BLOOD BROOK WATERSHED
CORRIDOR PLAN
NORWICH, VT

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1.0 EXECUTIVE SUMMARY

The Two Rivers-Ottauquechee Regional Commission (TRORC), as part of its Pre-Disaster Mitigation Planning grant from Vermont Emergency Management, commissioned development of a River Corridor Management Plan for the Blood Brook Watershed in Norwich, VT in 2007. Phase 1 (remote sensing) and Phase 2 (rapid field assessment) Stream Geomorphic Assessments were completed for the Blood Brook watershed in 2006 and 2007, respectively. TRORC completed a bridge and culvert assessment using geomorphic assessment protocols in 2006 as well. The Phase 1 assessment covered the entire watershed, and based on the results 7 mainstem and 7 tributary reaches of Blood Brook covering roughly 14 miles were prioritized for Phase 2 assessment. Further analysis based on these reaches (henceforth the "Project area") forms the basis for the corridor plan. The draft of this corridor plan, presented here, is designed to integrate information from the previous stream assessments and preliminary corridor planning. By assessing underlying causes of channel instability and encouraging the stream's return to equilibrium conditions, management efforts can be directed toward long-term solutions that help curb escalating costs and resolve or mitigate 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 aesthetic and recreational values of these streams. Assessment data are analyzed through the use of stressor, departure, and sensitivity analysis maps to integrate the findings in a more understandable and intuitive manner. The results are then utilized in a stepwise process designed to identify technically feasible projects consistent with managing toward equilibrium conditions and reducing conflicts with stream dynamics in an economically and ecologically sustainable manner. Whenever possible, efforts have also been made to include preliminary notes on social feasibility of project implementation and possible steps toward realizing these goals. The following list of projects, in recommended order of importance, were prioritized based on the results:

- All areas: incorporation of fluvial erosion hazard zones and belt-width corridors into planning processes, culvert sizing recommendations for private installations and continued support for the Town's culvert inventory and prioritization process
- Segment M04, Blood Brook by Norwich playing fields and Huntley Meadows
- Segment M08C, Blood Brook by Turnpike/Needham Rd intersection
- Segment M05A, Blood Brook from Moore Ln. to Sun Lion Rd.
- Segments M04-T2.01A&B, Charles Brown Brook from Blood Brook confluence to Beaver Meadow Rd. downstream of the Norwich Pool
- Segment M03-T1.01A, Bragg Brook below Heritage Ln.
- Segments M03A&B, Blood Brook from Rte. 5 to Brookside Dr.
- Segment M07A, Blood Brook downstream of Bobwhite Ln.

- Segment M07B & M08A, Blood Brook near the Turnpike/Upper Turnpike Rd. intersection
- Segment M08B, Blood Brook at bridge 1000 feet upstream of Upper Turnpike
- Segment M09A, Blood Brook, Old Orchard Ln. to Bramble Ln.

Results contributing to these recommendations in brief indicate 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 to significant downcutting of the streambed and/or channelization, the majority of these stream reaches have lost or are losing access to historical floodplains; 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 when they become too great for the power of the stream to transport further or at constrictions that reduce stream power sufficiently to accelerate deposition
- 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
- 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.
- Active restoration may be appropriate in conjunction with passive restoration in a number of circumstances within this watershed, particularly when human constraints present strong limitations to floodplain or meander access on certain portions of properties that may provide these benefits elsewhere.
- Although Norwich does not appear to be an “urban” setting by any stretch of the imagination, encroachment of roads and development are commonplace in the watershed. One of the most challenging aspects of protection and restoration work in the Blood Brook watershed is identification of areas where the river can be allowed to retain or regain floodplain access for attenuation of flow and sediment

loads. Opportunities are already limited by road encroachment and development constraints; limiting further development in floodplain and riparian corridor areas will avert future conflicts with inevitable river dynamics.

- Downstream reaches in the Project area are at a stage of channel evolution marked primarily by overwidening and lateral migration of the stream; upstream portions are actively downcutting or prone to further incision, posing potential risks to infrastructure and/ or further loss of floodplain, but also receiving significant sediment inputs from upstream
- Evolution of the channel as it attempts to reestablish equilibrium 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 Norwich explore incorporation of Fluvial Erosion Hazard zones into town planning processes. Options might include refinement of setbacks or buffers, zoning overlay districts, or similar mechanisms.
- Traditional channel management in response to erosion and lateral migration has often entailed further channelization, dredging, and hard armoring of banks for stabilization. Consistent with practices common throughout central Vermont following floods in the 1970s, extensive portions of the Blood Brook mainstem and part of Charles Brown Brook were bulldozed and windrowed with the stone removed from the channel, with hopes of conveying floodwaters more quickly through the watershed. These approaches have elevated both upstream and downstream impacts of increased stream power in particular, and are being augmented by increased stormwater inputs in some areas of the watershed.
- Portions of Turnpike Rd are particularly at risk for repeated flood damages, and Norwich may wish to perform a cost/benefit analysis on active floodplain and meander restoration or relocation of a portion of the road (either requiring willingness of landowners in the corridor) in comparison with long-term repair and maintenance costs of the road, bridges and culverts in their current locations
- The Blood Brook 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 and hydrologic inputs are elevated. 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. Due in part to the long-term processes resulting from this history of interaction, we currently find ourselves in an escalating cycle that involves an increasing level of investment to rebuild and/or protect property, infrastructure 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 (VTANR, 2003). Understanding both 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 is critical to successful implementation of such an approach. The time and thought that go into this work can contribute to transforming efforts that result in perpetual frustrated attempts at control, with often unanticipated consequences, into ones that reduce maintenance costs and increase enjoyment of enhanced resources.

2.1 PROJECT OVERVIEW

The Two Rivers-Ottauquechee Regional Commission (TRORC), as part of its Pre-Disaster Mitigation Planning grant from Vermont Emergency Management, commissioned development of a River Corridor Management Plan for the Blood Brook Watershed in Norwich, VT, including reaches (reaches are sections of stream with similar geomorphic characteristics, discussed further in Section 3.3 – Geomorphic Setting) on the Blood Brook mainstem and on Bragg Brook, Charles Brown Brook, and New Boston Brook tributaries. Phase 1 (TRORC, 2006) and Phase 2 (Redstart, 2007) Stream Geomorphic Assessments were completed for the Blood Brook watershed (Phase 1 and Phase 2 assessments are further described in section 4), and TRORC has completed a bridge and culvert assessment as well (TRORC, 2006). The Phase 1 assessment covered the entire watershed, and the Phase 2 study focused on 7 mainstem and 7 tributary reaches of Blood Brook, with a combined length of approximately 14 miles; these are the reaches analyzed for the Corridor Plan (henceforth the "Project area"). These projects were conducted under the aegis of the Vermont Agency of Natural Resources River Management Program and the Norwich Conservation Commission.

The plan presented here seeks to analyze and integrate the results of these assessments to provide the background for a community-based river corridor management plan for the Blood Brook watershed. The approach includes a strategy for prioritizing protection and restoration efforts using a process that will optimize the benefits and minimize the costs of future projects by including upstream and downstream dynamics in the planning process.

The Vermont Agency of Natural Resources River Management Program (VTANR-RMP) has been developing the framework for a process to facilitate such a prioritization strategy (VTANR, 2007b). 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. fluvial erosion hazard mitigation;
2. sediment and nutrient load reduction; and
3. aquatic and riparian habitat protection and restoration

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The Blood Brook Watershed is 18.6 square miles in area and lies almost entirely within the town of Norwich in east-central Vermont, and it drains the central portion of the town from the hills to the north and west to the confluence of Blood Brook and the Connecticut River in the southeast corner of the township. A map of the watershed and Phase 2 focus reaches for the Corridor Plan is included for reference (Fig. 1).

3.1.2 Political jurisdictions

Project reaches for the Blood Brook corridor planning area are all within the town of Norwich. A very small portion of the watershed in the southern section lies within the town of Hartford (Fig. 1); both of these towns are situated in Windsor County and are part of the 30-town planning area covered by TRORC.

3.1.3 Land use history and current general characteristics

Overall, the Blood Brook watershed in the early twenty-first century is roughly 60% forested, with a mixed coniferous-broadleaf forest dominant but closely followed by a predominantly deciduous forest (Table 1). Current forest species and age distributions indicate the watershed probably experienced extensive areas of deforestation and has reforested (Vermont has gone from 70-80% cleared to 70-80% reforested, statewide, in the last century plus). Settlement patterns and increased clearing leading up to the height of the "sheep craze" in Vermont in the late 1800s was followed by reforestation when many formerly cleared lands were abandoned as settlers moved on to more fertile lands further west in the United States (http://www.taedge.com/norwich/Town%20Plan/2-a%20History.pdf; Cronon 1983). Historical maps and photos of the Blood Brook watershed indicate extensive clearing and road development during the nineteenth century in particular (maps: http://docs.unh.edu/nhtopos/nhtopos.htm ; photos: www.uvm.edu/landscape/menu.php), with roads laid out in close proximity to the streams. The first sawmill in Norwich was erected on Blood Brook in 1766 (http://www.norwich.vt.us/), and numerous sawmills and gristmills were later built elsewhere in the watershed. Log drives on the nearby Connecticut River have been documented, and photos at both the Norwich Historical Society and nearby Dartmouth College indicate that logs were yarded for further transport by both river and rail in the village of Lewiston, near the base of the Blood Brook watershed where it joins the Connecticut River.

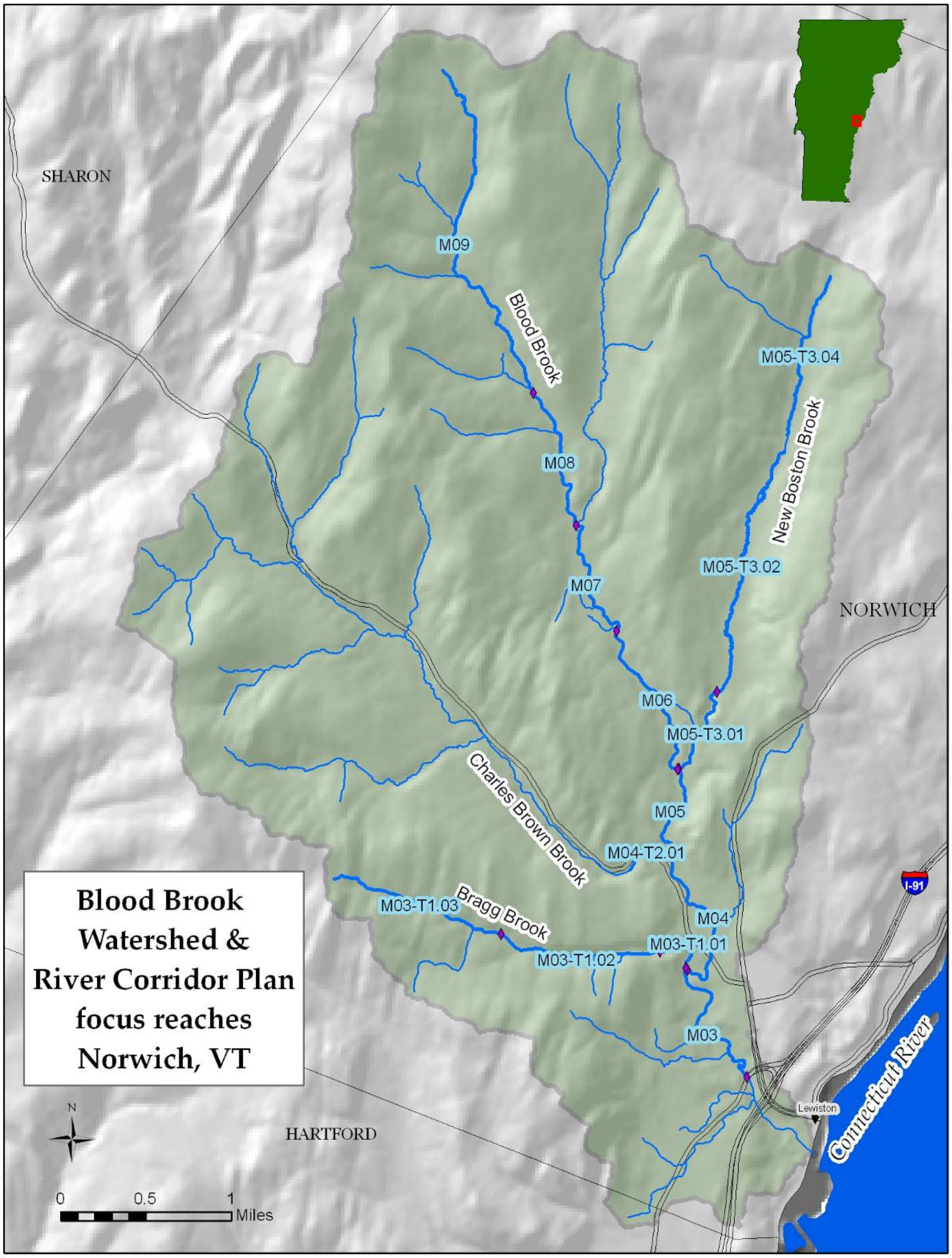


Figure 1. Overall watershed and focus reach map for the Blood Brook watershed River Corridor Planning Project area.

Table 1. Blood Brook watershed landcover/landuse (UVM-SAL 2002)

Category	
MIXED CONIFEROUS-BROADLEAF FOREST	24.3%
BROADLEAF FOREST (generally deciduous)	21.6%
CONIFEROUS FOREST (generally evergreen)	11.9%
FORESTED WETLAND	0.3%
NON-FORESTED WETLAND	0.4%
WATER	5.4%
ROW CROPS	14.6%
HAY/ROTATION/PERMANENT PASTURE	5.3%
OTHER AGRICULTURAL LAND	0.3%
RESIDENTIAL	11.0%
TRANSPORTATION, COMMUNICATION AND UTILITIES	4.9%
COMMERCIAL, SERVICES AND INSTITUTIONAL	< 0.1%
BARREN LAND	< 0.1%

Even with significant reforestation, the current overall forest cover of the watershed represents a considerably lower percentage than on the overall Vermont landscape, which is approximately 75% forested (UVM-SAL, 2002). The situation in the Blood Brook watershed is perhaps representative of landscape patterns in Vermont, however, as the lower proportions of forest cover are found in places where development and agricultural use are relatively more significant (Fig. 2). The "Upper Valley" (of the Connecticut River) area, within which Blood Brook is situated, represents a significant population, commercial, and transportation nexus with some of the perennially lowest unemployment rates in the Vermont and New Hampshire region. As such, residential, development and infrastructure pressures in the Blood Brook watershed are significant. In addition, geologic history (section 3.2, Geologic Setting) provides some particularly rich and valuable agricultural soils. These factors are reflected in land use analysis, with approximately 20% of Blood Brook watershed land in agricultural uses (including a relatively high 14.6% of total watershed land use devoted to intensively cultivated row crop production) and a significant proportion developed (roughly 15% combined residential, infrastructure, and commercial land uses; Table 1).

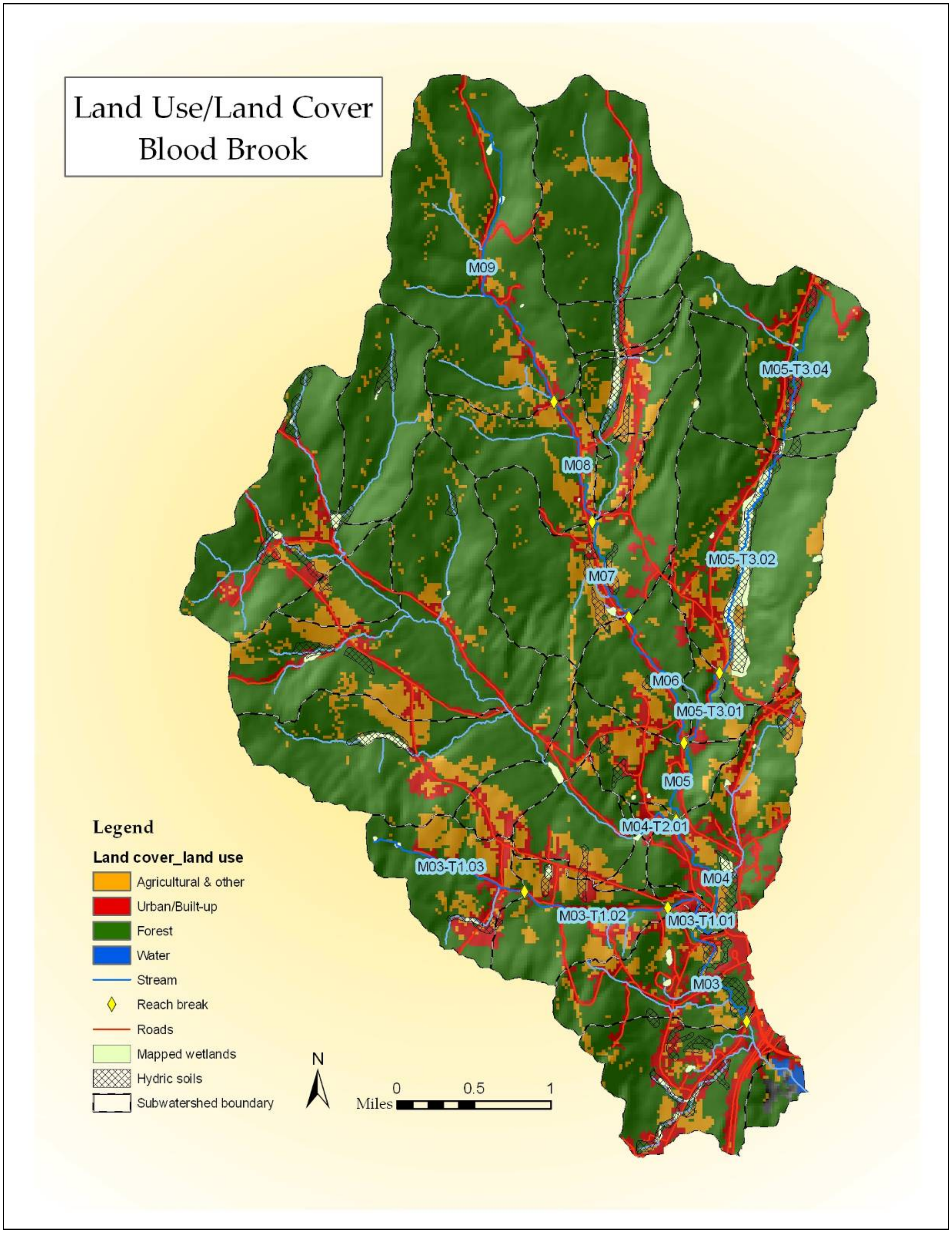


Figure 2. Landcover/landuse map for the Blood Brook watershed (UVM-SAL 2002). Subwatersheds indicate the drainage basin of a particular stream reach, designated in Phase 1 analysis

3.2 GEOLOGIC SETTING

The Blood Brook basin is ringed by hills on the north and west sides and ranges in elevation from about 1,850 feet above sea level in the northwest portion of the watershed to about 400 feet at the confluence of the Blood Brook mainstem and the Connecticut River in the southeast portion of the basin.

Primary bedrock materials in the basin, as in much of eastern Vermont, had their origins as sea sediments at the edges of great continents in ancient geologic history (Thompson and Sorenson, 2000). The limestones and mudstones prevalent in the area are some of the younger bedrock formations in the state, but they underwent significant metamorphosis before beginning the various weathering processes that now yield “sweet” soils high in calcium and other important plant nutrients (and hence valuable agricultural soils). Igneous intrusions created by volcanic activity form the basis of localized areas of more acidic, less nutrient-rich, and slower-weathering bedrock formations in the area.

The most recent glacial period (concluding 12,000 years ago) had a tremendous impact on the morphology and geologic substrate of the Blood Brook watershed. The retreating ice sheet left behind a dramatically altered landscape. During this post-glacial period, the landscape existed in the earliest stages of succession, with little terrestrial vegetation and large volumes of erodible material. The high elevations were composed of scoured, exposed bedrock, while mid- to lower elevations contained large glacial till deposits characterized by loose or compacted deposits of variable composition and moderate-high erodibility. Glacial till based on the bedrock present in this area weathers to become well-drained, loamy soil and, with the exception of river valleys, comprises the majority of the substrate in the Blood Brook watershed.

During the period of glacial retreat (from 15,000-12,000 years ago), a large lake formed that submerged lower elevations of the Blood Brook watershed. Known as Lake Hitchcock, it formed as an impoundment behind large volumes of glacial moraine deposited in central Connecticut that effectively dammed the Connecticut River valley. At its maximum extent, the lake body stretched 200 miles from Rocky Hill, CT, northward to St. Johnsbury, VT.

Fast-moving streams flowed over the newly exposed bedrock and glacial till, depositing coarse-sandy material (glacial outwash or ice-contact substrate) within stream channels and the shallow waters of the lake. Outwash deposits remain within the valleys of the Blood Brook watershed and are highly erodible. Fine silt and clay particles carried by streams settled in the deeper waters of Lake Hitchcock and formed lacustrine sediment deposits. Lacustrine soils are dominant in Blood Brook’s lower reaches.

Stream processes since the last glacial period have created alluvial deposits that comprise a large portion of the valley bottom and floodplains of the Blood Brook watershed. While these alluvial soils are generally considered of low erosion potential due to gentle slopes, the materials are actually highly erodible and can be a significant source of sediment from unstable streambanks.

Table 2 summarizes geologic and soil properties in the basin that are particularly important to watershed processes considered in the development of this Corridor Plan.

Table 2. Blood Brook basin geology and soils summary: pertinent parameters for corridor planning on Project area reaches (derived from Phase 1 summary reports)

Reach ID	Geologic materials			Valley side slopes		Soil Properties	
	Dominant	% Dom	Sub-Dominant	Left	Right	Flooding	Erodibility
Blood Brook mainstem							
M03	Alluvial	65.0	Till	Flat	Flat	Frequent	Moderate
M04	Alluvial	86.0	Ice-Contact	Flat	Flat	Occasional	Slight
M05	Ice-Contact	76.0	Alluvial	Steep	Hilly	None/Rare	Very Severe
M06	Ice-Contact	94.0	Till	Very Steep	Very Steep	None/Rare	Very Severe
M07	Ice-Contact	49.0	Alluvial	Flat	Hilly	None/Rare	Severe
M08	Till	62.0	Ice-Contact	Hilly	Steep	None/Rare	Very Severe
M09	Till	99.0	---	Very Steep	Very Steep	None/Rare	Very Severe
Bragg Brook							
M03-T1.01	Ice-Contact	63.0	Till	Flat	Hilly	None/Rare	Very Severe
M03-T1.02	Till	99.0	Ice-Contact	Very Steep	Very Steep	None/Rare	Very Severe
M03-T1.03	Till	99.0	---	Steep	Steep	None/Rare	Very Severe
Charles Brown Brook							
M04-T2.01	Ice-Contact	71.0	Till	Steep	Hilly	None/Rare	Very Severe
New Boston Brook							
M05-T3.01	Till	83.0	Ice-Contact	Very Steep	Very Steep	None/Rare	Very Severe
M05-T3.02	Alluvial	90.0	Till	Steep	Hilly	Frequent	Slight
M05-T3.04	Till		Alluvial	Steep	Very	None/Rare	Severe

3.3 GEOMORPHIC SETTING

For the purpose of geomorphic assessment and corridor planning, streams in the Project area were divided into "reaches", fourteen of which fall within the scope of this plan. A reach is a similar 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. Based on Phase 1 analysis, 7 mainstem and 7 tributary reaches were recommended for inclusion in Phase 2 field assessments (TRORC, 2006); nine of these reaches were identified as C-type streams in the Phase 1 study, with the remainder identified as B types (Table 3). The C-channel type is typically found in unconfined valleys, displays a meandering nature, and uses floodplains for sediment storage and dissipation of steam power. B-type streams are generally found in more confined valley settings with steeper slopes, and depending on their slope these kinds of streams may play important roles in sediment storage or function as transport reaches conveying high flows and sediment downstream. The importance of these factors will be discussed further in relation to sediment regime departure in section 5.1.4. Further detailed descriptions of the reaches, with associated Phase I and II observations, are found in Section 6 of this report along with maps depicting Phase 2 segment/reach delineations.

