bank armoring. This alternative locks the stream into its current or historic planform and meander geometry. High construction costs, long-term maintenance, and ecological impacts make this alternative preferable only where land use conflict is high and conversions are highly unlikely.

Active restoration attempts to restore rivers to a geomorphic state of dynamic equilibrium using human-constructed meanders, floodplains, and stabilized banks. Active-restoration projects are designed to work within human constraints and, when possible, restore rivers to reference conditions. Active restoration plans tend to have high upfront costs and achieve equilibrium and attendant relative bank stability in a comparatively short time period.

Passive restoration allows the stream to return to a natural equilibrium primarily by the removal of human constraints within the river corridor. Over an extended time, the stream will regain meanders and access to its floodplain by use of its own energy and watershed input. Active buffer revegetation, along with long-term protection of the river corridor, is essential to this approach. This alternative is less expensive than active restoration, but often requires a longer time period to achieve equilibrium conditions.

7.4 PROJECT RECOMMENDATIONS—GENERAL

A passive restoration approach is recommended as a preferred approach for the Project area due to low cost, moderate land-use conflicts, and high to extreme stream sensitivity (indicating the rate at which the river will return to dynamic equilibrium given its own energy and watershed inputs). Primary goals would be regaining access to floodplains, reestablishing stream meanders, and ensuring sediment transport continuity. Active restoration may be appropriate in conjunction with passive restoration in a limited number of circumstances within this watershed when human constraints present strong limitations to floodplain or meander access on certain portions of properties that may provide these benefits elsewhere. A no-action alternative may also be considered in segments that are heavily buffered, although most reaches require some protection and buffer revegetation that would be provided by a passive restoration approach. Continued channelization is typically discouraged due to high costs and ecologic impact, but is likely to be necessary in areas of existing development and road encroachment, where restoration opportunities are limited. It is important to identify other key attenuation assets when opting for continued channelization, so that floodplain access can be ensured elsewhere in the watershed and critical functions of nutrient and sediment storage within the watershed are preserved.

Almost all reaches of the Project area are currently functioning as transport reaches, with high sediment and water flows. Given the downstream transfer of impacts, it is generally recommended that restoration efforts begin with the upstream reaches. This approach will increase the likelihood of successful project implementation in downstream reaches. There are significant constraints to channel evolution in many areas of these reaches, however, and it will be equally important in this watershed to protect downstream areas capable of functioning as attenuation assets for flow, sediment, and nutrient discharges as the upstream areas equilibrate over time. Although permitting and zoning requirements are often perceived as an onus by property owners, it is important to remember the costs borne by downstream property owners in a flood, the substantial investment in infrastructure being made by the community, and the obligation to ensure the safety of all.

8.0 ASSESSMENT AND MONITORING RECOMMENDATIONS

8.1 RECOMMENDATIONS FOR FUTURE STREAM GEOMORPHIC AND PHYSICAL HABITAT ASSESSMENT

As noted in several parts of this report, bridges and culverts (and stream fords in some areas) appear to be playing a significant role in the dynamics of this watershed, with sediment transport continuity a prominent issue for stream equilibrium as well as flood hazard prevention and mitigation. Data for many of these structures were not available at the time of this report, and it is highly recommended that efforts be made to assess the status of these structures to improve the extent and quality of this information.

It is also highly recommended that points of gravel extraction within the watershed be documented and spatially located, as many of the stream dynamics noted in Phase 2 assessment indicate both upstream and downstream impacts from these practices that are difficult to assess due to lack of information. In addition, it is recommended that a headcut identified at the confluence of the Tweed mainstem and Middle Brook in reach T6.06 in Killington be reassessed for potential impacts to upstream structures and stream dynamics. No further recommendations are made at this time.

8.2 RECOMMENDATIONS FOR MONITORING OF ASSESSED REACHES AND IMPLEMENTED PROJECTS

It is recommended that periodic Corridor Plan updates be made, preferably at least every 10 years. WRP appears situated to coordinate such efforts in conjunction with VT ANR-RMP provided funding is available. These updates could include:

- Assessment of management strategies in light of project implementation

- Revision of reach and watershed scale management options
- Updates on financial and technical resources available to interested parties

It is further recommended that WRP consider having an intern or other interested party construct a narrative history of project implementation within the watershed, with a recently completed shapefile of project locations as a starting point, as a document that will be useful for assessing the long-term results of projects, as well as a celebration of the remarkable community efforts the Partnership has been involved in.

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