Table 3. Reaches included in corridor planning Project area, with preliminary Phase 1 reference stream type

Reach ID	Drainage Area (sq mi)	Channel Slope (%)	Valley Confinement Type	Reference Stream Type	Bedform
Blood Brook mainstem					
M03	17.64	1.3	Very Broad	C	Riffle-Pool
M04	15.73	0.9	Very Broad	C	Riffle-Pool
M05	9.27	2.0	Very Broad	C	Plane Bed
M06	6.04	2.1	Narrow	C	Riffle-Pool
M07	5.54	1.8	Very Broad	C	Riffle-Pool
M08	2.49	3.0	Very Broad	B	Riffle-Pool
M09	1.94	4.4	Narrowly Confined	B	Riffle-Pool
Bragg Brook					
M03-T1.01	1.21	4.9	Semi Confined	C	Riffle-Pool
M03-T1.02	1.17	5.9	Narrowly Confined	B	Step-Pool
M03-T1.03	0.59	7.2	Narrowly Confined	B	Step-Pool
Charles Brown Brook					
M04-T2.01	5.64	3.2	Semi Confined	C	Riffle-Pool
New Boston Brook					
M05-T3.01	2.79	2.9	Narrow	B	Step-Pool
M05-T3.02	2.63	0.8	Very Broad	C	Riffle-Pool
M05-T3.04	0.90	2.0	Very Broad	C	Riffle-Pool

3.4 HYDROLOGY

3.4.1 Blood Brook 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 Blood Brook drainage basin are summarized in the following report:

Blood Brook Streamflow Statistics Report*
Site Location: Vermont

Latitude: 43.7019
Longitude: -72.3007
Drainage Area: 18.6 mi^2

Peak Flow Basin Characteristics			
100% Statewide Peak Flow (18.6 mi^2)			
Parameter	Value	Min	Max
Drainage Area (square miles)	18.6	0.211	850
Percent Lakes and Ponds (percent)	0.12	0	6.86
Percentage of Basin Above 1,200 ft (percent)	32.1	0	100
Geographic Factor (dimensionless)	138692.3	-87	296194

Streamflow Statistics					
Statistic	Flow (ft^3/s)	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
				Minimum	Maximum
Q2	598	42	1.4	313	1140
Q5	897	40	2.3	475	1690
Q10	1120	41	3.2	587	2130
Q25	1440	42	4.6	752	2760
Q50	1700	43	5.5	876	3310
Q100	1980	44	6.3	996	3930
Q500	2700	49	7.6	1270	5740

*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 3. USGS StreamStats peak streamflow and basin characteristics statistics reports for the Blood Brook drainage basin.

Notable in these statistics is the relatively small percentage of lakes and ponds in the basin, which when present provide storage and attenuation of flows within the watershed, as well as the relatively small overall size of the watershed. The peak flow characteristics help in flood history comparison with other watersheds, as discussed below.

3.4.2 Blood Brook watershed flood history

There are no continuous-record stream gages in the Blood Brook drainage basin. The nearest gage of this type is the one found downstream on the Connecticut River mainstem at West Lebanon, NH, which spans the years 1912-2007 but records the drainage of a 4,092-square-mile area and sits below a major hydroelectric dam at Wilder that highly regulates flows and masks flood levels. The dam went into full operation in 1950, but major floods were recorded before then by the gage, in 1913, 1922, 1927, 1936 and 1938. The 1927 flood exceeded the 500-year discharge in many watersheds in Vermont and had extensive impacts in a wide area of the region (Johnson 1928). Even with dam regulation, high flow levels were recorded on the Connecticut in 1973 (Fig. 4). The 1973 flood was felt strongly in Norwich, where the Blood Brook mainstem nearly overtopped Rte. 5 where a high embankment completely blocks the floodplain at the base of reach M03 (Figs. 5, 6) and took out several bridges (notably at Beaver Meadow Rd. on reach M04; Fig. 6).

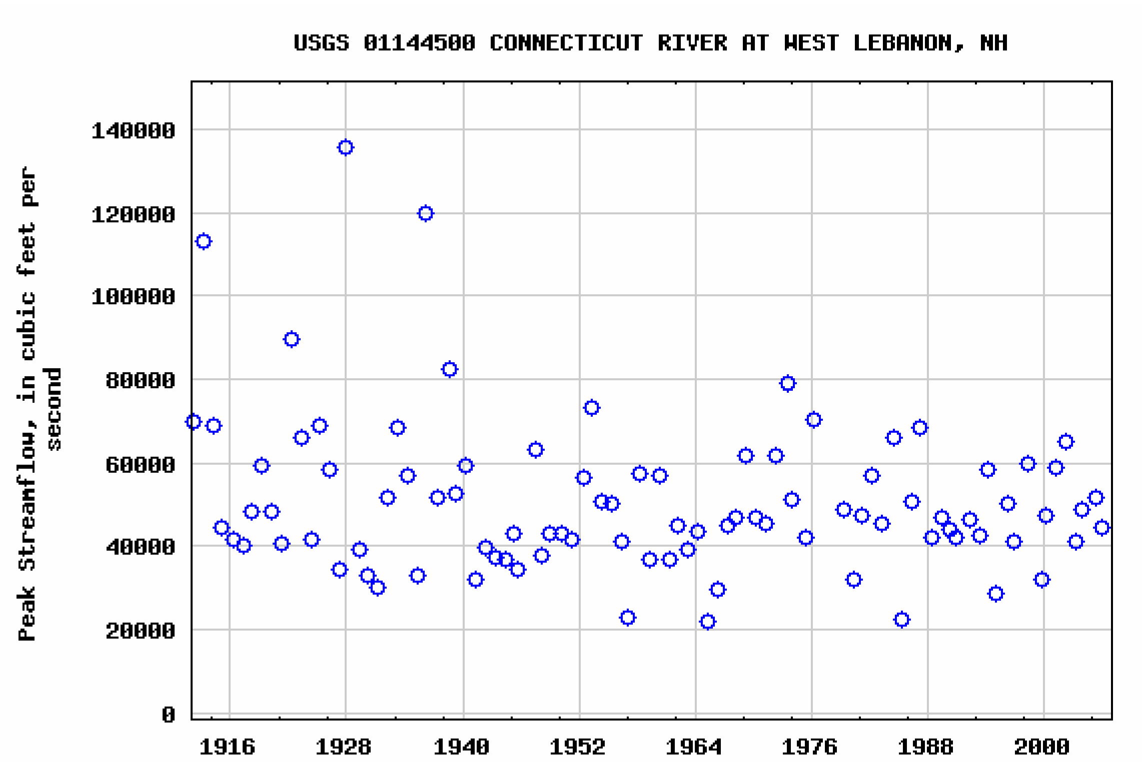


Figure 4. Peak flow discharge levels at USGS stream gage, Connecticut River at West Lebanon.

Figure 5. This debris catcher is located at the mouth of a 70-foot-long box culvert that runs underneath Rte. 5 at the downstream end of reach M03 on the Blood Brook mainstem, where floodwaters nearly overtopped the embankments in 1973 (Fig. 6).

Figure 6. Photos from 1973 show floodwaters rising up the embankments at Rte. 5 (also shown in Fig. 5) , as well as the damage caused at the Beaver Meadow Rd. bridge just north of the Norwich village center (photos courtesy of Andy Hodgdon).

A gage on Ayers Brook in Randolph, a tributary of the White River located approximately 30 miles west of the Blood Brook basin, has a continuous record spanning the years from 1941-2006 and monitors an unregulated drainage basin closer in size to Blood Brook (30 square miles). The 50-year-flood peak discharge was exceeded on Ayers Brook in 1973 and 1952, while the 200-year-flood level was exceeded in 1998 (Fig. 7). The 1998 flood was experienced in the Blood Brook basin as well, though not as extensively.

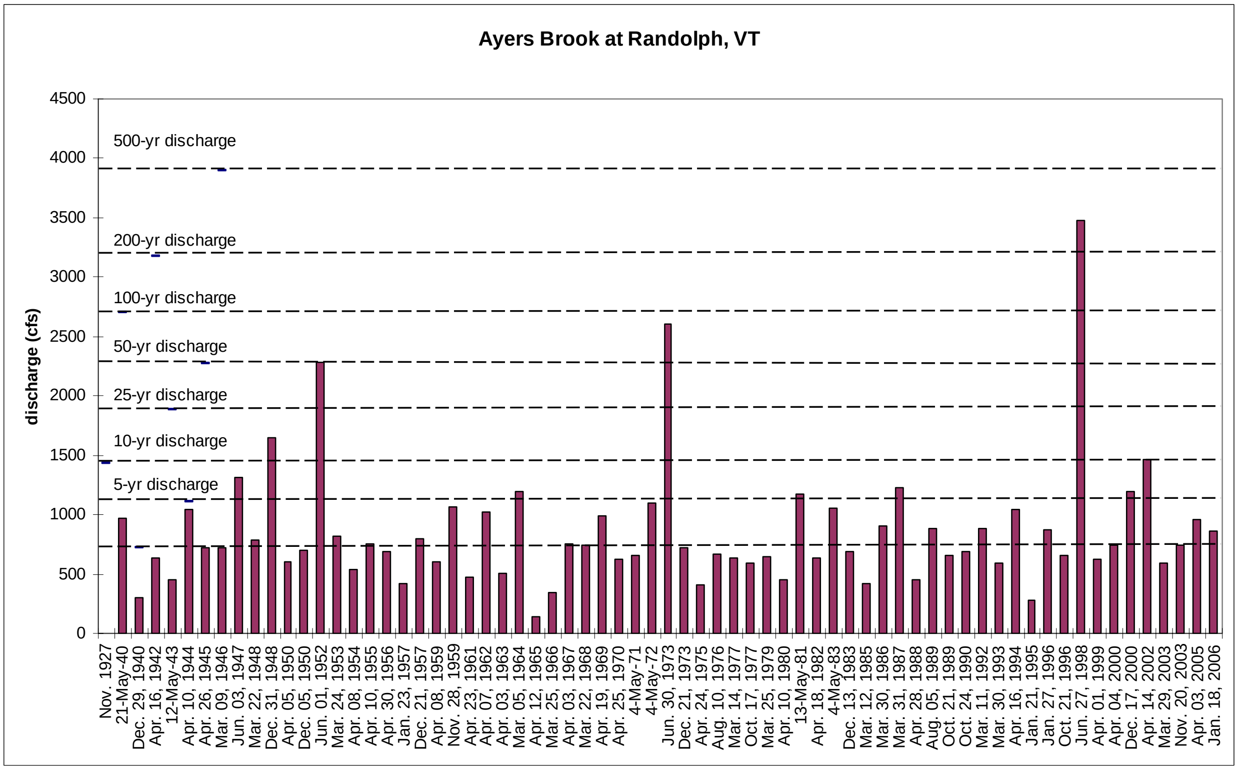


Figure 7. Annual and flood-level peak streamflows at the USGS continuous record stream gage on Ayers Brook. (Water years run from Oct. 1-Sept. 30.)

Farther downstream of Ayers Brook on the mainstem of the White, the USGS gage at West Hartford has a continuous record spanning 1912-2006, but it monitors a drainage basin of 630 square miles; unlike the West Lebanon gage on the Connecticut, this gage monitors an unregulated river. The magnitude of the 1927 flood is reflected in the records from this gage (Fig. 8), as are the tempering effects of the larger drainage basin on flow volumes, including inputs from more localized floods. The 10-year discharge level was exceeded at West Hartford in 1998, whereas the smaller basin upstream at Ayers Brook exceeded the 200-year discharge at that time (Fig. 7). Also noticeable is the fact that the 1973 flood, which impacted Blood Brook heavily, was experienced in a wider geographic area as well, approaching the 100-year discharge on Ayers Brook and the 25-year discharge at West Hartford. A vital point to note, however, is 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.

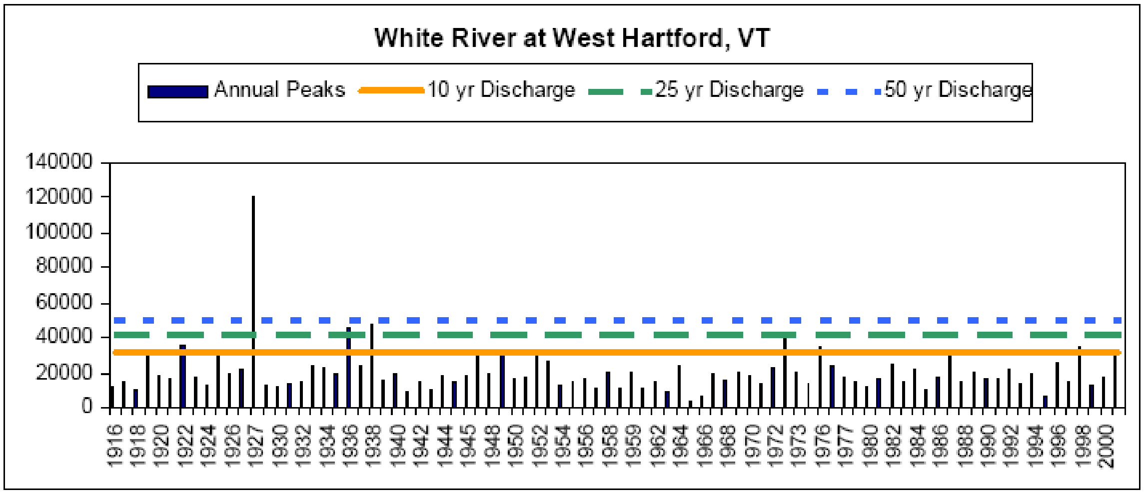


Figure 8. Annual and flood-level peak streamflows at the USGS continuous record stream gage on the White River (VTANR 2007e, Appendix L).

3.5 ECOLOGICAL SETTING

The Blood Brook watershed hosts a native resident fish community that includes brook trout (pers. comm., Rich Kirn, VT Fish & Wildlife Fisheries biologist, and Andy Hodgdon, Norwich Road Foreman). Although hydrologically connected to the Connecticut River, however, the watershed appears to be somewhat ecologically severed from that water body by a box culvert that passes under Rte 5 just downstream of the reaches included in this corridor plan (Fig. 5), as well as by having numerous culverts identified as obstructions to aquatic organism passage (TRORC, 2006). The base of Blood Brook where it reaches the confluence of the Connecticut, downstream of the corridor planning area, is frequently used by birds along the Connecticut River flyway as well as by a large variety of other wildlife. The importance of the Connecticut as a flyway may be contributing to the spread of invasive plants through bird dispersal, however, and buckthorn, honeysuckle, Japanese barberry, and burning bush were notable presences along the lower reaches of the Blood Brook mainstem in particular.

Reach M03, the first stretch of the Blood Brook mainstem included in the corridor planning area, features a mix of open farmland and regenerating floodplain forest, and Blood Brook and its tributaries have been a focal point for the Norwich Conservation Commission and other interested parties in development of priorities for an Open Space planning process (NCC, 2004). Wetland habitats are extensive along New Boston Brook in particular, and numerous beaver ponds are present in the upper portions of the watershed on most streams.

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. Limestone and mudstone bedrock in the area contribute to potential habitat for a number of uncommon or rare species, however, and support a number of butternuts (a USDA Forest Service Region 9 sensitive species) within the riparian corridor. Other species of concern are not well documented.

4.0 METHODS

4.1 STREAM GEOMORPHIC ASSESSMENT

In an effort to provide a sound basis for decision-making and project prioritization and implementation, the Vermont Agency of Natural Resources (VTANR) has developed protocols for conducting geomorphic assessments of rivers. The results of these assessments provide the scientific background to inform planning in a manner that incorporates an overall view of watershed dynamics as well as 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 (VTANR, 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 channel 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, Phase 1 Stream Geomorphic Assessment (SGA) and a Bridge and Culvert Survey (utilizing geomorphic assessment protocols (VTANR, 2007e) Appendix G) were completed by TRORC in 2006. Phase 2 SGA was conducted by Redstart Forestry & Consulting in 2007.

All Phase 1 and Phase 2 data were entered into the most current version of the VTANR Stream Geomorphic Assessment Database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm), where they are available for public viewing. 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, beaver dams, 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 Stream Geomorphic Assessment Tool (SGAT) ArcView extension, which permits geographic information systems implementation of the data. Maps displaying this information are being made available for public use as well (http://maps.vermont.gov/imf/sites/ANR_SGAT_RiversDMS/jsp/launch.jsp?popup_blocked=true).

4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS

Quality assurance/quality control (QA/QC) checks were initially conducted by TRORC and Redstart utilizing the QA/QC tools developed by VTANR and implemented through the SGA Database. 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 (VTANR, 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 Blood Brook (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, the rows of stone pushed up along the midstream portions of the Blood Brook mainstem (particularly in reach M05 along Turnpike Rd. from the bridge on Sun Lion Rd. downstream toward the Moore Ln. bridge) in bulldozing after the 1973 flood were noted as berms. Although this captures some of the functional equivalence in high flows, the changes in bed condition from removal of stone are noted here as well.

It should also be noted that although 14 reaches were included in Phase 2 assessment (and were broken into 27 segments) in the Blood Brook watershed, two reaches (M05-T3.02 and M05-T3.04, both on New Boston Brook) and two segments at the upstream ends of streams (M03-T1.03C - Bragg Brook and M09C - Blood Brook), did not receive full assessments due to the influence of impoundments and wetlands (in accordance with VTANR Phase 2 protocols). These reaches received field assessments of a limited set of parameters, but because of the anomalous dynamics of these systems, they were not assessed using the geomorphic assessment portions of the protocols and may accordingly be lacking data for analysis in some portions of this plan. Impounded reaches were excluded in Phase 1 analysis as well and thus lack data for some parameters.

5.0 RESULTS

The following sections summarize pertinent results of Phase I and II SGA data collection for the Blood Brook watershed. Stressor, departure, and sensitivity maps are presented as a means to integrate the data that has 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 towards a healthy equilibrium (VTANR, 2003). 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 (VTANR, 2007b). Section 5.1 presents an analysis of stream departure from reference conditions: sub-sections 5.1.1 and 5.1.2 summarize watershed-scale stressors on the physical stability and habitat conditions of the stream, and sub-sections 5.1.3 - 5.1.6 characterize reach-scale stressors. Sub-section 5.1.7 characterizes the hydrologic and sediment regime departures for reaches included in Phase 2 assessment within the Blood Brook 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 as to the potential rate of subsequent channel evolution (VTANR, 2007b) Sec. 5.2).

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 (VTANR, 2007b).

As discussed in section 3.1.3 (Land use history and current general characteristics) indications are that the Blood Brook watershed experienced extensive areas of deforestation historically, and portions of the watershed are still lacking in forest cover due to significant development and agricultural use. Historical clearing throughout much of Vermont in the late 18th and 19th centuries initially contributed to higher runoff of both water and sediment, with attendant changes in hydrology including higher peak flows, direct runoff discharges, and lower and seasonally later minimum flows, as well as earlier spring snowmelt and more frequent winter thaws on slopes exposed to greater levels of sunlight (USDA-FS, 2000). Significant inputs of sediment, derived from erosion and gullying on exposed soils of denuded hillsides, accrued in the river valleys. Removal of large woody debris from stream channels (which, particularly in steeper gradient streams, often provides vital storage of sediments higher in the watershed), was often related to use of streams for log drives, mill power and agricultural uses. In conjunction with road development and other encroachments, channel straightening, and bank armoring, these alterations served 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. While it is difficult to quantify the extent of these hydrologic changes, 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. It is also worth noting that hemlock stands (and possibly other conifers) can enhance the stability of water temperatures and diversity of aquatic biota in comparison with hardwood stands, in part by moderating the hydrologic inputs, temperature, and groundwater recharge cycles to streams in response to precipitation and snow melt (Evans, 2002). Purer stands of conifers represent approximately 12% of the forest cover in the overall watershed (Table 1) with hemlock common along streams at elevations such as those in the Blood Brook watershed.

While intensified hydrologic impacts 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 Blood Brook watershed. Although Phase 1 assessment generally indicated greater than 75% forest cover in the upper portions of the watershed, this figure dropped significantly in a number of sections of the watershed where development and agricultural use were higher. In addition, upper portions of the Blood Brook mainstem and Bragg Brook are receiving significant stormwater inputs to the stream (Fig. 9). Analysis of hydric soils overlaid with current crop and developed land uses (Figure 2, Sec. 3.1.3) also indicates likely impairment of wetland attenuation of precipitation inputs in the Blood Brook watershed, although lack of baseline historical data makes it difficult to quantify and establish impact thresholds for this parameter. Intensively cultivated crop land can generate considerable inputs of overland runoff as well as sediment when exposed during significant precipitation events. Phase 1 and 2 geomorphic assessment also indicated that many roads and crop lands have been ditched over time, further contributing to intensified hydrologic inputs to streams (Fig. 9).

The legacy of deforestation and current lack of forest cover in areas of the watershed form a backdrop that often exacerbates or otherwise influences adjustment processes evidenced in the assessed streams. Where downcutting has been sufficient to limit access to historical floodplains and high volume flows are now contained within the channel, 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.

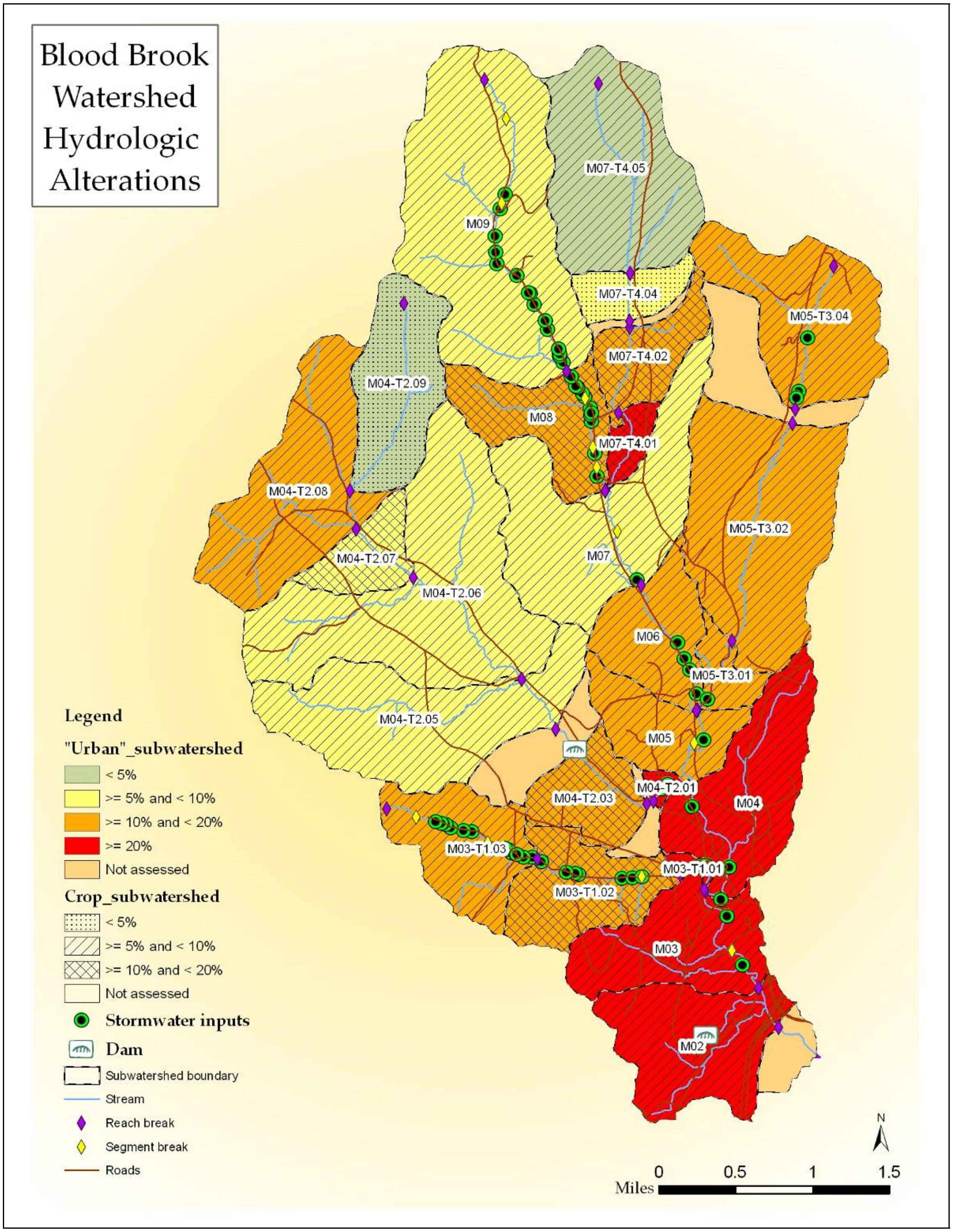


Figure 9. Hydrologic alterations map for the Blood Brook corridor planning area.
Labels denote the entire subwatershed draining to the stream reach indicated by the label.
Subwaterhseds 'Not assessed' were excluded from Phase 1 analysis due to the influence of wetlands and impoundments.

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 VTANR River Corridor Planning Guide (VTANR 2007b):

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.

Lower portions of the Blood Brook watershed have gentle terrain along valley walls, but the higher portions of the streams generally have steeper valley walls and erodible geologic materials, providing the backdrop for a characteristically high sediment load system. At the watershed scale, Phase 1 analysis indicated that the large majority of soils along the streams of the Blood Brook watershed have an erodibility rating of "very severe" (Table 2, section 3.2). Lower erodibility ratings occur in portions of the watershed where valley side slopes are flat or moderately hilly, but these same stream reaches often have highly erodible stream banks (which can be a significant source of sediment) due to dominant or sub-dominant alluvial soil parent materials. In some portions of the basin, erodible materials present in sideslopes are particularly sensitive to stormwater inputs and other changes in hydrology (Fig. 10), yet another contribution to a high sediment-load system.

Figure 10. Highly erodible soils on sideslopes above New Boston Brook, like many sedimentary and lacustrine deposits in the Blood Brook watershed, are sensitive to increased stormwater inputs.

A primary exception to this overall characterization as a high sediment load system exists in portions of the watershed where beaver ponds, other impoundments, and wetlands serve to retain sediments higher in the watershed. This can leave immediate downstream reaches “sediment starved”, subjecting erodible bed and bank materials to increased water power (because it is carrying lower sediment loads) and also more sensitized to other hydrologic changes (e.g., stormwater inputs or land clearing) that increase the power of water in the stream. One illustration of this is the installation of a check dam on Charles Brown Brook (Fig. 11) downstream of the “Norwich Pool” impoundment (the dam in reach M04-T2.03, Fig. 9), likely placed to limit upstream migration of headcutting and erosion processes due in part to trapping of sediments above the impoundment. “Headcuts” (or less dramatic “nickpoints”) can be formed by, and contribute to, the deepening of a stream channel when the power of moving water begins to erode the upstream end of an area of different elevations in the streambed. Headcuts can sometimes move upstream rapidly in flood conditions. Similar processes can begin to move upstream on tributaries that are at a higher elevation than the mainstem, eroding sediments that are then contributed to the sediment load of the mainstem in a process of “tributary rejuvenation”. If downcutting of the channel is significant enough, vertical instability of adjacent steep banks may contribute to “mass wasting” or “mass failures” that can also contribute large amounts of sediment to the system.

Figure 11. The check dam in this photo was likely installed to limit upstream migration of headcuts and bed degradation below the Norwich Pool impoundment, indicating sensitivity of the stream to the "sediment starving" resulting from retention of sediments above the dam in reach M04-T2.03.

Geomorphic instability related to the downcutting of streambeds in the Blood Brook basin (and loss of floodplain access) has resulted in channel adjustment processes that are manifested largely in redistribution of fine sediment loads in concentrated areas of the lower Blood Brook mainstem in particular, while larger bed load sediments were observed to be moving through the watershed in episodic flood-related discharges often appearing as sediment "slugs". Tributary rejuvenation was noted in all reaches, along with numerous mass failures, indicating substantial contributions of sediment from tributaries as these portions of the watershed adjust their elevations to reconnect with incised reaches downstream. Mass wasting and gully formation were contributing large amounts of various sized sediments along portions of the upper Blood Brook mainstem and Bragg Brook in particular (the latter largely related to a single water-line blowout below which the sideslope has begun to heal over - the sediment discharge is still moving through the stream network, however). Deposition appeared particularly heavy in reach M08, between Old Orchard Lane and Upper Turnpike roads, and reaches M03 and M04 below the confluence of Charles Brown Brook and the Blood Brook mainstem. A rapid watershed-scale visual assessment of sediment load indicators suggests significant aggradation occurring in these areas (Fig. 12). Flood chutes were common in the upper portions of the mainstem and along Bragg Brook, as well as reach M06 (mainstem above New Boston Brook confluence). Further stressors in this system can include sheet and gully erosion on exposed soils of tilled croplands in the river corridor in particular, where ditching systems can transport these materials easily in runoff events. Figure 12 illustrates watershed-scale distribution of sediment load indicators in the Blood Brook drainage basin related to all of these processes in a manner designed to indicate areas of high activity, but these are also detailed at a finer scale in the reach maps in Chapter 6.

Important implications of this sediment regime in the Blood Brook basin include elevated erosion levels in reaches undergoing adjustments related to increased stream power, plus a high likelihood for channel avulsions and similar planform changes (e.g., flood chute access and formation) in high water events as well as heavy deposition (and thus further possibilities for changes in channel direction) when stream power decreases at constrictions such as bedrock outcrops and undersized culverts and bridges.

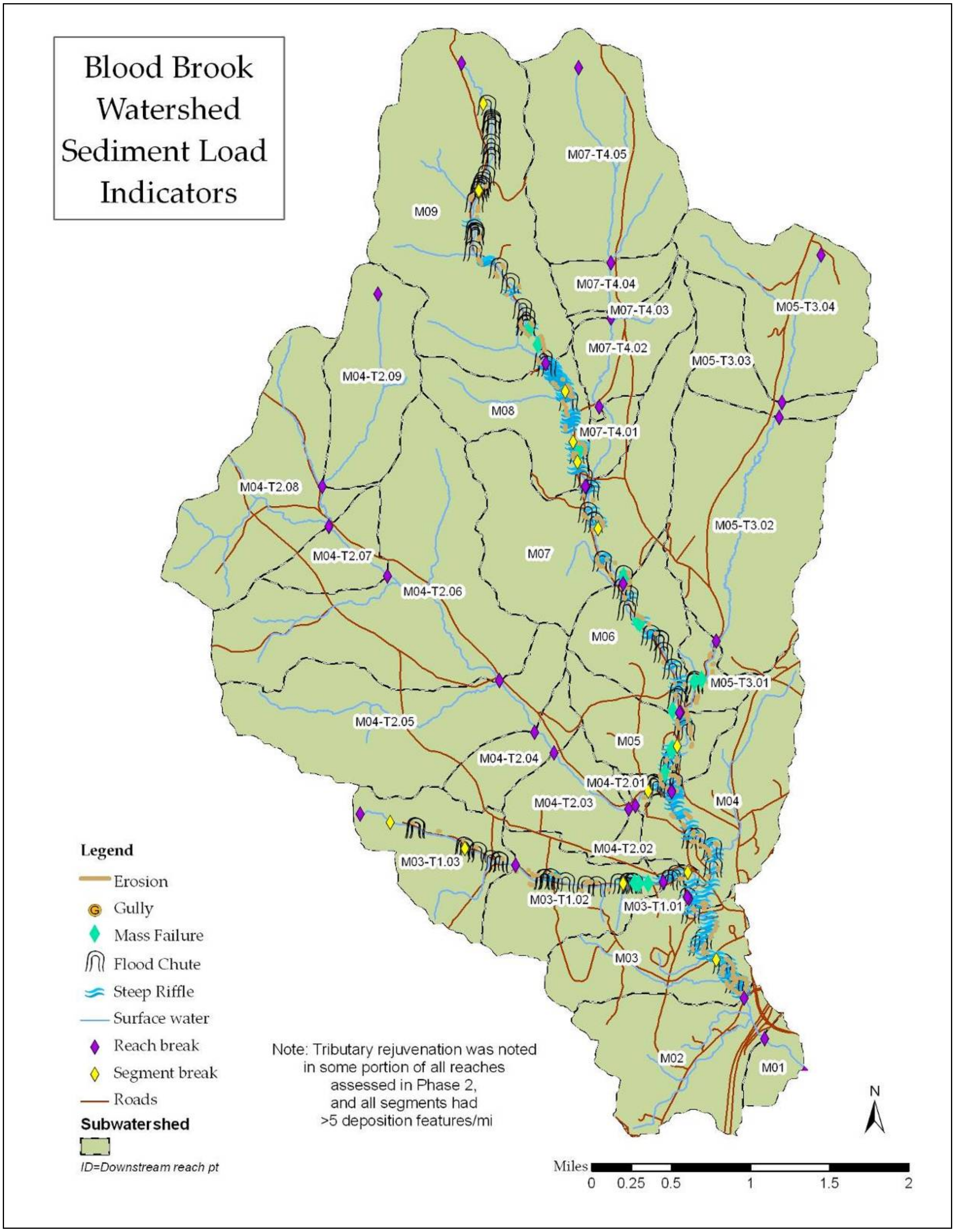


Figure 12. Watershed-scale sediment load indicators for the Blood Brook corridor planning area. Labels denote the entire subwatershed draining to the stream reach indicated by the label. Symbols only appear on reaches included in the Phase 2 analysis.

5.1.3 Reach scale sediment regime 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 (VTANR, 2007b). 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 semi-quantitative 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 (VTANR 2007b).

		Sediment Transport Increases	**Sediment Transport Decreases**
	Stream power as a function of:	**Stressors that lead to an Increase in Power**	**Stressors that lead to an 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
	Resistance to power by the:	**Stressors that lead to an 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 (sub-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 (sub-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 Blood Brook watershed are identified in Table 5.

Table 5. Blood Brook 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.

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream Segment	Hydrologic	Sediment Load	Stream Power	Boundary Resistance
M03A	Increased flows Deforestation Roads and ditching (P1 - subshed: >20% urban, 5-10% crop) Wetland loss: Moderate (subshed: crop)	Increased load Trib rejuv (in M03B), mass failures on Bragg Brook P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Erosion: >=20%	Increased stream power: slope Straightening: 5-20% Encroachment: 5-20% Sediment reduction: below waterfalls at Elm St Decreased stream power: slope Constriction at Rte 5, base of segment Decreased stream power: depth P2 Deposition range: >5/mi Beaver activity downstream end Increased stream power: depth below waterfalls at Elm St	Decreased bed resistance Snagging – debris catcher, removal Decreased bank resistance LB Erosion: >=20% RB Erosion: 5-20% RB subdom buffer <25ft Increased bank resistance RB revetments: 5-20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M03B	Increased flows Deforestation Roads and ditching (P1 - subshed: >20% urban, 5-10% crop) Wetland loss: Moderate (subshed: crop)	Increased load Trib rejuv (in M03B), mass failures on Bragg Brook P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: 5-20% Sediment reduction :below waterfalls at Hopson Rd, Constrictions/ Controls: >5 LB revetments: 5-20% Increased stream power: depth below waterfalls at Hopson Rd	Increased bed resistance 4 waterfalls, 2 ledge grade controls Decreased bank resistance LB Erosion: >=20% RB and LB subdom buffer <25ft Increased bank resistance LB revetments: 5-20%
M04	Increased flows Deforestation Roads and ditching (P1 - subshed: >20% urban, 5-10% crop) Wetland loss: Moderate (subshed: crop)	Increased load Trib rejuv; mass failures in M05 P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: >=20% Decreased stream power: slope Dogleg, base of segment Decreased stream power: depth Dogleg deposition; Bragg Brook confluence	Decreased bed resistance Windrowing, dozing Decreased bank resistance LB and RB Erosion: 5-20% RB dom buffer <25ft Increased bank resistance LB and RB revetments: 5-20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M05A	Increased flows Deforestation Roads and ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low (subshed: crop)	Increased load Mass failures P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: 5-20% Decreased stream power: depth Charles Brown Brook confluence	Decreased bed resistance Windrowing, dozing Decreased bank resistance LB and RB Erosion: 5-20%
M05B	Increased flows Deforestation Roads and ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low (subshed: crop)	Increased load Mass failures, New Boston and M06 P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: >20% Increased stream power: depth Windrowing (effectively bermed)	Decreased bed resistance Windrowing, dozing Decreased bank resistance LB Erosion: >20% RB Erosion: 5-20% LB dominant buffer <25 ft Increased bank resistance LB revetments: >20% RB revetments: 5-20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M06	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low (subshed: crop) 4 stormwater inputs	Increased load Mass failures in-reach and upstream P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5/mi Decreased load Reduction below 5 constrictions and one grade control	Increased stream power: slope Straightening: >=50% Encroachment: >20% Increased stream power: depth Dredging 4 stormwater inputs Decreased stream power: slope 3 constrictions Decreased stream power: depth Upstream of New Boston Brook confluence	Decreased bed resistance Dozing, dredging, snagging Increased bed resistance Ledge grade control (1) Decreased bank resistance RB Erosion: 5-20% RB subdom buffer <25ft Increased bank resistance RB revetments: 5-20%
M07A	Increased flows Deforestation Roads, ditching (P1 - subshed: 5-10% urban, 5-10% crop) Wetland loss: High (subshed: ag and develop-ment - esp. corridor)	Increased load Mass failures bottom of reach P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: >20% Decreased stream power: depth Upstream of 2 small unnamed trib confluences	Decreased bed resistance Dozing, snagging Decreased bank resistance RB Erosion: 5-20% Dominant buffer <25ft both banks Increased bank resistance RB revetments: >20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M07B	Increased flows Deforestation Roads, ditching (P1 - subshed: 5-10% urban, 5-10% crop) Wetland loss: High (subshed: ag and development - esp. corridor)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment: 5-20%	Decreased bed resistance Dozing, snagging Decreased bank resistance LB Erosion: 5-20% RB dominant, LB subdom buffer <25ft
M08A	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 10-20% crop) Wetland loss: Low 1 stormwater input (11 subshed)	Increased load Mass failure upstream in M08B P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Localized reduction below 1 constriction	Increased stream power: slope Straightening: >=50% Encroachment: >20% Decreased stream power: slope 1 constriction and 1 grade control (weir) Decreased stream power: depth Upstream of unnamed trib (Needham) confluence	Decreased bed resistance Dozing, snagging Increased bed resistance weir (log check dam – requires maintenance) Decreased bank resistance Dominant buffer <25ft both banks Increased bank resistance RB revetments: >20%
M08B	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban,10-20% crop) Wetland loss: Low 1 stormwater input (11 subshed)	Increased load Mass failure P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Localized reduction below 1 constriction	Increased stream power: slope Straightening: >=50% Encroachment: >20% Decreased stream power: slope 1 constriction	Decreased bed resistance Dozing, snagging Decreased bank resistance LB erosion >20% RB erosion 5-20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M08C	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 10-20% crop) Wetland loss: Low 4 stormwater inputs (11 subshed)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5	Increased stream power: slope Straightening: >=50% Encroachment:>20% Increased stream power: depth 4 stormwater inputs Decreased stream power: depth Upstream of unnamed trib confluence (drains pond above Old Orchard Ln)	Decreased bed resistance Dozing Decreased bank resistance LB erosion 5-20% RB erosion 5- 20% Increased bank resistance LB revetments 5-20%
M08D	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 10-20% crop) Wetland loss: Low 5 stormwater inputs (11 subshed)	Increased load Mass failures upstream in M09A P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Localized reduction below 3 constrictions	Increased stream power: slope Straightening: >=50% Encroachment: >20% Increased stream power: depth 5 stormwater inputs Decreased stream power: slope 3 constrictions	Decreased bed resistance Dozing, snagging Decreased bank resistance LB erosion 5-20% RB erosion 5-20% RB dominant buffer <25ft LB subdom buffer <25ft Increased bank resistance LB revetments >20% RB revetments >20%

Blood Brook mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M09A	Increased flows Deforestation Roads, ditching (P1 - subshed: 5-10% urban, 5-10% crop) Wetland loss: Low 14 stormwater inputs (15 subshed)	Increased load Mass failures P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 8 constrictions and 5 grade controls	Increased stream power: slope Straightening: >=50% Encroachment: >20% Increased stream power: depth 14 stormwater inputs Decreased stream power: slope 8 constrictions Decreased stream power: depth Upstream of unnamed trib	Decreased bed resistance Dozing, snagging Increased bed resistance 5 ledge grade controls Decreased bank resistance LB erosion 5-20% RB erosion 5-20% Increased bank resistance LB revetments 5-20%
M09B	Increased flows Deforestation Roads, ditching (P1 - subshed: 5-10% urban, 5-10% crop) Wetland loss: Low 1 stormwater input (15 subshed)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 1 constriction and 10 grade controls	Decreased stream power: slope 1 constriction, beaver dam Increased stream power: depth 1 stormwater input Decreased stream power: depth Beaver dam	Increased bed resistance 10 ledge grade controls
M09C	Increased flows Deforestation Roads, ditching (P1 - subshed: 5-10% urban, 5-10% crop) Wetland loss: Low Stormwater inputs not assessed	Sediment load Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)

Bragg Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M03-T1.01A	Increased flows Deforestation Roads, ditching (P1 - subshed: >20% urban) Wetland loss: High 2 stormwater inputs (3 subshed) Water line break in M03-T1.02 (one-time, 1970s)	Increased load Mass failures upstream in M03-T1.02 (one-time water-line break, 1970s) P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Localized reduction below 1 constriction	Increased stream power: slope Straightening: >=50% Encroachment: >20% Increased stream power: depth 2 stormwater inputs Decreased stream power: slope 1 constriction Decreased stream power: depth Sediment slugs from M03-T1.02	Decreased bed resistance Snagging Decreased bank resistance LB dominant buffer <25ft
M03-T1.01B	Increased flows Deforestation Roads, ditching (P1 - subshed: >20% urban) Wetland loss: Low 1 stormwater input (3 subshed) Water line break in M03-T1.02 (one-time, 1970s)	Increased load Mass failures upstream in M03-T1.02 P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Localized reduction below 1 grade control	Increased stream power: slope Encroachment: >20% Increased stream power: depth 1 stormwater input, 1 grade control Decreased stream power: depth Sediment slugs from water line break	Decreased bed resistance Snagging Increased bed resistance 1 ledge grade control Increased bank resistance RB revetments 5-20%

Bragg Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M03-T1.02A	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 10-20% crop) Wetland loss: Low 1 stormwater input (7 subshed) Water line break in M03-T1.02 (one-time, 1970s)	Increased load Mass failures (one-time water-line break, 1970s) P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 8 grade controls	Increased stream power: slope Encroachment: >20% Increased stream power: depth 1 stormwater input, 8 grade controls Decreased stream power: slope 8 constrictions Decreased stream power: depth Upstream of unnamed trib confluence	Increased bed resistance 6 ledge, 2 waterfall grade controls
M03-T1.02B	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 10-20% crop) Wetland loss: Moderate (subshed – ag, development) 6 stormwater inputs (7 subshed) Water line break in M03-T1.02 (one-time, 1970s)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 5 constrictions and 1 grade control	Increased stream power: slope Encroachment: >20% Increased stream power: depth 6 stormwater inputs, 1 grade control Decreased stream power: slope 5 constrictions	Increased bed resistance 1 ledge grade control Decreased bank resistance LB erosion 5-20% LB dominant buffer <25 ft Increased bank resistance LB revetments 5-20%

Bragg Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M03-T1.03A	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Moderate (subshed – ag, development) 7 stormwater inputs (14 subshed) Water line break in M03-T1.02 (downstream; one-time, 1970s)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 6 constrictions and 3 grade controls	Increased stream power: slope Encroachment: >20% Increased stream power: depth 7 stormwater, 3 grade controls Decreased stream power: slope 6 constrictions Decreased stream power: depth Upstream of unnamed trib alluvial fan mid-segment	Increased bed resistance 3 ledge grade controls Decreased bank resistance Dominant buffer <25ft both banks Increased bank resistance RB revetments 5-20%
M03-T1.03B	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low 7 stormwater inputs (14 subshed) Water line break in M03-T1.02 (downstream; one-time, 1970s)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 1 constriction and 14 grade controls	Increased stream power: slope Encroachment: >20% Increased stream power: depth 14 grade controls Decreased stream power: slope 1 constriction	Increased bed resistance 12 ledge, 2 waterfall grade controls

Bragg Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M03-T1.03C	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low Stormwater inputs not assessed (14 subshed)	Sediment load Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)

Charles Brown Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M04-T2.01A	Increased flows Deforestation Roads, ditching (P1 - subshed: >20% urban) Wetland loss: Low "Norwich Pool" impoundment upstream (store/release)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load "Norwich Pool" impoundment upstream (store/release) and waterfall grade control	Increased stream power: slope Straightening: >20% Encroachment: >20% Increased stream power: depth Waterfall grade control Decreased stream power: slope Constriction and check dam above falls	Increased bed resistance 1 waterfall, 1 weir (log check dam – requires maintenance) Decreased bed resistance Dozing Decreased bank resistance LB erosion 5-20% Dominant buffer <25ft both banks Increased bank resistance Revetments >20% both banks

Charles Brown Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M04-T2.01B	Increased flows Deforestation Roads, ditching (P1 - subshed: >20% urban) Wetland loss: Low "Norwich Pool" impoundment upstream (store/release)	Increased load P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: 1 (unique in Project area) Decreased load "Norwich Pool" impoundment upstream (store/release)	Increased stream power: slope Straightening: >=50% Encroachment: >20% Decreased stream power: depth Upstream of Blood Brook confluence	Decreased bed resistance Dozing Decreased bank resistance RB erosion 5-20% LB dominant buffer <25ft Increased bank resistance LB revetments >20% RB revetments >20%

New Boston Brook Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M05-T3.01	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Low (moderate upstream)	Increased load Mass failure P2 Deposition range: >5/mi P2 sum steep riffles & mid-bars: >5 Decreased load Reduction below 5 constrictions and 1 grade control	Increased stream power: slope Straightening: >5-20% Encroachment: >20% Increased stream power: depth 1 ledge grade control Decreased stream power: slope 5 constrictions	Increased bed resistance 1 weir Decreased bank resistance RB erosion 5-20% Subdominant buffer <25ft both banks Increased bank resistance LB revetments 5-20% RB revetments 5-20%

New Boston Brook Stressors Identification Table	Watershed Input Stressors		Reach Modification Stressors	
M05-T3.02	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Moderate - crop Stormwater inputs not assessed	Sediment load Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)	Not assessed (wetlands and impoundments)
M05-T3.03	Increased flows Deforestation Roads, ditching (P1 – not assessed) Wetland loss: Moderate - development	Sediment load Not assessed (impoundments)	Not assessed (impoundment)	Not assessed (impoundment)
M05-T3.04	Increased flows Deforestation Roads, ditching (P1 - subshed: 10-20% urban, 5-10% crop) Wetland loss: Moderate – ag, development 3 stormwater inputs Multiple impoundments	Sediment load Overall loading not assessed (wetlands and impoundments) But localized increase below one stormwater gully, reductions below constrictions and impoundments noted	Increased stream power: slope Encroachment: 5-20% Increased stream power: depth 3 stormwater inputs, scour below 4 constrictions Decreased stream power: slope Above gully deposition Decreased stream power: depth Above 4 constrictions	Increased bed resistance 1 dam Decreased bank resistance Subdominant buffer <25ft both banks

5.1.3a Channel slope modifiers

Results for the Blood Brook Project area indicate that primary stressors contributing to slope increases include extensive straightening of the channel along with road and development encroachment (Fig. 13). Phase 1 analysis indicated 50% to 100% of total reach length having been straightened in half of the stream reaches in the Project area; 14 of 23 segments assessed in Phase 2 exceeded a 50% straightening threshold. Encroachment exceeded 20% of stream length in 18 of 23 segments assessed in Phase 2. Roads and developments within the river corridor contribute to an increased channel slope when structural measures are used to protect those encroachments.

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 plays a significant role in enhancing sediment transport capacity as a result of the increased slope and depth at flood stage. Tributary rejuvenation noted in all Project reaches (Fig. 12) indicates that these streams have incised. Tributary rejuvenation generally suggests increased sediment contributions from tributaries as downcutting proceeds upstream, a process often evidenced in the presence of headcuts or localized nickpoints. These indicators of active incision processes can occur along lower reaches as well, and numerous headcuts (most of these were nickpoints rather than deeper headcuts) were noted in Phase 2 assessment along the Blood Brook mainstem (above reach M05) and Bragg Brook in particular. In this type of sediment regime, the enhanced transport capacity due to slope increases 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, and undersized bridges and culverts are frequently focal points for this type of deposition.

Dams and beaver ponds also present slope decreases in the stream, but depending on their location may exacerbate the dynamics contributing to slope increases. This appears to be the case in the Project area, as these structures are primarily located in the upstream portions of the watershed and appear to be contributing to "sediment starving" (see sub-section 5.1.2, Watershed sediment regime stressors) that actually increases stream power downstream.

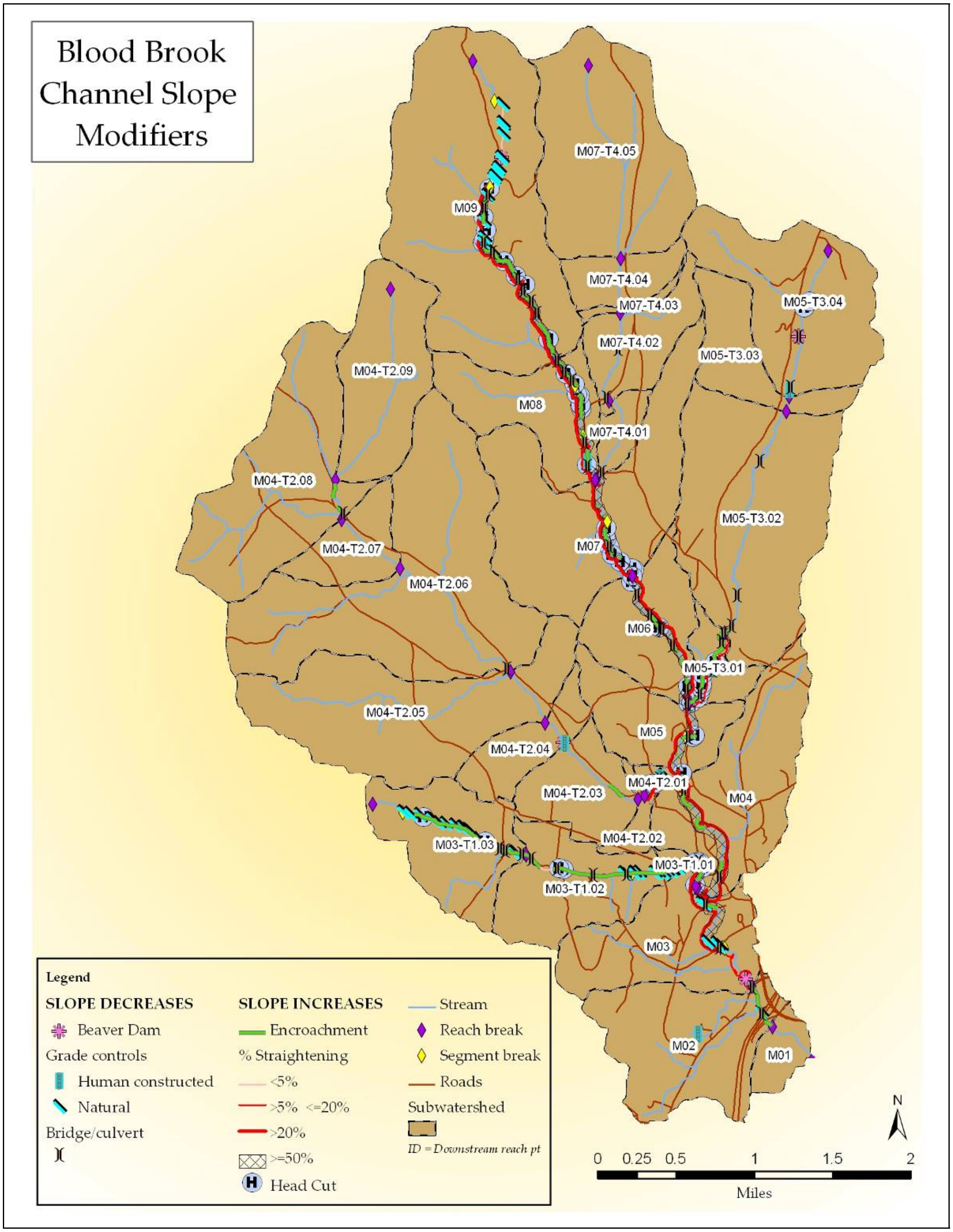


Figure 13. Reach-scale stressors: Channel slope modifiers maps for the Blood Brook corridor planning area.

As was common practice in many portions of central Vermont during flooding in the 1970s, bulldozing of the stream channel occurred along Turnpike Rd. and Beaver Meadow Rd (Blood Brook mainstem), and Beaver Meadow Rd. from the "Norwich Pool" impoundment downstream (Charles Brown Brook) following the 1973 flood (pers. comms., Linda Cook, former selectboard member, and Andy Hodgdon, Norwich Road Foreman, Sept. 2006). More recent dredging occurred in reach M06 (Fig. 14), and a large flow and sediment increase resulted from a one-time water line rupture upslope of Bragg Brook in the 1970s (pers comms., Andy Hodgdon, Dec. 2006; Fig. 15). These impacts initiated a process of bed degradation that has increased slope and also limited access of the stream to much of its historical floodplain, further increasing stream power. Upstream migration of degradation processes is still occurring, but has been limited to some extent by the presence of critical bedrock and ledge grade controls in upper portions of the watershed (Fig.13).

Figure 14. Bulldozing after the 1973 flood pushed windrows of stone from the stream and exposed lodgment till (grey stripe in the bed of the stream at left) in reach M05 and other areas, and more recent channelization has occurred in reach M06 on the Blood Brook mainstem (right).

Figure 15. Mass failure/gully along Bragg Brook appears related to a one-time break in a water line upslope of the stream, which contributed to channel slope increases through downcutting and and localized slope and depth decreases through significant deposition.

5.1.3b Channel depth modifiers

Phase 1 and 2 data collection in the Blood brook Project area indicated significant road or berm encroachment in at least some portion of all but one reach assessed in Phase 2 (18 out of 27segments showed >20% of the segment with these encroachments), which has served to reduce the effective width of the valley and floodplain in 9 of 12 reaches receiving full assessments (Fig. 17). 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 mid-channel deposits and the wider channel that results from backwater conditions. Stream power is reduced in these areas, leading to further deposition. Heavy deposition was noted in all segments assessed in Phase 2 (Fig. 17). Recent dredging in Reach M06 on the Blood Brook mainstem also contributes to the potential for more shallow depths during low to high flows due to the over-widened channel that typically results from dredging. Stream dynamics related to this practice are complex, however, and it is also important to recognize that headcutting up and downstream of dredging sites can contribute to channel incision in flood flows. Bridge and culvert impacts can be complex as well: the structures themselves tend to increase stream depth and power in high flows, but undersized bridges and culverts (as well as grade controls) often present constrictions that serve to decrease stream power and evidence deposition up and/or downstream of such structures. If bridges and culverts are not sized adequately to transport sediment as well as water in high flows, significant deposits can accumulate, decreasing stream depth and increasing risks for channel avulsions and outflanking of structures (Fig.16). This is a prominent issue in the Blood Brook corridor planning area (Redstart, 2007; TRORC, 2006), and only 7 of 27 segments assessed in Phase 2 had fewer than two constrictions or grade controls per mile of stream.

Stormwater inputs were documented in Phase 2 fieldwork throughout the study area, but were particularly concentrated in the upstream portions of the Blood Brook mainstem and on Bragg Brook (Fig. 17). 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 16. Cumulative deposition now obstructing a culvert at Old Orchard Ln. indicates the culvert is not sized adequately to transport sediment as well as water at high flows (photo courtesy of TRORC 2006).

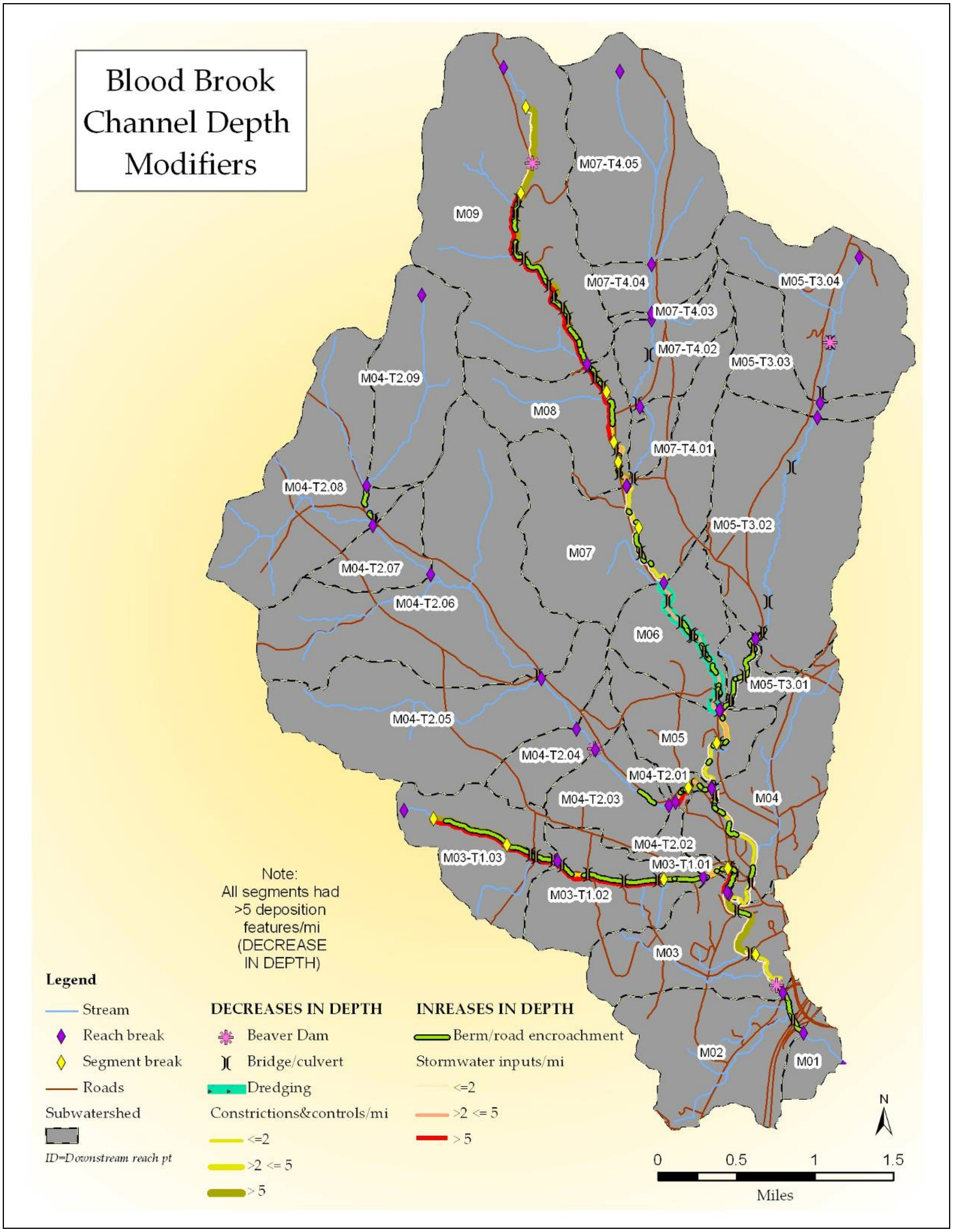


Figure 17. Reach-scale stressors: Channel depth modifiers maps for the Blood Brook corridor planning area.

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 of the Project area. Cobble was predominant in most of the watershed, and important ledge and bedrock grade controls include waterfalls near the Elm St. and Hopson Rd. bridges in segment M03B as well as the old mill site on Charles Brown Brook (segment M04-T2.01A). Although considered coarse bed, cobble deposition deriving from upstream erosion had formed plane bed features in several portions of the Project area. Localized areas of heavy deposition in upper reaches on the Blood Brook mainstem and Bragg Brook, as well as in the lower mainstem reaches of M03 and M04 (more expectedly) were reflected in gravel materials being predominant in Phase 2 assessments. The bed in these areas should be considered less resistant to erosion. In addition, bulldozing and dredging along significant portions of the mainstem have removed much of the stone from the stream bed, exposing it to greater possibilities for erosion in high flows and increasing downcutting evidenced by frequent occurrence of headcuts/nickpoints in much of the Project area (Fig. 14; Fig. 13).

Bank materials in the Blood Brook watershed are also easily erodible in high flows, and cohesive lower bank materials were predominant in only 7 of the 27 segments assessed in Phase 2: 3 on Bragg Brook plus the uppermost portions of the mainstem (M09), along with more limited sections of the mainstem in reaches M03, M05, and M07. High levels of erosion were noted in the lower mainstem reaches of the Project area, with moderate to high levels documented along most of the rest of the mainstem and the midstream portions of Bragg Brook. Much of this erosion coincided with areas where vegetated buffers were lacking or diminished (Fig. 18); it is clear that the presence of wooded buffers greatly aids the stability of the banks in the corridor planning area. With road and development encroachment commonplace along the streams of the watershed, minor to locally extensive areas of riprap revetments have been placed throughout the watershed to limit erosion in areas of development and agricultural use where these buffers are lacking (Fig. 18), exacerbating some of the channel slope and depth modifications discussed in sections 5.1.3a and 5.1.3b above. The non-cohesive nature of the majority of bank materials in the Project area, in conjunction with factors increasing stream power, have made some of these revetments subject to failure.

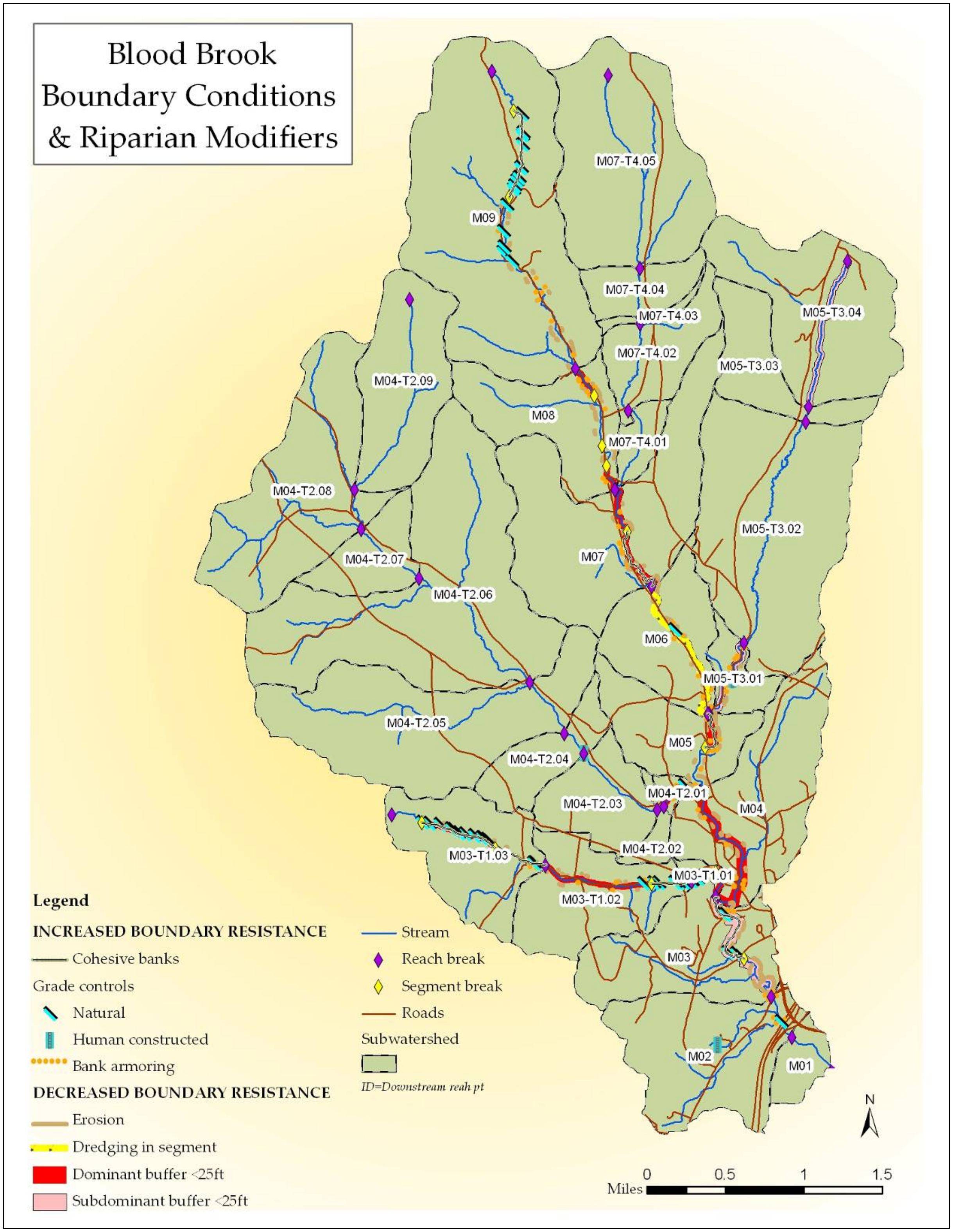


Figure 18. Reach-scale stressors: Boundary conditions & Riparian modifiers maps for the Blood Brook corridor planning area.

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 and lead to an uneven distribution of power and sediment. 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 (VTANR, 2007b).

Phase 1 assessment identifies a 'reference type' for all reaches, and Phase 2 assessment helps confirm that typing or identify departures from equilibrium conditions associated with that stream type and subsequent adjustment processes a stream may be undergoing to re-establish equilibrium. Reference conditions for the majority of reaches in the Blood Brook Project area were C and B type systems (based primarily on natural valley confinement and valley slope; see Table 3, Section 3.3). The C channel type is typically found in unconfined valleys, displays a meandering nature, and uses floodplains for sediment storage and dissipation of steam power. Under reference conditions, the sediment regime of the C type reaches in the Project area – including the length of the Blood Brook mainstem and the downstream reaches of the tributaries – 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 (Table 4 ; (VTANR, 2007b), pp. 34-36). The most downstream reaches assessed on Blood Brook and Bragg Brook, plus reach M08 off of Turnpike Rd in the upper portion of the mainstem, were expected to have gravel substrates; all other reaches would be characterized with cobble substrates under reference conditions.

Reference conditions for the upstream portions of the streams assessed in Phase 2 would be a B type step-pool system (the single exception was M03-T1.03, the upstream portion of Bragg Brook, where the steeper slope and narrowly confined valley would mean an A type characterization). All of these reaches would be characterized by cobble substrates under reference conditions and would typically demonstrate a Transport sediment regime.

Table 4. Pertinent reference sediment regime parameters for Blood Brook corridor planning project reaches (VTANR, 2007b).

Sediment Regime	Natural Valley Types	Reference Stream Types	Applicable Blood Brook Project Reaches
Transport	NC, SC, NW Valley Slope >= 2%	A3, B3, B4	M03-T1.02, M03-T1.03 M05-T3.01
Coarse Equilibrium (in = out) & Fine Deposition	NW, BD, VB Valley Slope < 2%	C3, C4	M03, M04, M05, M06, M07, M08, M09 M03-T1.01, M04-T2.01

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

3 = Cobble substrate; 4 = Gravel substrate

Sediment regime departure is determined based on a number of parameters measured in Phase 2 assessments (VTANR 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 5. Pertinent data for characterizing Blood Brook Project area existing sediment regime using Phase 2 data (VTANR, 2007b).

<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>

Schumm (Schumm, 1977; Schumm, 1984) has described five stages of channel evolution (F-stage model; Fig. 19) for reaches where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time, paraphrased 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.

Phase 2 measurements found incision (downcutting) of both a current and historical nature throughout the Blood Brook corridor planning Project area, indicating limited access (and potential ongoing loss) of the streams to historical floodplains in many reaches in conjunction with extensive straightening and channelization that have served to increase stream power. The reference sediment regime in the Project area has thus been converted to one in which the majority of reaches in the Project area function as transport reaches, with coarse deposition occurring primarily when stream power is reduced or sediment load exceeds the carrying capacity of the stream (Fig. 20).

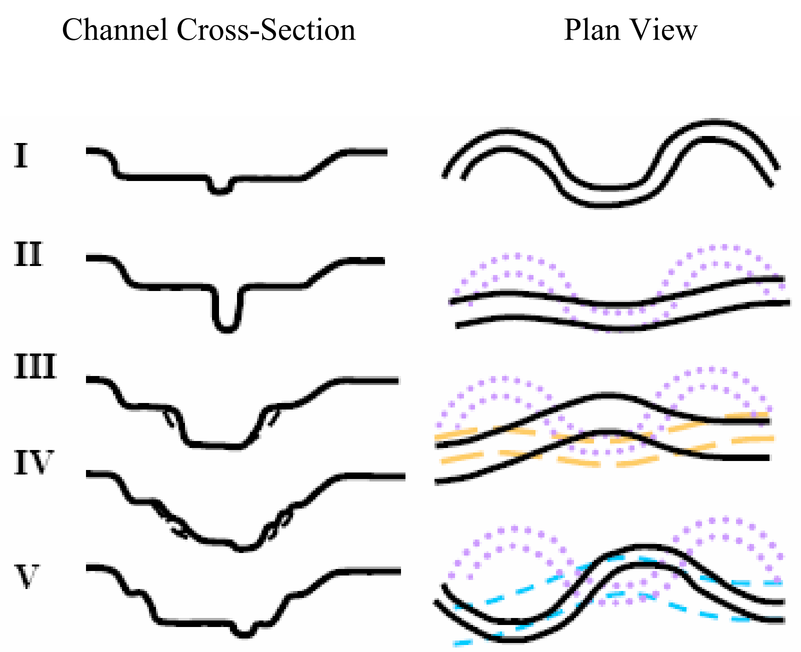
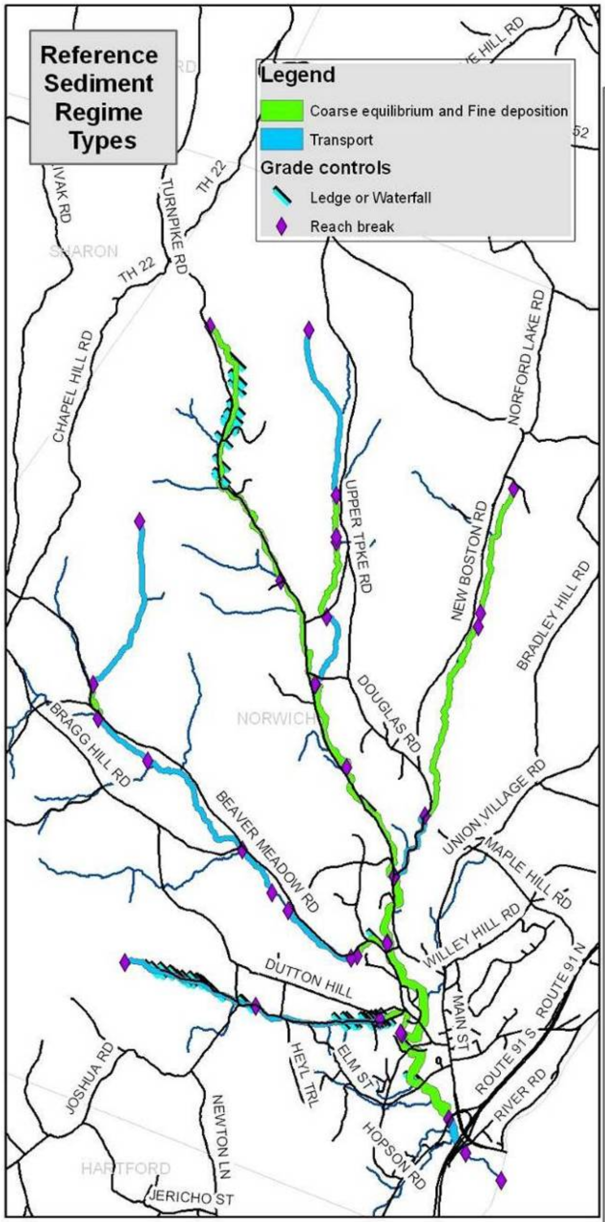


Figure 19. Channel evolution process showing channel downcutting or incision in Stage II (cross-section), widening through Stages III and IV, and floodplain re-establishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a flood-driven process taking place over decades (VTANR 2007a).



Blood Brook 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 most reaches on the Blood Brook mainstem and New Boston Brook as C type streams. These reference type streams utilize access to their floodplains as a primary means to store sediment and nutrients, and the reference sediment regime is generally 'Coarse Equilibrium (in = out) & Fine Deposition'. Other tributary reaches in the Project area were identifed as primarily B type streams, with a few steeper gradient A type streams. Reference streams of these types would exhibit a 'Transport' sediment regime.

Due to changes in hydrology and sediment storage and transport within the watershed (largely related to channelization and encroachment issues, 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 three reaches within the Blood Brook Corridor Planning Project area have been converted to transport 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 bedrock controlled areas or undersized culverts).

Although important grade controls have limited downcutting in both downstream and upstream portions of the watershed, much of the stream channel in the Project area has incised sufficiently to prevent access to historical floodplains, and upstream portions of the mainstem are continuing to incise. Channel evolution will 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 exacerbate 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 higher in the watershed.

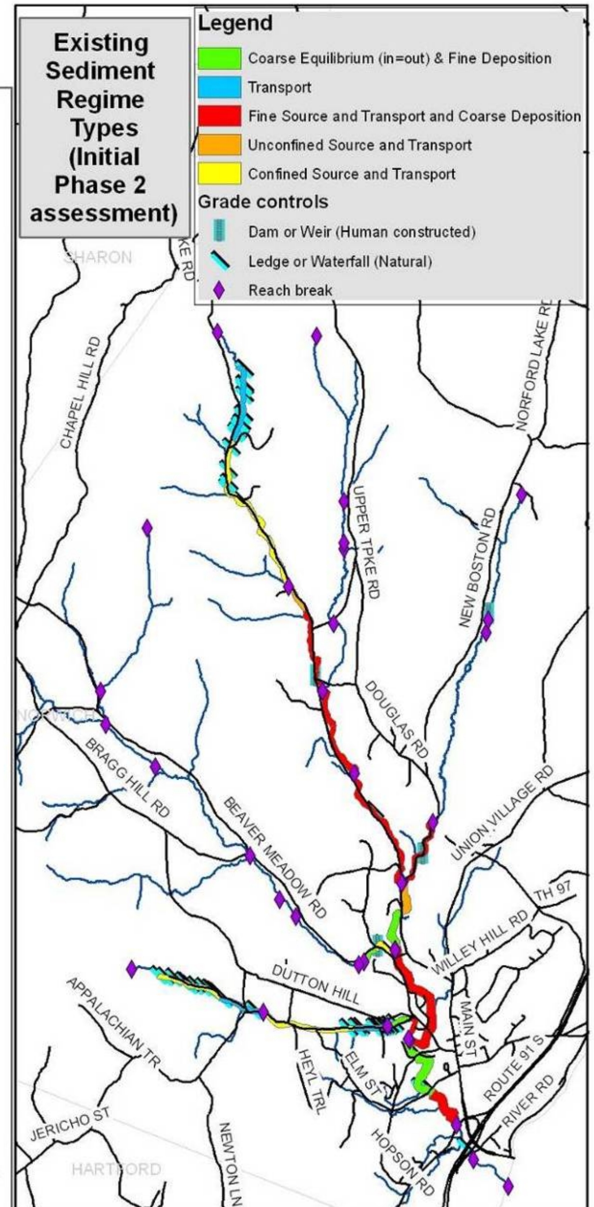


Figure 20. Sediment regime departure in the Blood Brook corridor planning Project area.

The active nature of degradation processes in portions of the Project area strongly influences the evolutionary prospects of the streams, likely impacts in flood events, and potential project identification and prioritization. Phase 2 assessments indicated the mainstem of Blood Brook generally at stage II to stage III in the upstream reaches, with the lower reaches moving further into stage III (Table 6). Although initial Phase 2 assessment characterized reach M05A with a Coarse Equilibrium and Fine Deposition sediment regime, this was based on an incision ratio of 1.25 being classed as <1.3. Active incision in this portion of the stream following bulldozing, plus extensive straightening and windrowing of stone along the banks (not technically considered bank armoring, but see Fig. 21), led to reclassification of the sediment regime for this segment as a Fine Source and Transport and Coarse Deposition reach, consistent with other pertinent classification criteria beyond incision ratio and bank armoring (Table 6).

Figure 21. Windrowing of stone along reach M05 is not technically considered bank armoring, but frequent presence, along with a very broad valley, incision ratio of 1.25, and extensive erosion and mass failures elsewhere in segment M05A led to sediment regime reclassification from Coarse Equilibrium and Fine Deposition to Fine Source and Transport and Coarse Deposition. In segment M05B there was additional bank armoring present and less coarse deposition, and the sediment regime was classed as Unconfined Source and Transport.

Stream segments evaluated in Phase 2 on the tributary reaches of Charles Brown and New Boston Brooks were also assessed as being in Stage II, but bed degradation is limited by the presence of bedrock and ledge in some areas. On Charles Brown, installation of a check dam below the Norwich Pool in segment M04-T2.01B has limited incision artificially, and coarse sediment is retained above the dam; the original sediment characterization as Coarse Equilibrium and Fine Deposition was thus modified to Confined Source and Transport (Table 6).

Table 6. Sediment regime characterization criteria for Blood Brook Project area reaches (see Table 5 above for color coding and brief description of sediment regimes,).

Reach/Segment (Sediment Regime[1])	Incision ratio	Valley Type	Straightening(%) Bank armor (%-Range)	Channel Evolution Stage[2] Geomorphic Condition	Existing Stream type
Blood Brook					
M03-A (FSTCD)	2.2	VB	15.7 5-20	III (F) Poor	C4
M03-B (CEFD)	1.1	VB	53.5 5-20	IIb (D) Fair	B4c
M04-0 (FSTCD)	1.8	VB	88.7 5-20	III (F) Fair	C3
M05-A (FSTCD)	1.25	VB	100 <5	III (F) Poor	C3b
M05-B (UST)	1.7	BD	100 >20	III (F) Fair	C3b
M06-0 (FSTCD)	1.9	NW	100 5-20	II (F) Fair	C3b
M07-A (FSTCD)	2.0	NW	100 5-20	II (F) Fair	C3
M07-B (FSTCD)	1.7	SC	100 <5	III (F) Fair	B3
M08-A (FSTCD)	1.5	VB	100 5-20	III (F) Fair	C4b
M08-B (FSTCD)	3.2	NC	100 <5	III (F) Fair	B4
M08-C (FSTCD)	1.7	VB	100 5-20	III (F) Fair	C3b
M08-D (UST)	3.4	SC	100 >20	III (F) Poor	B4
M09-A (CST)	1.7	NW	59.7 5-20	II (F) Fair	C3b
M09-B (T)	1.2	NC	0 <5	I (D) Good	B3

[1] Brief descriptions of Sediment Regime types indicated by the letters in parentheses are given above in Table 5.
[2] (F) or (D) stage evolution model primarily based on resistance to erosion of bed material: see text below.
Gray highlight indicates an anomalous parameter (from original sediment regime characterization) that influenced decision to choose the designated sediment regime indicated in this table (see text above)

Reach/Segment (Sediment Regime[1])	Incision ratio	Valley Type	Straightening(%) Bank armor (%-Range)	Channel Evolution Stage[2] Geomorphic Condition	Existing Stream type
Bragg Brook					
M03-T1.01-A (FSTCD)	1.5	SC	76.3 <5	III (F) Fair	E4b
M03-T1.01-B (CEFD)	1.2	NW	0 5-20	III (F) Fair	C4b
M03-T1.02-A (T)	1.2	NC	0 <5	IIb (D) Fair	B3a
M03-T1.02-B (CST)	2.0	NC	0 5-20	III (F) Fair	B3a
M03-T1.03-A (CST)	1.8	NC	0 5-20	II (F) Fair	B4c
M03-T1.03-B (T)	1.0	NC	0 <5	I (D) Good	A3
Charles Brown Brook					
M04-T2.01-A (CST)	1.3	SC	23.8 >20	IIc (D) Fair	B3c
M04-T2.01-B (CST)	1.2	SC	92.1 >20	II (F) Fair	C3b
New Boston Brook					
M05-T3.01-0 (FSTCD)	1.7	NW	17.8 5-20	II (F) Fair	C3b

[1] Brief descriptions of Sediment Regime types indicated by the letters in parentheses are given above in Table 5.
[2] (F) or (D) stage evolution model primarily based on resistance to erosion of bed material: see text below.
Gray highlight indicates an anomalous parameter (from original sediment regime characterization) that influenced decision to choose the designated sediment regime indicated in this table (see text above)

Three out of six segments on Bragg Brook were at stage III (widening and lateral migration), with two segments listed at stage II but again containing grade controls that limit further incision. M03-T1.03B (upstream end of Bragg Brook - Stage I, in regime) was a notable exception to the predominant stages of channel evolution in the Project area. In segments with bedrock and ledge present, a different process of channel evolution from that summarized above is occurring (D-stage model), whereby a stream with a bed significantly more resistant to erosion than its banks moves more rapidly into aggradation and lateral adjustment processes (VTANR, 2007e)

Appendix C). In this model, a stream that departs from a stable Stage I moves through subsequent processes paraphrased as follows:

IIb. Limited incision, migration of headcuts and erosion of riffle features leading to formation of planebed. Subsequent evolution can occur, but it is not uncommon for a Bc planebed stream type to persist for decades

IIc. Widening/Migration – Stream attempts to re-establish equilibrium through bank erosion and redeposition, increasing channel length and sinuosity as weak riffle-pool features are added to the planebed through aggradation

IId. Aggradation and widening, planform adjustment - Stream becomes extremely depositional and may become braided; water shifts through different channels and chute cutoffs, continues to erode banks, and eventually begins to reestablish riffle-pool features through aggradation that begins to narrow the channel to a single thread

III. Stabilizing – Widening and planform adjustments; stream moves back to pre-adjustment channel dimension, pattern and profile that may or may not be at a lower elevation in the landscape; sedimant transport capacity (energy grade) moves back into balnce with the sediment loading regime within the watershed

It should be noted that the resistant nature of the bed in these situations can actually direct increased stream power toward the banks, and these stream types can be dramatically altered by rapid or catastrophic channel avulsions onto more erodible sediments nearby, leaving the former channel abandoned (VTANR, 2007e), Appendix C).

Substantial deposition caused segment M03-T1.03A on Bragg Brook to join the downstream reaches and reach M08, which were expected by Phase 1, as characterized by gravel substrates. Increased stream power following extensive channel straightening has likely been exacerbated by increased stormwater inputs (Fig. 9), and evolution of the stream is now utilizing contributions of sediment from tributary rejuvenation and erodible banks in the watershed (evidenced in particular by the significant number of mass failures) to attempt to balance that power with increased sediment loading. Heavy deposition evident in these areas (Fig. 12) indicates the function of these segments as valuable attenuation assets (Table 7) and places a high priority on protecting these functions in areas that do not have lateral constraints that conflict with channel evolution processes likely to follow from this deposition (primarily widening and lateral migration).

Table 7. Blood Brook corridor planning Project area Departure Analysis Table indicating where river segments are constrained from adjustment, converted to transport streams, and/or have existing or future potential as a place to attenuate sediment load.

BBW_Departure Analysis Table	Constraints		Transport		Attenuation (storage)		
River Segment	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
Blood Brook mainstem							
M03A		Human: Agriculture		X	X	X	X
M03B	Natural: Waterfalls	Human: Development, roads, agriculture Natural: Bedrock outcrops			X		somewhat limited
M04		Human: Development, roads, agriculture, rec		X	X	X	limited
M05A		Human: Roads, agriculture		X	X	X	X
M05B		Human: Development, roads		X	X		limited
M06		Human: Roads, development, agriculture		X	X	X	limited
M07A		Human: Roads, agriculture		X	X	X	somewhat limited
M07B		Human: Roads, development, agriculture		X	X	X	somewhat limited

BBW_Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
Blood Brook mainstem cont'd							
M08A	Human: check dam	Human: Roads, agriculture		X	X	X	somewhat limited
M08B		Human: Roads, development, ag		X	X	X	limited
M08C		Human: Roads, development		X	X	X	X
M08D		Human: Roads, development		X	X	X	limited
M09A	Natural: Ledge	Human: Roads, development Natural: Bedrock outcrops (a few)	X			X	limited
M09B	Natural: Ledge	Human: Roads Natural: Bedrock outcrops	X				
Bragg Brook							
M03-T1.01A		Human: Roads, development		X	X	X	limited (bottom), important
M03-T1.01B	Natural: Ledge	Human: Roads, development			X	X	X
M03-T1.02A	Natural: Ledge	Human: Roads, development	X			X	

BBW_Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
Bragg Brook (cont'd)							
M03-T1.02B	Natural: Ledge	Human: Roads, development	X	X			
M03-T1.03A	Natural: Ledge	Human: Roads, development	X	X	X		limited
M03-T1.03B	Natural: Ledge	Human: Roads, development	X				
Charles Brown Brook							
M04-T2.01A	Natural: Waterfalls Human: check dam	Human: Roads, development. agriculture		X	X		limited (bottom), important
M04-T2.01B		Human: Roads, development		X	X		limited

Natural lateral constraints occur in the form of bedrock and ledge outcrops on both mainstem and tributary reaches, but the most significant constraints to channel evolution in the Project area are associated with human-built encroachments (Fig. 22). The extensive nature of these constraints in the Project area increases the importance of identifying and protecting attenuation assets that don't conflict with such land uses. Failure to do so will increase flooding impacts, both in channel-forming annual high flows as well as larger flood events, on downstream reaches.

The important vertical constraints to channel evolution that occur in the form of waterfalls and ledge grade controls in the Project area (Fig. 22) provide vital functions in limiting incision of the bed that would further limit floodplain access and increase stream power. Log check dams (weirs) that have been placed below the Norwich Pool and on the Blood Brook mainstem just above the junction of Turnpike and Upper Turnpike Rds provide similar functions, and may play an important role in allowing the stream to utilize its own sediment inputs to begin to rebuild floodplains at a lower elevation. Such structures require frequent maintenance, however, and should be considered temporary structures at best. In addition, it should be noted that in areas where vertical constraints are present the likelihood of lateral evolution is increased.

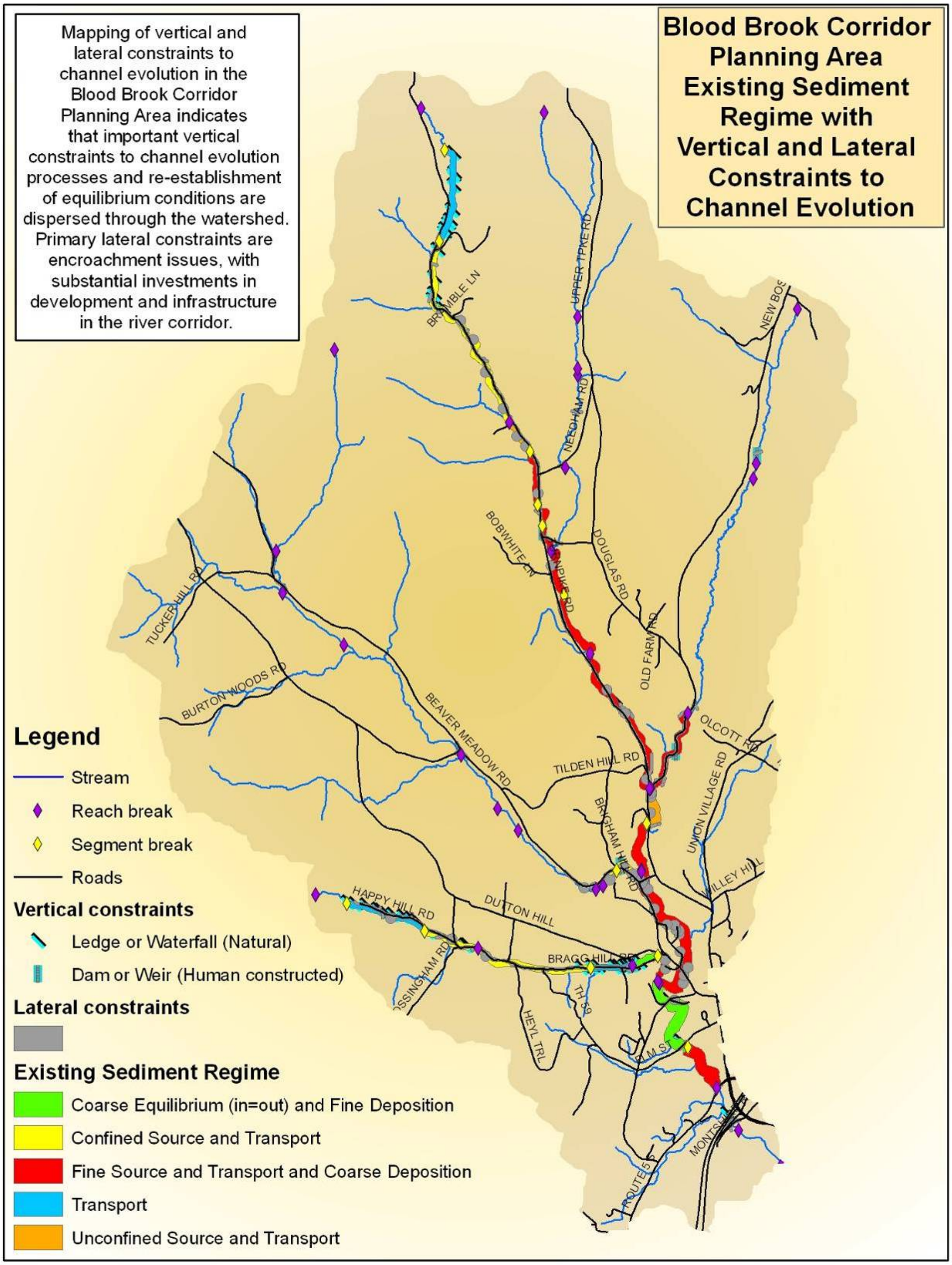


Figure 22. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution in the Blood Brook corridor planning Project area.

Seven of 23 segments fully assessed in Phase 2 were classed as planebed rather than riffle-pool or step-pool systems, generally indicative (except in steep gradient or bedrock-controlled areas) of erosion of bed features by degradation processes and increased stream power, and/or 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. With active degradation along much of the upper portions of the Blood Brook mainstem, it is likely that planebed features in many of these segments are related to upstream migration of incision processes in the watershed. Although Phase 2 assessment confirmed Phase 1 bedform typing in reach M05 on the Blood Brook mainstem as planebed, it is likely that this typing in Phase 1 was based on windshield survey observations rather than predicted reference conditions; the Phase 1 assessment was updated to reflect a reference riffle-pool bedform during preparation of this report. This area, in fact, showed some of the clearest indications of bulldozing after the 1973 flood (Fig. 14, Fig. 21), with much of the bed exposed and plane bed features formed by subsequent deposition of gravel and small cobble materials. The presence of planebed features in assessed reaches strongly overlaps with the reported extent of that bulldozing, primarily located on the Blood Brook mainstem along Turnpike Rd. and along Charles Brown Brook below the Norwich Pool (see sub-sec. 5.1.3a, Channel slope modifiers).

To summarize, the existing sediment regime in the Blood Brook Project area features limited floodplain access and increased stream power with deposition currently occurring even in typical Transport reaches. Bulldozing following the 1973 flood (and more recent dredging in reach M06) removed bed armoring in extensive areas of the Project area, and windrowing of the stone along the banks has elevated depth and stream power in high flows. Subsequent deposition has formed planebed features in numerous segments and is only beginning to form weak riffles and bed features in these areas. Incision processes appear to be migrating upstream in the watershed, while downstream reaches are accruing the sediments being transported. Erosion, widening, and lateral migration are active processes in most reaches and segments but are further advanced in downstream reaches. As channel evolution proceeds and these streams attempt to rebuild meanders and floodplains to reestablish equilibrium between increased stream power and the sediment loads being carried by it; a majority of sediments is being transported to downstream reaches. The primary exception to this is reach M08 in the upper portion of the Blood Brook mainstem (Fig. 12). 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, particularly at undersize culverts.

The combination of increased stream power and sediment transport in the Project area raises the following issues on Blood Brook and assessed tributaries:

a) Although cobble is the common dominant bed material in most reaches, removal of stone from the bed of these streams means that maintenance of banks through continued channelization and armoring will increase the likelihood of further bed incision. This would further limit access to floodplain and initiate or prolong channel adjustments;

b) Ledge grade controls present in several areas of the watershed provide important checks to limit the vertical extent and upstream migration of further incision. Portions of the streams lacking these controls are particularly susceptible to further bed degradation, although lodgment till exposed in these beds is somewhat resistant to erosion in low and moderate flows (but is likely to erode in higher level floods);

c) Banks are generally erodible and are particularly susceptible to accelerated levels of erosion when bedrock is present in the bed but lacking in the banks, or when upstream factors such as bank armoring or stormwater inputs increase stream power;

d) lack of access to floodplain and extensive channel straightening means that the bulk of sediment deposition impacts is being transferred to downstream reaches: coarser bed loads are moving in sediment “slugs” and finer washload sediments are being transported further downstream, often over long distances at high flows;

e) 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;

f) lack of access to floodplains and meanders for sediment storage means that nutrients are being transported downstream and out of the Blood Brook watershed.

Given the: a) extensive degree of encroachment through portions of the Project area; b) maintenance of infrastructure along the river corridor; and c) current stream adjustments to both historical downcutting (likely a legacy of deforestation) and more recent impacts from bulldozing and windrowing, restoration of meander patterns and floodplain access will be a critical but highly challenging component in re-establishing equilibrium conditions along Blood Brook and its tributaries. Identification of “attenuation assets” 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 limited due to road and development encroachments and will require careful consideration (Fig. 22).Lower reaches on Blood Brook plus segment M05A and portions of M08 on the mid and upper portions of the mainstem are particularly important to consider in terms of attenuation assets, as are the lowest reaches of Bragg Brook and Charles Brown Brook. These opportunities are further discussed in Section 6 on preliminary project identification.

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 the Blood Brook 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 requires 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 (VTANR, 2007d), Phase 2 Step 7.7; (VTANR, 2007b), Sec. 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. Concern for the adjustment processes occurring in a reach and decisions about whether and how to best address those concerns are tempered or elevated by consideration of the equilibrium conditions a stream is moving toward and whether current processes are supporting or inhibiting such evolution.

Due to the alteration of sediment and flow regimes that has converted many Project area reaches to transport reaches, plus erodible boundary conditions and high levels of current aggradation, High sensitivity was noted in most reaches and segments of the Blood Brook corridor planning area (Fig. 23). In general, the high sediment load and high sensitivity noted indicates good possibilities for success of passive geomorphic projects, which would allow the river to utilize its own energy and watershed inputs to re-establish meanders, floodplains, and self maintaining equilibrium conditions over time. It should be emphasized, however, that given the erodible boundary conditions in many areas of these streams channel evolution will likely entail elevated erosion and lateral migration as the streams try to reestablish a new floodplain and meanders at a lower elevation (Fig. 19).

In annual and bi-annual high water events (the "channel-forming flows") this type of channel evolution is often evidenced as undercut or sloughed banks and formation or accessing of flood chutes off either side of the main channel as the river balances the energy of stream power and sediment load. While many of us have a visceral reaction to the appearance of these processes, it is important to recognize the role that they play in balancing stream power and sediment load, and increases the importance of corridor protection to allow these processes to proceed. In higher level flood events, rapid and catastrophic changes in channel locations and/or dimensions have contributed to flooding being the most frequent, costly and damaging of natural disasters in Vermont (VTANR 2007a). These kinds of changes often occur at channel constrictions, or areas where bedrock dominates bed materials while the banks and surrounding landscape contain more easily erodible materials. Efforts to curtail these processes through bank armoring or similar efforts inhibit these evolution processes (although this is likely to be temporary) and could dramatically delay reestablishment of equilibrium conditions. High (rather than Extreme or Very High) sensitivity ratings indicate that these streams could be significantly delayed in re-establishing equilibrium conditions, prolonging the current elevation of impacts on downstream reaches (including flood hazard risks as well as nutrient and sediment loading in a manner detrimental to aquatic health). This elevation of impacts is related to increased stream power (in relation to sediment load) due to the straightened planform (loss of meanders) and loss of floodplain currently evidenced in much of the Project area.

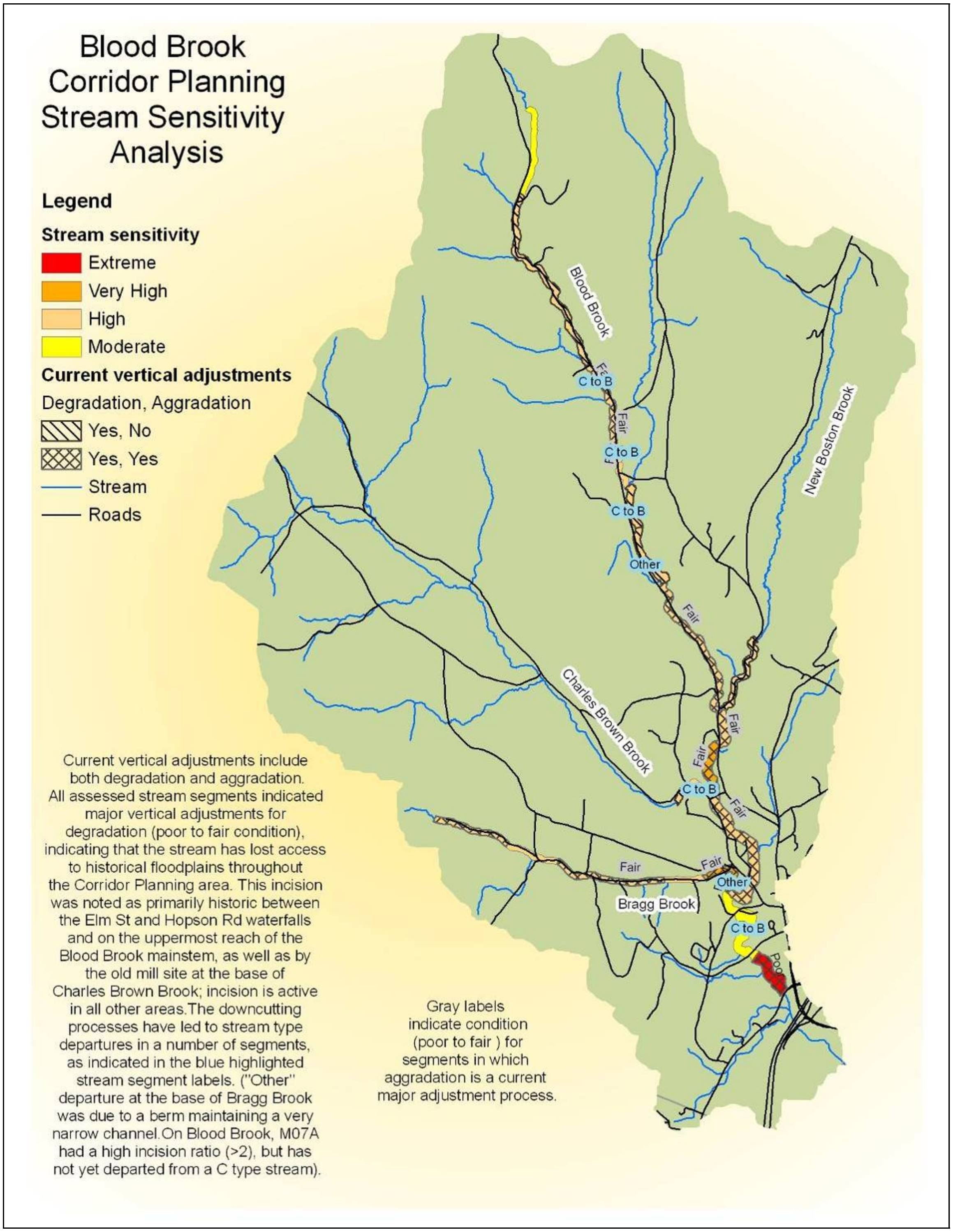


Figure 23. Stream sensitivity map for the Blood Brook corridor planning Project area.

Extreme sensitivity was indicated in segment M03A (most downstream segment of the Blood Brook mainstem), as well as Very High ratings in both segments of reach M03-T1.01 at the downstream end of Bragg Brook and segment M05A (Blood Brook mainstem between Moore Ln. and Turnpike Rd. near Sun Lion Dr.). The value of these segments as attenuation assets (Table 7) in addition to these elevated sensitivity ratings are indicators that protection of the stream corridors in these areas offers a critical, cost-effective approach to stream restoration with optimal benefits in terms of overall watershed dynamics, safety and property protection.

Moderate sensitivity in segments M03B and M09B is largely related to the widespread presence of ledge and bedrock outcroppings and grade controls in these areas of the stream. Channel evolution is likely to occur in a more extended timeframe than in other areas of the watershed, and these segments thus would receive a lower priority in terms of project implementation or prioritization for watershed dynamics. All other reaches in the Project area have High sensitivity ratings, but one segment of these merits particular further consideration. Segment M08C, on the Blood Brook mainstem along Turnpike Rd between the Turnpike/Upper Turnpike Rd junction and Old Orchard Ln., is the only segment of a highly valuable attenuation reach high in the watershed that is located in a largely wooded and undeveloped corridor.

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 step-wise 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 (VTANR, 2007b, 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 Head Cuts 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 majority of reaches in the Project area are highly sensitive to watershed inputs. The high sediment load currently working through the watershed (Fig. 12) indicates that passive geomorphic projects may offer an appropriate management alternative in much of the Project area, although time scales for re-establishment of equilibrium conditions based solely on watershed inputs might be measured in decades rather than possible five-year windows in reaches with very high or extreme sensitivity. These time frames would need to include mitigation of upstream impacts to facilitate channel evolution in lower portions of the watershed, and further changes to hydrology or sediment loading could significantly alter or delay these processes. Encroachment issues are commonplace, placing a particularly high priority on protecting dwindling attenuation assets within the river corridor, the first item identified in the stepwise procedure. Although Step 2, planting stream buffers, should receive a high priority as part of any protection or restoration efforts, most reaches are vertically unstable and planting projects should primarily utilize low-cost approaches or provide adequate setbacks to avoid loss of high-value planting stock to widening and planform adjustments in particular. The third item, stabilization of streambanks, is generally not recommended due to vertical adjustments (Fig. 23) 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 clearly needs to be carefully assessed in regards to site-specific recommendations and critical infrastructure. It should be reinforced, however, that the current conversion of most 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 sensitive to erosion in most reaches, and although the gravel materials aggrading in many reaches are considered "coarse" bed materials, they are still fine enough to be sensitive to degradation processes. Increased stream power due to extensive straightening and channelization along the mainstem of Blood Brook makes Step 6.4, arresting head cuts and nick points, an item to be regularly assessed, as further downcutting of the channel could initiate further channel adjustments and delay establishment of equilibrium conditions. Check dams have been installed on Charles Brown Brook below the Norwich Pool and on the Blood Brook mainstem just above the Turnpike Rd./Upper Turnpike Rd. intersection to provide these types of measures. It is important to realize that these types of structures are temporary and require maintenance, but they may provide time for the watershed to begin to re-establish equilibrium based on its own hydrologic and sediment inputs. Moving away from an ongoing need for such measures will also require mitigation of increased stream power in upstream reaches, and the step-wise project identification process often indicates a "need for watershed strategies" in downstream reaches within the Project area.

Channel constrictions at stream crossings (i.e., bridges and culverts) are a predominant issue in the Blood Brook watershed, and recommendations concerning these issues can be found in both the Phase 1 and Phase 2 reports for Blood Brook (Redstart, 2007; TRORC, 2006). These issues are thus noted in most reaches for potential project identification, but they are frequently (though not always) given a lower priority in watershed planning. Numerous bridges and culverts either partially or fully block floodplain access and are thus at risk for failure and are potential contributors to channel avulsions in flood events. Newer installations in Norwich are designed to outflank in such conditions, reducing structural damage and subsequent repair and maintenance costs, and Norwich has developed a culvert and bridge inventory designed to be updated every four years to assist in maintenance and replacement prioritization efforts (pers. comm., Andy Hodgdon, Norwich Road Foreman, Dec. 2006). The Phase 2 report recommendations were to continue support of such efforts at a town level, as well as to encourage private installations to address channel constriction issues in particular.

The remaining listed steps are more reach-specific and are discussed further below.

6.1 REACH DESCRIPTIONS - PRELIMINARY PROJECT IDENTIFICATION

With these overarching considerations, preliminary project identification for the Blood Brook corridor planning 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 “Fluvial Erosion Hazard (FEH) corridor” drawn on either side of the stream (VTANR, 2007a). The width of this corridor is based on over 30 years of research and data collected from hundreds of streams around the world, and it approximates the extent of lateral adjustments likely to occur over time in a meandering stream type. “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” (VTANR, 2007d), p.17). Background imagery for the reach maps is from the National Agricultural Imagery Program (NAIP), dated 2003. Reach descriptions found in the Phase 2 report (Redstart, 2007) include photo documentation of many of the features noted in the more abbreviated descriptions included here.

6.1.1 Preliminary project identification: reach M03 – Blood Brook mainstem, Rte. 5 to Bragg Brook confluence below Fairview cemetery (Hillside Rd.)

Reach M03 is the farthest-downstream reach within the Project area, extending 5,600 ft. (1.1 mi.) between a large debris catcher maintained by state road crews at the entrance to a culvert beneath Route 5 on the downstream end and the confluence with Bragg Brook, below Hillside Cemetery, at the upstream end (Fig. 24). The reach was segmented for Phase 2 assessment, with significant differences in stream dynamics largely attributable to two series of grade controls present in the upstream segment (M03B), while M03A has highly erodible boundary conditions and diminished stream buffers in portions of the segment.

Establishment and maintenance of a protected river corridor in both segments would be beneficial to the stability and habitat condition of the stream, helping to accommodate stream meander geometry and provide access to critical floodplain. River corridor protection has been initiated, with conservation easements limiting development already in place along portions of the right bank in the downstream segment (M03A). Buffer revegetation (utilizing low-cost stock and a significant setback from current bank location, due to vertical instability and high likelihood of channel widening and/or lateral migration) may be a good candidate for funding opportunities through the Conservation Reserve Enhancement Program (CREP) administered by the Natural Resources Conservation Service, which will provide financial incentives for farmers willing to establish adequate buffers and corridor protection.

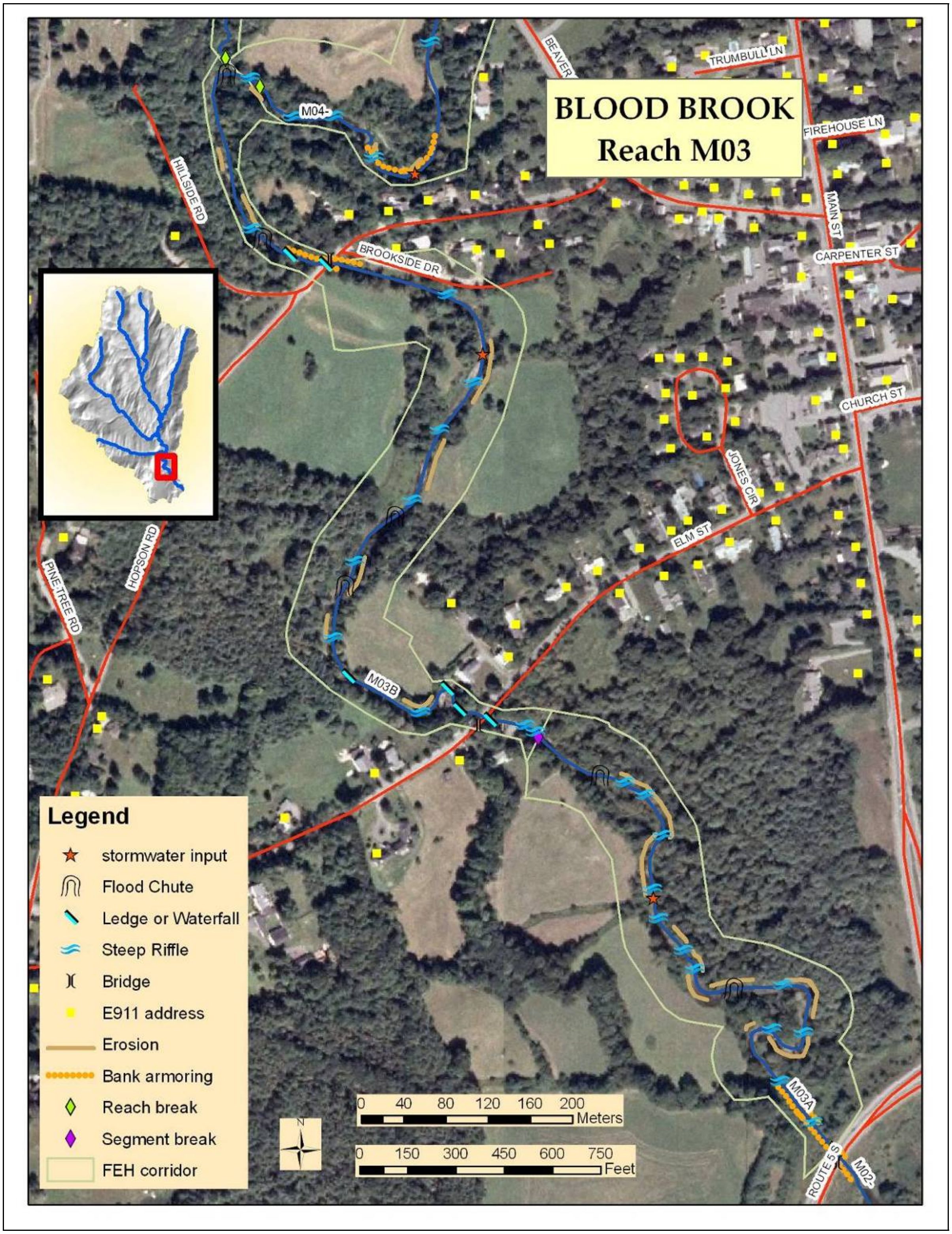


Figure 24. Reach map for Blood Brook mainstem reach M03.

Table 8. Blood Brook Reach M03 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, 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 #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03A (1,2,3)	Protect river corridor	High	High	Y	Some land already conserved Attenuation asset Extremely sensitive – linked to mitigation of upstream impacts
M03A (4)	Plant stream buffer/ fencing?	High	Low	Y	Wide buffer, low-cost stock Further measures need watershed strategies (>5yr)
M03A (25)	Replace structure	Low	Low	Y	Modification more likely; overflow culverts? Flood mitigation, may not significantly increase attenuation assets
M03B (1,2,3)	Protect river corridor	High	High	Y	Limited but important opportunities – ag lands
M03B (4)	Plant stream buffer/ fencing?	High	High	Y	Mixed cost – High sensitivity and grade controls mean bank impacts are elevated in bedrock areas Further measures need watershed strategies (>5yr)
M03B (25)	Replace structure	Low	Low	Y	Hopson Rd.; flood mitigation, may not significantly increase attenuation assets

The downstream 2,225 ft. (0.4 mi.) of this reach, M03A, was one of three segments in the Phase 2 study to be classed in poor condition on the Rapid Geomorphic Assessment, and it was the only segment to be rated extremely sensitive to watershed changes. The bedform was bordering on plane bed in many areas, with widely spaced riffles beginning to reform through aggradation. The valley in this segment was very broad, but the incision ratio was calculated as 2.2, indicating very limited access to the floodplain. Erodible materials present in the bed mean that further incision is possible, but active headcuts were not noted and are likely to be “washed out” quickly by significant deposition in this segment. Upstream migration of these processes is limited by the waterfalls present at Elm St., at the base of segment M03B. Numerous depositional features including mid-channel, point, side, and diagonal bars were present in the segment, as well as two active flood chutes, indicating current dominant processes of aggradation, widening, and planform change as the stream tries to establish a new floodplain at a lower elevation. The active widening and planform adjustment impacts (particularly bank erosion and lateral migration) in this reach are likely to remain high because of the stage of channel evolution and the extreme sensitivity to disturbances or stressors of the downstream segment. Eroding banks averaging 4-5 ft. in height were noted on roughly 40% of the left bank and 10-15% of the right bank in the segment, with an additional 10-15% of the right bank having been riprapped for bank stabilization. Banks on both sides of the stream were dominated by non-cohesive gravel substrates on the lower banks and sand on the upper banks. If the corridor is adequately protected in these conditions, the potential for rapid re-establishment of stream equilibrium exists, but is also highly dependent on mitigation of upstream impacts in the watershed.

Buffer width generally exceeded 100 ft. on the left bank in segment M03A, although invasive species (primarily honeysuckle and buckthorn) dominated the near bank and buffer vegetation on both sides and was also significant in the understory of the forest that represented the dominant left bank riparian corridor use. Hayfields represented the dominant land use in the right bank riparian corridor, and buffer width on this side was predominantly 51-100 ft. but dropped to less than 5 ft. in portions of the segment. These diminished buffers would be the areas that may be particularly appropriate for Conservation Reserve Enhancement Program projects (Fig. 25).

Figure 25. Although river corridor protection has been initiated in segment M03A, diminished buffers may present opportunities for project implementation with potential partners such as the Conservation Reserve Enhancement Program.

Massive embankments underlying Route 5 at the end of the segment, where the stream enters a long culvert, are almost perpendicular to the stream. Efforts to ensure stream access to the floodplain upstream in the reach, and/or installing overflow culverts at this crossing, would help provide a flood mitigation measure but would probably not significantly affect the attenuation assets offered within the reach. This area was reportedly nearly overtopped by floodwaters in 1973 (Figs. 5 and 6, Sec 3.4.2, Flood history, of this report). With substantial investments in infrastructure, the Vermont Agency of Transportation may be a potential partner for project implementation.

Segment M03B runs from below the Elm St. falls to just above the confluence with Bragg Brook (reach M03-T3.01). Fieldwork identified a B-type gravel riffle-pool stream, a departure from the reference C-type stream. This change was primarily due to greater entrenchment from historic incision. Waterfalls at Elm St. downstream and Hopson Rd. upstream were the most notable features in the segment. The two bridges in this segment were built at the locations of these falls (Fig.26), and the presence of these grade controls and numerous areas of exposed bedrock contributes substantially to limiting further degradation of the streambed. The Elm St. bridge is sized at 131% (bedrock beneath the bridge is narrower), and the one at Hopson Rd. 82%, of bankfull width. Both showed evidence of sedimentation upstream of the structures, likely due to constriction presented by bedrock, and both block the floodplain; they could conceivably be at risk and potential contributors to channel avulsion in a flood event or ice jam but would not be likely to trigger further channel adjustments in response to such events. A relatively low incision ratio of 1.1 is likely related to the presence of the grade controls and ledge outcrops, and it indicates some access to floodplain in parts of the segment. Confinement was classified as Very Broad despite minor encroachment by development at the edge of the valley.

Figure 26. The bridges at Elm St. (left) and Hopson Rd. (right) were built near the locations of waterfalls. Substantial bedrock outcrops at these locations increase stream stability and limit channel adjustments but also create channel and floodplain obstructions that could increase the possibility of channel avulsion in a flood or ice jam.

Erosion was noted on outside bends in M03B (roughly 20% of the left bank and 5% of the right bank, averaging about 3 ft. in height), particularly upstream of the waterfalls and in the midstream portion of the segment, where buffer widths dropped from 51-100 ft. on the right bank and >100 ft. on the left bank to a 5- to 25-ft. width on both banks. Diminished buffers were related to mowing of hayfields present in the midstream portion of the segment, in contrast to dominant forest cover in the riparian corridor of both banks through most of the segment. Riprap was in place at the upper end of these hayfields and continued upstream along both sides of the adjacent Hopson Rd. bridge. Sediment storage features included mid-channel, point, side, and diagonal bars, as well as four active flood chutes. The combination of erosion, aggradation, and active flood chutes ws indicative of ongoing planform adjustment processes. Erosion is likely to continue to be high at this stage, and the bedrock and grade controls present in the segment will mean that banks are more likely to erode than the bed material. Corridor protection and stream buffer plantings are thus high priorities in this segment. As in segment M03A, further project implementation would ideally focus on watershed strategies and mitigation of upstream impacts first.

6.1.2 Preliminary project identification: reach M04 – Blood Brook mainstem, Bragg Brook confluence below Hillside cemetery to Charles Brown Brook confluence above Moore Lane

Reach M04 includes roughly 5,575 ft. (1.05 mi.) between the confluence of Bragg Brook (reach M03-T3.01) and the confluence of the Blood Brook mainstem and Charles Brown Brook (reach M04-T2.01) just upstream of the Moore Ln. Bridge (Fig. 27). The reach was not segmented for the Phase 2 study. High reach sensitivity emphasizes a need for corridor protection as well as a lower priority for further project implementation in this reach until upstream impacts are mitigated with watershed strategies.

Table 9. Blood Brook Reach M04 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M04-0 (1,2,3)	Protect river corridor	High	High	Y	Huntley Meadows, playing fields important attenuation assets; importance accentuated due to right bank development and infrastructure
M04-0 (4)	Plant stream buffer	High	Low	Y	Wide buffer, low-cost stock Further measures need watershed strategies
M04-0 (26)	Replace structure	Low	Low	Y	Replaced 1989; blocks floodplain, but no further geomorphic incompatibilities

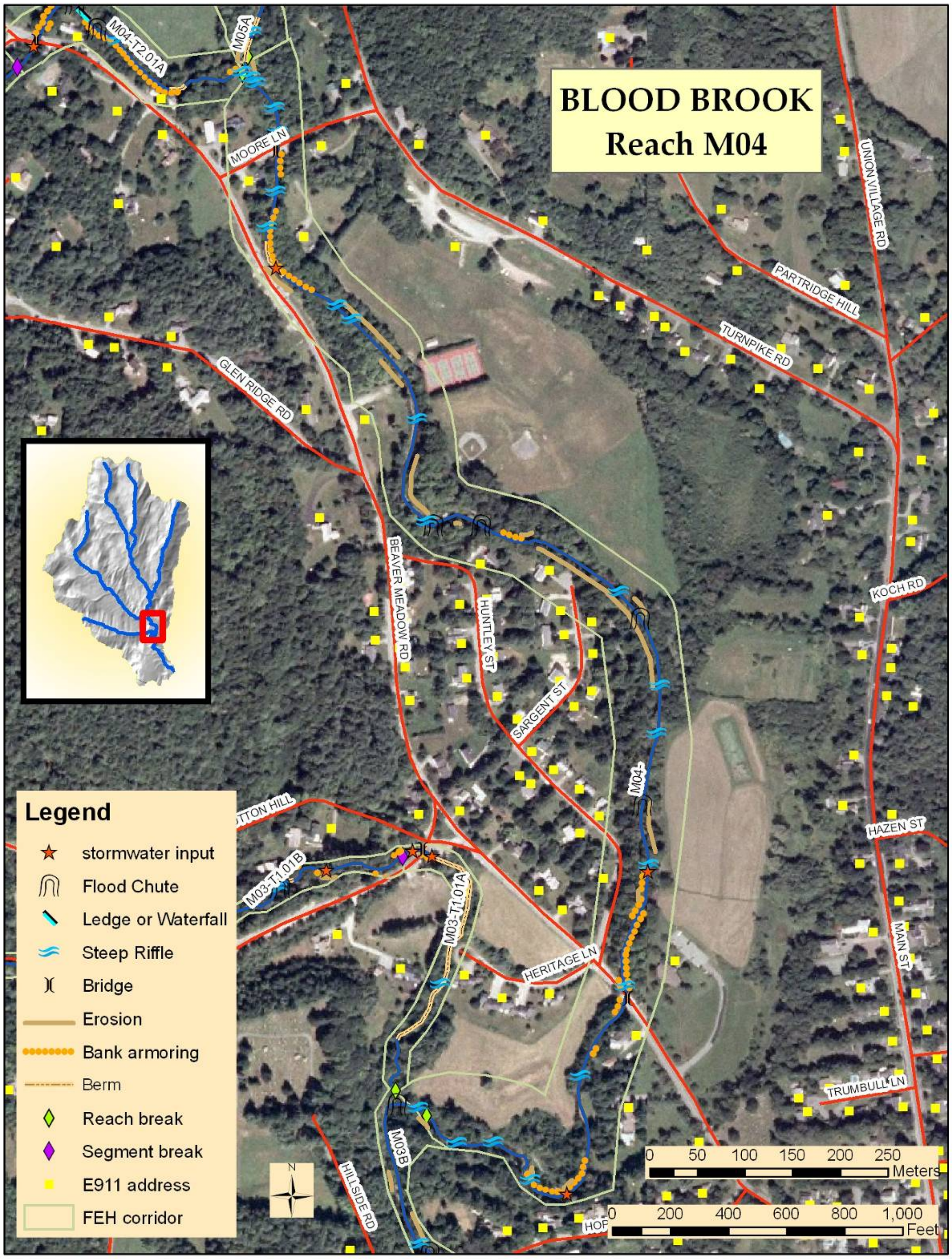


Figure 27. Reach map for Blood Brook mainstem reach M04.

Field assessment confirmed Phase 1 typing as a Rosgen C cobble riffle-pool stream type; confinement type was Very Broad. The dominant and subdominant land uses were hay production and residential land use, respectively, in the floodplain within the left bank riparian corridor. The dominant land use in the right bank riparian corridor was residential development, and development on Sargent and Huntley streets lies within the Blood Brook floodplain and Fluvial Erosion Hazard corridor on this side of the stream. Indications are that floodwaters moved toward Huntley Meadows in the 1973 flood (see Sec 3.4.2, Flood history, of this report), placing a high value on protection of floodplain attenuation assets in the left bank corridor. The Norwich playing fields and tennis courts, along with contiguous hayfields, occupy a portion of the riparian corridor along approximately 50% of the left bank of the reach. Buffer widths of 51-100 ft. in the area of these fields were characteristic of the left bank dominant buffer width, with narrower buffers of 26-50 ft. common in areas where fields and lawns were mowed closer to the stream. In the right bank riparian corridor, a dominant buffer width of just 5-25 ft. reflected mowing of both residential and hay lands.

With substantial human investments in the riparian corridor, bank armoring was frequently observed. Erosion was noted on roughly 20% of the left bank and 15% of the right bank in this reach; an additional 10% of the left bank and 15% of the right bank were rip-rapped. The bridge at Moore Ln. is sized at 82% of bankfull width and blocks the floodplain, so is likely to be at risk and a potential contributor to channel avulsion in a flood event. The bridge was replaced in 1989, however, and sedimentation noted above the structure in Phase 2 was not as severe as at other constrictions in the Project area. The area upstream of the American Legion post (right bank corridor above Huntley and Sargent Streets) has been a site of frequent erosion impacts and is substantially armored, as is the right bank just downstream of the Moore Ln. bridge. The revetments near Moore Ln. received maintenance and upgrade work in 2007 in a joint project between town road crews and Vermont Youth Conservation Corps workers, in coordination with TRORC and the Better Backroads program. The valley wall is much closer to the stream in this area than other portions of the reach, but it likely represents the outer limits of potential lateral migration on this side of the stream; Beaver Meadow Rd. and a recently built house (not shown on 2003 aerial photography) occupy the floodplain between the current stream location and the valley wall. Continued commitment to maintenance of the infrastructure and development in these areas will place a much higher value on protection of attenuation assets in the playing fields and Huntley Meadows downstream in this reach, as well as floodplain areas upstream in reaches M04-T2.01 (base of Charles Brown Brook) and M05 (Blood Brook mainstem above Moore Ln.), as discussed further in the sections of this report dealing with those reaches.

Sediment storage was represented by mid-channel, point, side, and diagonal bars, and four flood chutes were noted in the reach. Long-term residents and town officials recall this area being bulldozed after flooding in 1973, and some of these flood chutes may be relics of channelization or straightening of the stream at that time. The combination of aggradation and erosion are contributing to lateral migration of the stream in this reach, and widening and planform change were noted as the dominant current processes.

6.1.3 Preliminary project identification: reach M05 – Blood Brook mainstem, Charles Brown Brook confluence above Moore Lane to New Boston Brook confluence

Reach M05 covers approximately 3,345 ft. (0.63 mi.) between the confluence of the Blood Brook mainstem and Charles Brown Brook (reach M04-T2.01), upstream of the Moore Lane bridge and the confluence with New Boston Brook (reach M05-T3.01) near the junction of Turnpike and New Boston Roads (Fig. 29). The stream was divided into two segments for Phase 2 assessment based on buffer widths, which generally exceeded 50 ft. on both banks through most of segment M05A, and diminished buffers, significant corridor encroachments, and rip-rapping to protect investments in the belt-width corridor in segment M05B. Extensive bulldozing that occurred on the Blood Brook mainstem after the 1973 flood was particularly evident in this reach, with a frequent lack of bed protection and exposure of lodgement till, windrows of stone (effectively functioning as riprap or berms) ranging from cobble to boulder size along both banks, and a likely access point for a bulldozer in the downstream section.

Table 10. Blood Brook Segment M05A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M05A (1,2,3)	Protect river corridor	High	High	Y	Attenuation asset High sensitivity – linked to mitigation of upstream impacts
M05A (4)	Plant stream buffer	High	Low	Y	Augmentation; buffers generally >50 ft., almost always >25 ft.
M05A (18)	Remove berms	Low	Low	Y	Upstream and downstream ends of segment need to be evaluated carefully for impacts to development and infrastructure; mid-segment section is short and not likely to gain much more floodplain access
M05A (34)	High priority river corridor protection at downstream reaches and Restore incised reach with bedforms and floodplain features	High	High	N	Assess RB floodplain restoration and possible impacts on development at base of Charles Brown Brook, Moore Ln.; assess placement of windrowed stone into stream

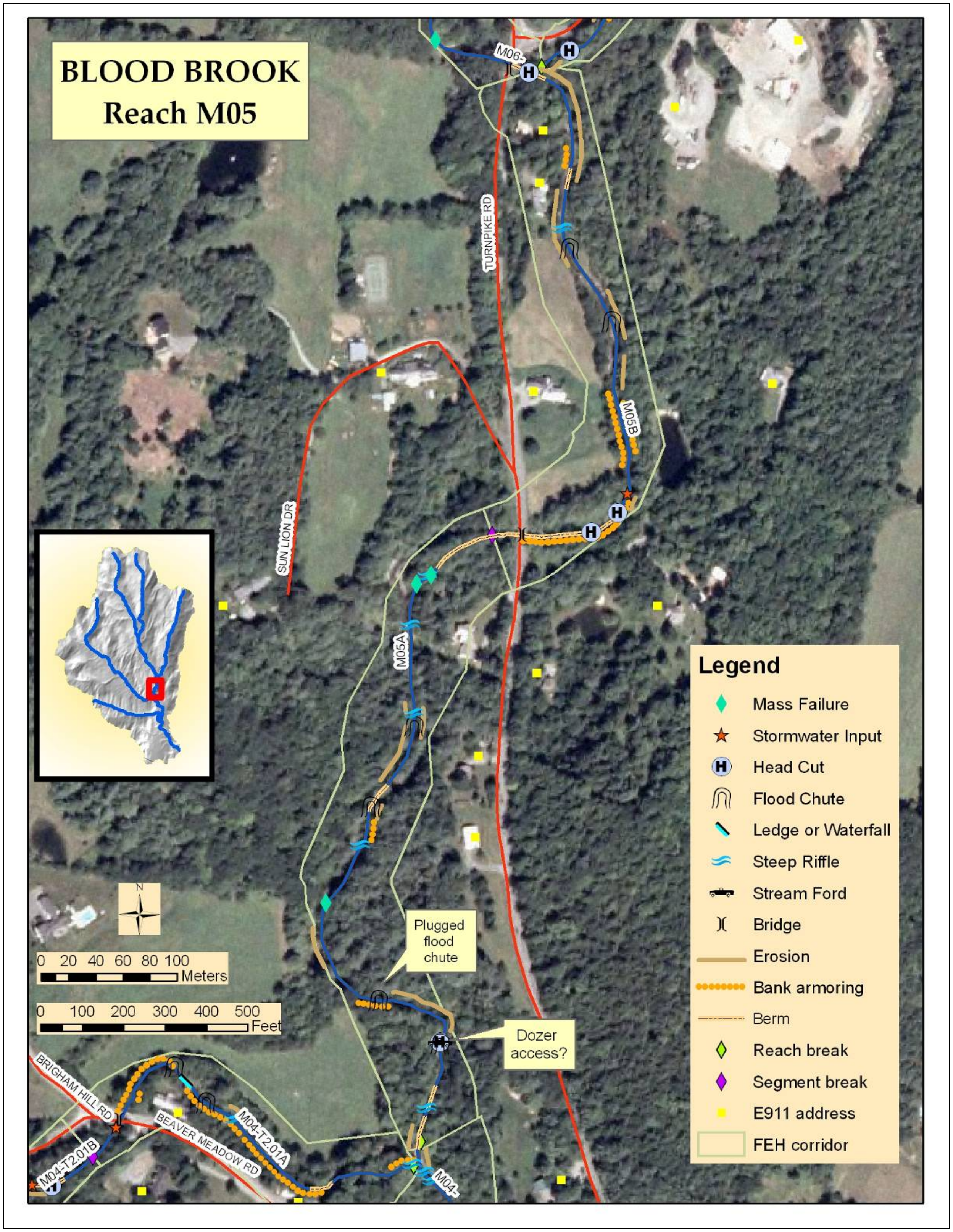


Figure 28. Reach map for Blood Brook mainstem reach M05.

Reach M05 was noted in Phase 2 fieldwork as a C cobble-type stream with planebed features (likely resulting from bulldozing rather than a naturally occurring bedform) in the upstream segment and weak riffles forming in the downstream segment due to aggradation. Segment M05A includes roughly 1,860 ft. (0.35 mi.) extending to shortly downstream of the bridge on Turnpike Rd. at Sun Lion Drive. Confinement type for the segment was Very Broad, and an incision ratio of 1.3 indicated limited access to floodplain. Incision processes contributing to one documented headcut in this segment appear to be offset fairly rapidly by deposition. Roughly 15% of the left and 20% of the right bank in the segment exhibited erosion averaging over 3 ft. in height, and two mass failures were noted on the right bank in the mid- and upstream portions of the segment.

With minimal development in the belt-width corridor, only 3% and 4% of the left and right banks in M05A, respectively, were rip-rapped. However, windrowed stone acts as a berm along roughly 20% of the segment, primarily in the area just downstream of the bridge at Turnpike Rd. below Sun Lion Drive (Fig. 29).

Figure 29. Windrowed stone pushed from the stream channel after the 1973 flood effectively functions as a berm on both sides of the stream in portions of segment M05A.

It appears that some of the stone removed from the bed was also used to plug an old flood chute (or possibly the former stream channel) in the lower portion of segment M05A, possibly to divert the channel away from the edge of a nearby hayfield (Fig. 30). Removing this plug could potentially allow greater floodplain access for the stream with a minimum of damage, as the area below it is largely wooded at this point and has no substantial development on the mainstem above the mouth of Charles Brown Brook. While this might help to attenuate moderate flood levels, this flood chute would likely be accessed at higher level discharges anyway. The straighter course of this channel might actually serve to shorten meander length and thus increase rather than decrease stream power in the short term if it is accessed on a regular basis; it would not necessarily hasten a return to equilibrium conditions. The wooded riparian zone in this section does represent a highly valuable attenuation asset, however, emphasizing a need for corridor protection.

Figure 30. Windrowed stone was used to plug the head of a flood chute in the downstream portion of segment M05A.

Table 11. Blood Brook Segment M05A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

M05B (1,2,3)	Protect river corridor	High	High	Y	Only limited opportunities in upstream portion – encroached
M05B (4)	Plant stream buffer	High	High	Y	Mixed cost – High sensitivity
M05B (15)	Arrest head cuts	High	Low	Y	Monitor: Currently nickpoints; exposed till; may eventually wash out as sediment slugs from upstream move into reach
M05B (26)	Replace structure	Low	Low	N	Looks new; partially blocks floodplain, but no further geomorphic incompatibilities

M05B includes 1,490 ft. (0.28 mi.) at the upstream end of the reach. Local residents recall that bulldozing in this segment included rerouting of a former meander bend to the edge of a hayfield in the midsection of the segment. Lack of bed protection and frequent lodgement till exposure were evident, particularly in the lower half of the segment. Erosion was extensive, with roughly 40% of the left bank eroded to an average of 4 ft. in height and an additional 45% of the segment rip-rapped on this side. Roughly 10-15% of the right bank was eroded (especially at the location of the former meander), and another 15% was rip-rapped. Erosion included areas of significant bank failure where the bank was composed of non-cohesive gravel and silt substrates, or underlain by lodgement till or clay. Right bank corridor land use was primarily residential and hayfield, and buffer widths on this side were 5-25 ft. and dropped to less than 5 ft. in several areas, with lack of a bank canopy through the lower portion of the segment. Left bank corridor use was noted as forest and the buffer was >100 ft., but bank canopy was moderate (51-75%), much of the tree cover on this side of the stream was quite young, and there was a significant herbaceous component to the buffer vegetation.

Sediment storage in segment M05B included mid-channel, point, side and diagonal bars, but these were not as extensive as in downstream segments. An incision ratio of 1.7 indicated greater loss of floodplain access than in the downstream segment of the reach. Headcuts and tributary rejuvenation were noted, indicating active degradational processes along with the widening that is occurring. Two active flood chutes were noted in the segment, indicating potential lateral migration as the stream attempts to regain equilibrium. With lodgement till exposure frequent in segment M05B, much of the sediment from upstream reaches continues to be transported over the top of the till in annual high flows. Areas where there was some larger stone in the channel were accumulating deposition and beginning to reform some of the few weak bed features and stream meanders present in the segment. While relatively resistant to erosion, the till is also at risk of being torn away in chunks given floodwaters of sufficient erosive capacity.

With much of the large stone that was windrowed still close at hand, it may be feasible to place some of it back on the streambed to increase roughness of the bed and decrease stream erosive power. Removal of berms in this segment, however, would likely present high risks to existing development and infrastructure. The Turnpike Rd. bridge below Sun Lion Dr. is relatively new (2-3 years old) and is accompanied by a large section of windrowed stone augmented with additional riprap. The bridge is sized at 97% of bankfull width and showed some minor deposition upstream, but no further evidence of geomorphic incompatibilities. Because it partially blocks the floodplain, however, it may be at risk from and a potential contributor to channel avulsion in a flood event.

6.1.4 Preliminary project identification: reach M06 – Blood Brook mainstem, New Boston Brook confluence to confluence of small tributary draining from pond at 645 Turnpike Rd.

Reach M06 extends 5,444 ft. (1.03 mi.) upstream of the confluence of New Boston and Blood Brooks past four town-road crossings to a point just before a new house development on the right bank (Fig. 31). It drains 6.04 sq. mi. and was left unsegmented.

Table 12. Blood Brook Reach M06 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M06-0 (1,2,3)	Protect river corridor	High	High	Y	Current opportunities very limited due to encroachment; risk of flood damage may recommend cost-benefit analysis of road relocation
M06-0 (4)	Plant stream buffer	High	Low	Y	Ag lands may have funding opportunities
M06-0 (25)	Replace structures	High	High	Y	Needs evaluation on a case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization

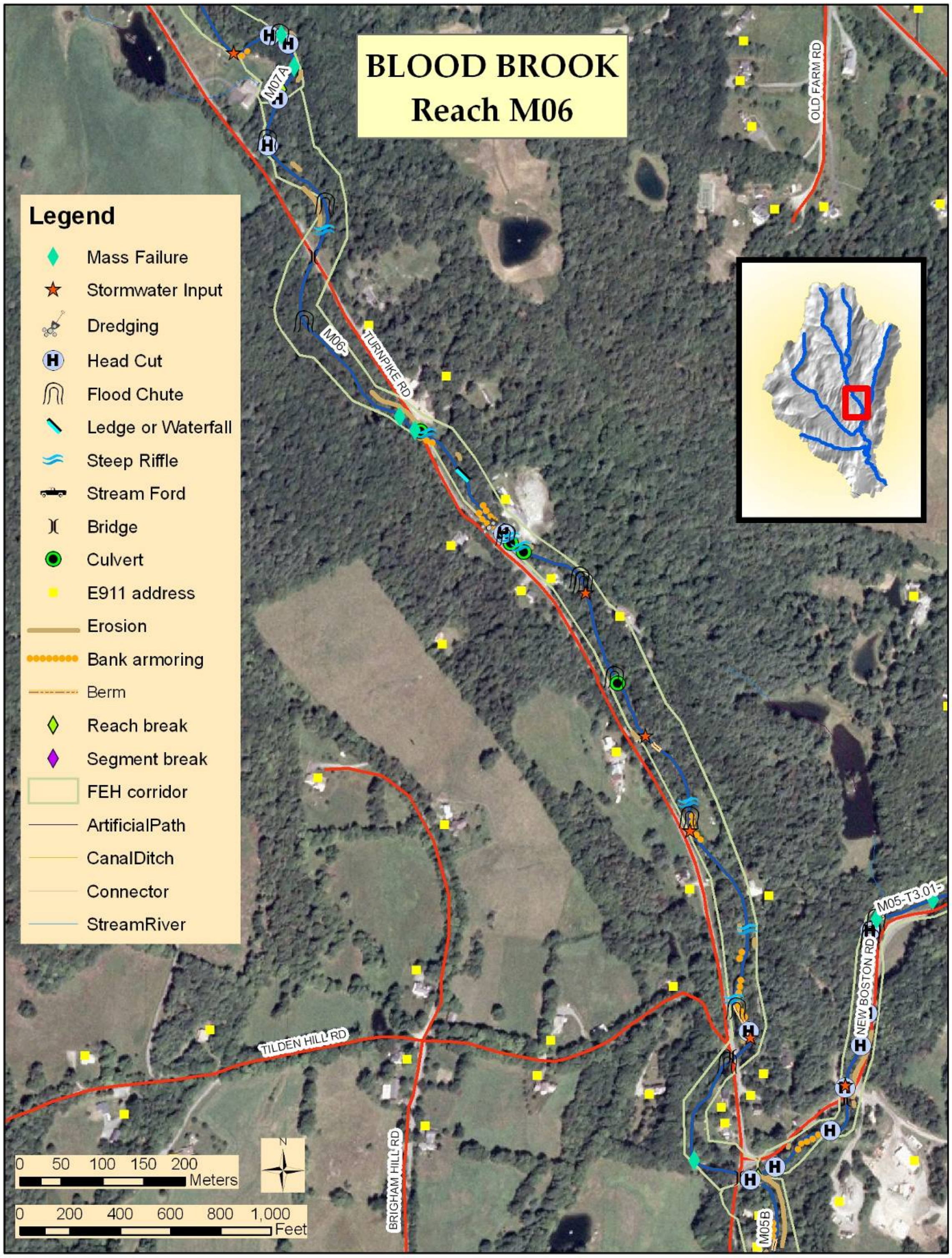


Figure 31. Reach map for Blood Brook mainstem reach M06.

Reach M06 had a C-type channel (occasionally confined to a B-type, particularly in areas of encroachment; Fig. 32) with a cobble substrate.

Figure 32. Road encroachment in reach M06 sometimes confines the stream sufficiently to change both the valley confinement type and stream type (C to B) over short distances.

Straightening and dredging have contributed to replacement of riffle-pool features with planebed forms in reach M06. Degradation was evidenced by multiple mass failures, headcuts, and nickpoints, and an incision ratio of 1.9 indicated lack of floodplain access. Sediment inputs from mass failures both in this reach (Fig. 33) and farther upstream contribute to significant aggradation in this reach, and widening and attempted lateral migration were noted in Phase 2 assessment. Headcuts documented in the reach are thus likely to quickly wash out, given the high bed load of the system, but may need to be monitored in the event of a flood. Ledge grade controls in the upper third of the reach should also help limit upstream migration of headcuts.

Figure 33. Mass failures in reach M06 are providing sediment that will contribute to channel evolution processes as the stream attempts to reestablish floodplains and meanders.

Road encroachment and channel constrictions were common. The stream passed under five bridges, through one culvert, and past one unfinished bridge abutment. Structural projects along Turnpike Rd. (Blood Brook mainstem) are moving to the top of the list of priorities for the town road crew, based on the structures inventory and planning process currently in place (pers. comm., Andy Hodgdon, Town Road Foreman, Dec. 2006). All but two of the town bridges and one private bridge create some constriction of the channel, and only one town bridge was denoted with no evidence of geomorphic incompatibilities. All but one of the town bridges were also noted as flood-prone constrictions, indicating potential structure risk and/or channel avulsion in a flood event. One of the private bridges had reportedly washed out several times, and the former bridge was being replaced at the time of Phase 2 assessment. Bank erosion in this area was noticeable, and the channel just upstream had been recently dredged (Fig. 34). The channel constrictions and associated impacts presented by these structures are a high priority in watershed planning, as project implementation in downstream reaches will be dependent on mitigation of impacts in this portion of the watershed in order to facilitate equilibrium establishment. This is particularly true in terms of potential channel avulsions as well as migration of headcuts upstream and sediment plugs downstream if any of these structures are impacted by flooding, ice jams, or similar incidents.

Figure 34. Recent dredging just upstream of a private bridge replacement project in Reach M06.

6.1.5 Preliminary project identification: Reach M07 – Blood Brook mainstem, confluence of small tributary draining from pond at 645 Turnpike Rd. to confluence of unnamed tributary below Turnpike Rd./ Upper Turnpike Rd. junction

Reach M07 extends 4,379 ft. (0.83 mi.) upstream from the tributary mouth draining from a pond on the west side of Turnpike Rd. to the confluence of the mainstem and a tributary entering on the left bank shortly before Upper Turnpike Rd. (Fig. 35). The reach drains 5.54 sq. mi. and was divided into two segments of 2,570 ft. (0.49 mi.) and 1,809 ft. (0.34 mi.). The segments differed in buffer widths and levels of encroachment as well as human-caused differences in stream type (a C- to B-type stream departure). The lower segment (M07A) was a C-type stream dominated by cobble substrates, with a weak riffle-pool bed form, but an incision ratio of 2.0 indicated significant loss of floodplain access. The upper segment (M07B) was a B-type stream due to historic degradation that has caused loss of floodplain access and consequent stream entrenchment.

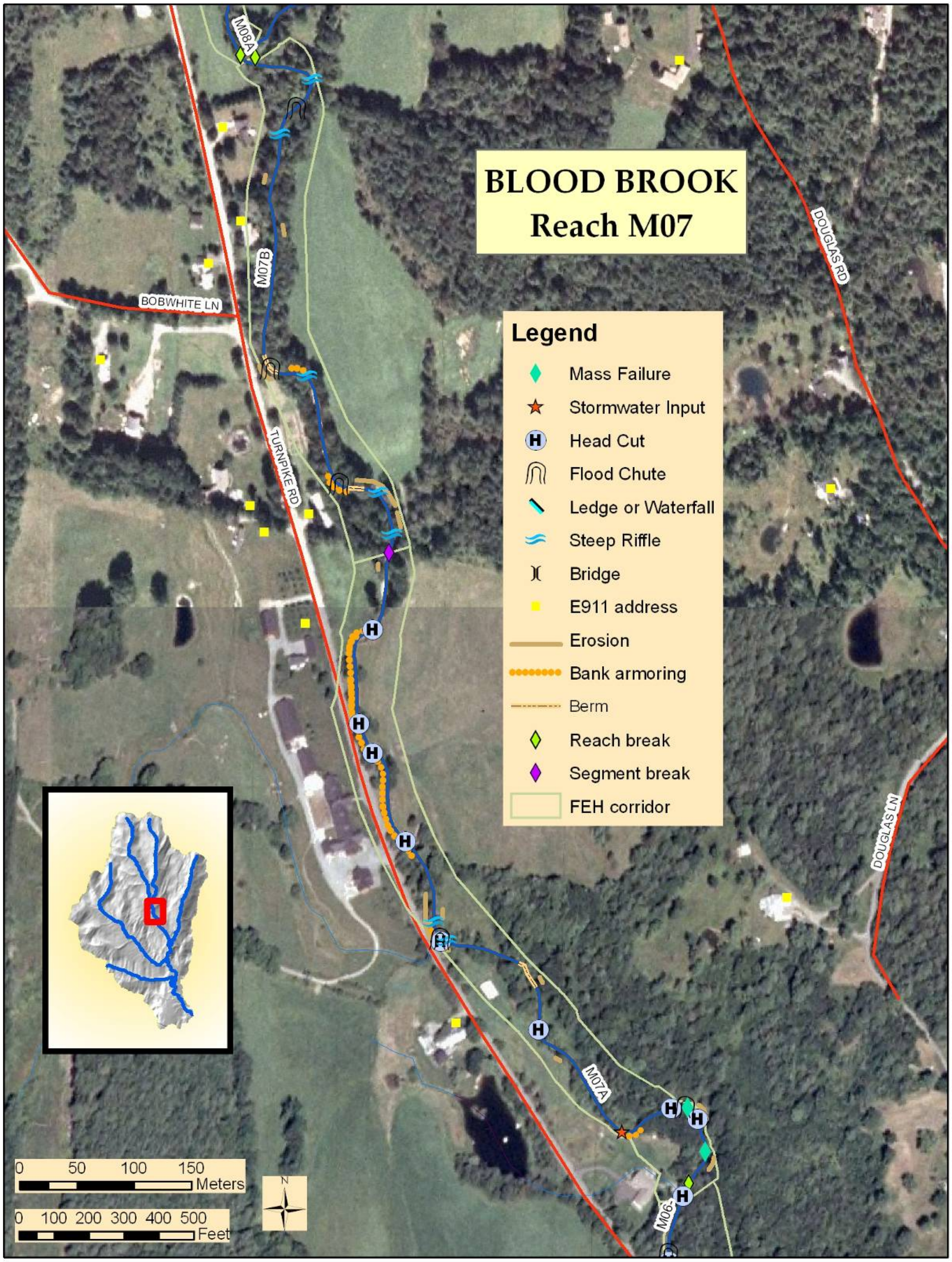


Figure 35. Reach map for Blood Brook mainstem reach M07.

Table 13. Blood Brook Segment M07A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M07A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M07A (4)	Plant stream buffer/ fencing	High	High	Y	Ag lands may have funding opportunities
M07A (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures
M07A (18)	Remove berm	Low	Low	Y	Short section (90 ft.); gain of floodplain access likely to be minimal
M07A (36)	Potential restoration/ protection project	High	High	N	Information gathering: Sigler ag lands; may warrant active restoration

Segment M07A showed frequent encroachment in the river corridor from development and roads, and vegetated buffers were lacking in much of this reach. This section of stream had been straightened in the past, and there were distinct indications of degradation (Fig. 36); further progression of this downcutting could significantly alter stream dynamics and lengthen the timescale for re-establishment of equilibrium conditions in this portion of the watershed.

Figure 36. Lack of buffers, headcuts, undercut banks and exposed lodgment till were all noted in Reach M07.

Table 14. Blood Brook Segment M07B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M07B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M07B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation; limited areas <25ft., mostly by road
M07B (36)	Potential restoration/ protection project	High	High	N	Information gathering: Sigler ag lands; may warrant active restoration

The incision ratio in this segment M07B was lower than in the downstream segment (1.7 as opposed to 2.0), but the stream had already lost access to floodplain historically in this section. There were still some signs of active degradation, but aggradation and channel widening (Fig. 37) were the more dominant processes in the upstream segment, and a planebed bedform was noted in field assessment. No headcuts were observed; they would likely wash out quickly in this area anyhow.

Figure 37. Channel widening and aggradation were dominant processes in the alluvial soils along segment M07B.

Although no alluvial fans were noted in assessments of this area, the presence of alluvial soils and steep valley walls converging from two streams above the upstream portion of this segment (Fig. 38) suggests that there is at least significant sedimentation occurring, and/or that it has occurred historically, here. This situation would lead to a naturally unstable portion of the stream channel, with significant shifts in location probable over time; river corridor protection is thus a high priority.

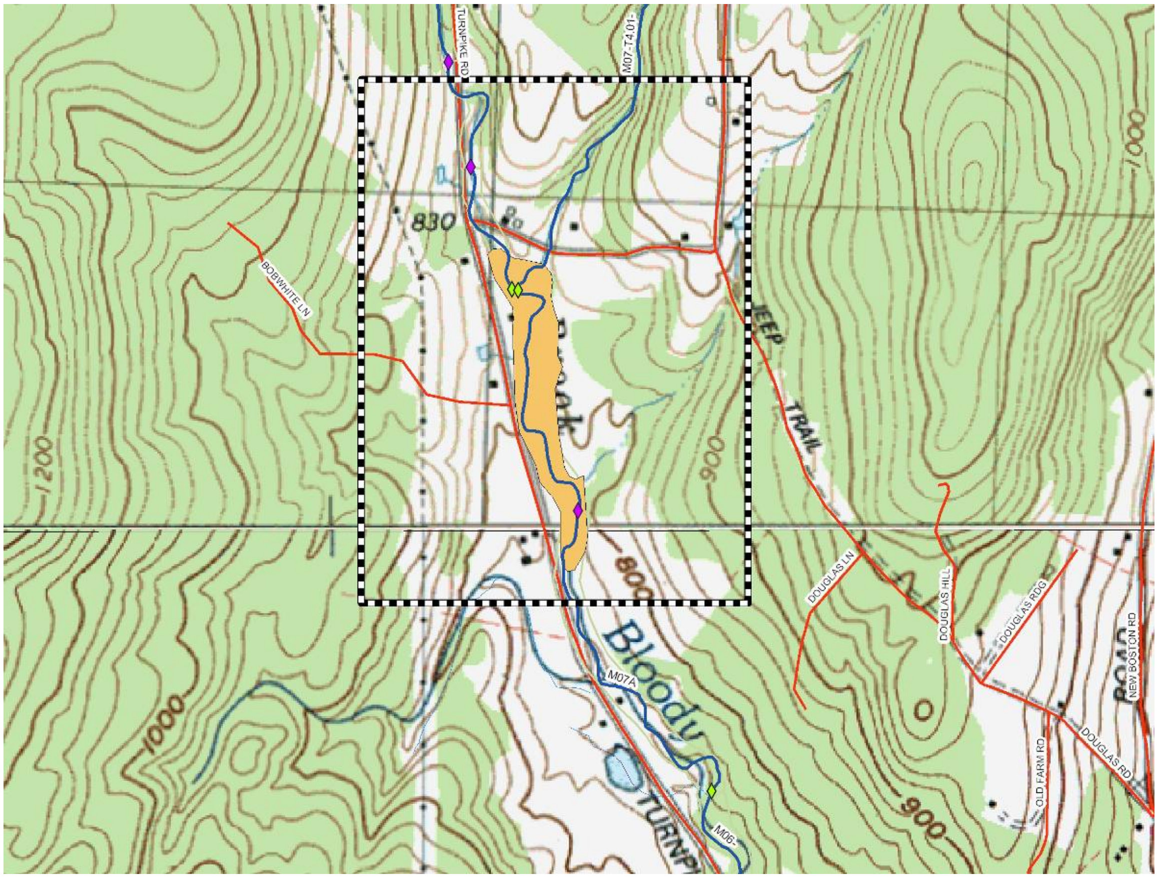


Figure 38. Alluvial soils (indicated by orange solid polygon at center) and steep valley walls bounding convergent streams just above segment M07B suggest the presence of an alluvial fan in this area that would lead to a naturally unstable and shifting portion of the stream channel.

6.1.6 Preliminary project identification: reach M08 – Blood Brook mainstem, confluence of unnamed tributary below Turnpike Rd./ Upper Turnpike Rd. junction to Old Orchard Ln.

Reach M08 includes roughly 4,900 ft (0.93 mi.) from the confluence of the Blood Brook mainstem and an unnamed tributary (reach M07-T4.01), which is below the junction of Turnpike and Upper Turnpike Roads, to just above a culvert beneath Old Orchard Ln. (Fig. 39). The reach was broken into four segments after the initial walk-through, primarily on the basis of changes in confinement and stream/floodplain relationships as the proximity of the valley wall to the stream varied through the reach. The overall reach was assessed as a C-type stream. In portions of the reach, however, the stream was channelized against the valley walls, which likely occurred sometime in the 1800s in order to maintain agricultural land; segments M08B and M08D were thus assigned a modified B-reference type due to long-standing historical incision and entrenchment.

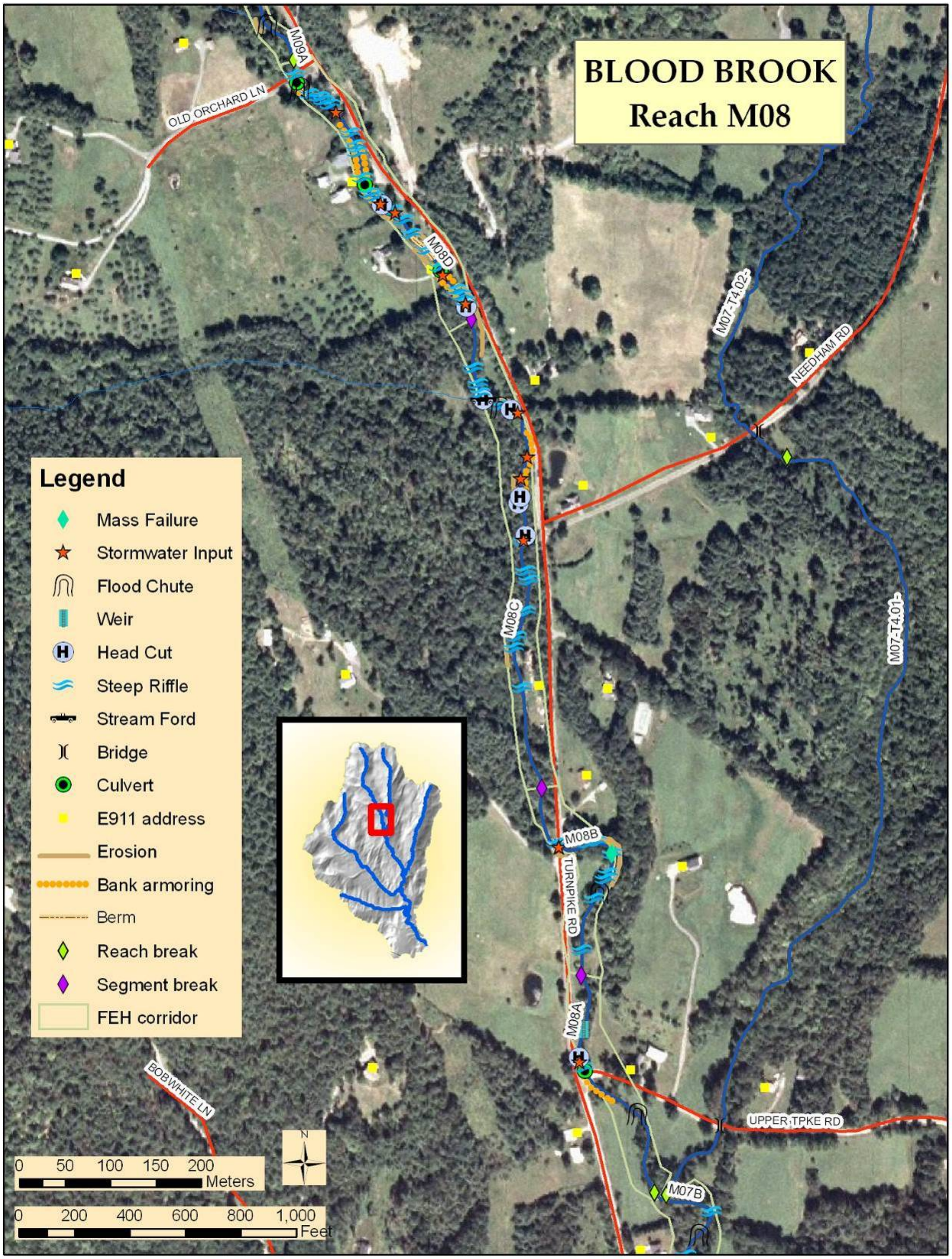


Figure 39. Reach map for Blood Brook mainstem reach M08.

Table 15. Blood Brook Segment M08A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited primarily due to road encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08A (4)	Plant stream buffer/ fencing	High	High	Y	Ag lands may have funding opportunities
M08A (15)	Arrest headcuts	High	High	Y	Currently has check dam in good shape, but could pose loss of floodplain and threats to road
M08A (36)	Potential restoration/ protection project	High	High	N	Information gathering: may be linked to culvert replacement at Turnpike/Upper Tpk., but will require consideration of property and infrastructure protection and possible channel bed stabilization

Segment M08A comprises roughly 950 ft. (0.18 mi.) of the lower end of the reach to a check dam grade control installed approximately 150 ft. above the junction of Turnpike and Upper Turnpike Roads. In contrast to Phase 1 preliminary typing of the stream as a B channel, this portion of the reach was observed to be a C gravel riffle-pool system. The type difference was attributed to a naturally wider available floodplain due to the valley wall being located farther from the stream in this segment, and the stream's ability to access that floodplain. Road encroachment was the primary issue in the segment, with roughly 40% of the upper portion affected. Although the steep banks by the road in this segment were currently vegetated, erosion threatened to undercut the same road just upstream in the next segment, and widening or lateral adjustment in this segment could quickly become an issue given the highly erodible nature of the bank materials. An elevated pipe from under Turnpike Rd. carries overflow from a pond perched above the floodplain, and bed degradation in association with this outfall appears to be a primary reason for installation of the check dam a short distance upstream (Fig. 40). The check dam was in good shape at the time 2006 field assessments, and given the degree of incision downstream, it may be playing a significant role in preventing upstream migration of headcuts.

Figure 40. An elevated pipe carrying overflow from a pond above the floodplain daylights on the steep banks below Turnpike Rd. in segment M08A (left). Degradation of erodible bed materials below this outfall has formed a 3-foot-deep pool, and concern about upstream migration of this downcutting may be a primary reason for installation of a check dam just upstream of this point (right).

An incision ratio of 1.5 in this segment indicates some recent loss of floodplain access. Sediment storage was minimal in segment M08A, though steep riffles were associated with deposition above and below the squashed culvert passing under Upper Turnpike Rd. Considered a "100-year culvert" at the time of installation, that culvert is sized at 65% of reference bankfull width and was flagged for a number of geomorphic incompatibilities, including partial obstruction of the inlet by significant deposition. It was nearly overtopped by high waters during a storm that brought three inches of rain in two hours during February 2006, which may well have eroded the surrounding banks if the ground had not been frozen (pers. comm., Andy Hodgdon, Town Road Foreman). Replacement of the structure may well initiate changes in bed elevation and/or bank stability, however, and would require consideration of property protection and possible channel bed stabilization. The downstream portion of the segment may be part of a possible alluvial fan not identified in previous assessments (see Fig. 38), which would make it naturally unstable. Hayfields were the dominant land use on both sides of the riparian corridor, and buffers were limited in most areas to 5-25 ft. in width on both sides, with some wider buffers present.

Segment M08B starts at the check dam above the junction of Turnpike and Upper Turnpike Roads and extends a little over 900 ft. (0.17 mi.) upstream, to roughly 250 ft. above the next bridge upstream on Turnpike Rd. (Fig. 39). The valley wall was continuous with much of the left bank, but the valley is wide, and the confinement was noted as broad in this segment; entrenchment due to historic incision is indicative of loss of floodplain access on the right bank and a change of stream type to a B type, (Fig. 41).

Erosion averaging 3.5 ft. in height was evident along 25% of the left bank, and a mass failure 25 ft. in height was present on this side of the stream shortly downstream of the Turnpike Rd. bridge, where the stream meets the left bank valley wall. Erosion averaging 4.5 feet in height was observed along 10% of the right bank.

Figure 41. Long-term maintenance of the stream against the valley wall in segment M08B has contributed to sufficient downcutting, causing stream entrenchment and loss of floodplain access.

Table 16. Blood Brook Segment M08B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation; buffers generally good, reach vertically unstable
M08B (36)	Potential restoration/ protection project	High	High	N	Information gathering: may be linked to bridge replacement at Turnpike/Upper Tpk., but will require consideration of property and infrastructure protection

Buffer widths in segment M08B were fair to good, with 26-50 ft. in width along the hayfields on the right bank and greater than 50 ft. elsewhere through the segment. Hayfields dominated the right bank corridor land use, and the bridge in the midstream section of the segment was aligned at a relatively sharp angle to the stream corridor (Fig. 42). The combination of these factors (as well as historical maps indicating this routing of the stream occurred sometime between 1894 and 1944; http://docs.unh.edu/VT/strf96se.jpg and http://docs.unh.edu/VT/strf44se.jpg) indicates that the stream has likely been maintained against the left valley wall over time. Although the bridge is sized at 67% of reference channel width, the angle of this bridge and its arrangement with an adjoining driveway form both a channel and a flood-prone constriction to the stream and make this structure a concern in a flood event, as well as a contributor to significant deposition above the structure due to the constriction. As with the squashed culvert in segment M08A, however, replacement of the structure may well initiate changes in bed elevation and/or bank stability and would require consideration of property protection. Channel bed stabilization may be less of an issue in this section of the stream, as it is relatively far away from upstream roads and structures.

Figure 42. Bridge alignment and the presence of a driveway above the right bank (right side of this photo) combine to form both a stream channel and a flood-prone constriction in segment M08B.

Segment M08C begins across from 914 Turnpike Rd. and extends 1,850 ft. (0.35 mi.) upstream to the edge of a wooded area downstream of a private culvert under the driveway leading to 1037 Turnpike Rd.; it was segmented due to a change in confinement and differences in corridor land use and buffers. Cross-section data indicated an E-type stream due to a very low width/depth ratio, but the stream channel was not as sinuous as is typical for an E-stream and widens shortly downstream, remaining wider through the remainder of the segment; the cross-section may have been located too close to culvert influences in the next segment upstream to have been fully representative. The important point is that for either a C- or E-type stream, floodplain access is available to the stream.

Table 17. Blood Brook Segment M08C Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08C (1,2,3)	Protect river corridor	High	High	Y	Important attenuation asset
M08C (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, roadside and recently cut banks by residential development; buffers generally good, reach vertically unstable
M08C (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures

Although the stream currently has floodplain access in this section, an incision ratio of 1.7 indicates downcutting. The terrace above the right bank of segment M08C was logged within the last 10 years, and the hydrology of a small tributary appears to have changed, as a gully has begun to open below this terrace well back from the stream. Tributary rejuvenation was noted at the confluence of this tributary with the Blood Brook mainstem. Four stormwater inputs were noted, as a number of road ditch culverts have been recently installed; one of these also carries overflow from a pond. A stream ford set up to access the log landing was noted as an active headcut (Fig. 43), and other headcuts were noted (though they are currently better deemed nickpoints) in relation to stormwater inputs in the segment. The stream ford mimics, to some degree, a common stream dynamic in upland streams where large woody debris can provide sediment storage and attenuation benefits, and its removal may entail more problems than will allowing current processes to proceed (pers. comm., Rich Kirn, VT Fish & Wildlife fisheries biologist, Oct. 2006). This ford is downstream of several culverts already indicating scour and potential undermining, however, and the stream approaches Turnpike Rd. shortly upstream as well. Potential migration of headcuts in this portion of the stream should be monitored and may need to be arrested.

Figure 43. A log dam in segment M08C (left) that appears to have been installed as part of a stream ford to access a log landing has been eroded and is now forming an active headcut with the potential to migrate upstream rapidly (right).

Erosion was noted along roughly 10% of both the right and left banks, averaging 2-3 ft. in height, and an additional 10-15% of the left bank was rip-rapped. Depositional features were common, with sediment storage noted in mid-channel, point, side, diagonal, and one delta bar. Twenty-seven pieces of large woody debris were observed in the segment; these can offer habitat and sediment storage advantages. The significant aggradation and sediment storage occurring in this segment indicate the high value of this area as an attenuation asset, and the largely wooded corridor is currently relatively undeveloped; river corridor protection is strongly recommended in this area.

Segment M08D was typed in Phase 2 fieldwork as a B gravel riffle-pool stream. Steep valley walls on the right bank in particular indicated that deep incision (incision ratio 3.4) in this segment is long-standing in nature, but cross-section data also indicated more recent abandonment of the floodplain at a lower elevation was likely but obscured by road ditching and possible other excavation or earth moving off the left bank. A series of three undersized culverts in short succession accentuate the semi-confined setting defined by the valley walls for the stream in this segment, although an entrenchment ratio of 2.1 indicated that the stream is only moderately entrenched and maintains some access to the narrow floodplain (particularly in the downstream portion).

Right bank corridor use was residential and pasture, and buffer widths were limited to 5-25 ft. with some areas of 26-50 ft. on this bank. Horses have access to the stream at one point, with fencing placed to provide the stream as their water supply; Japanese knotweed covers a portion of the right bank near this point. Unlike downstream portions of the mainstem, potentially invasive plants such as knotweed are not an extensive presence in this portion of the watershed. Management of invasive plants, while not integral to protecting and enhancing geomorphic health, could be investigated, and partnerships with willing landowners could be developed. Early detection and rapid response are great advantages in such efforts, and establishment of wooded buffers would help provide shading and competition that can act as a deterrents to the spread of knotweed and provide a far greater advantage, in terms of bank stabilization via more extensive root systems. Although left bank corridor use was noted as predominantly forest with some residential development, road encroachment contributed to limiting the buffer width to 26-50 ft., narrowing to 5-25 ft. in significant portions of the segment. Erosion was noted on 10-15% of both banks, averaging 3 feet high on the left bank and 3.5 ft. on the right bank. Roughly 25% of the left bank and 55% of the right bank were rip-rapped, and another 15% of the segment was bermed on one (10%) or both (5%) banks. These are low berms, and their removal would not permit much floodplain access.

The perpendicular orientation of the driveways and road above the culverts in this segment presents channel and flood-prone constrictions that, in conjunction with the close proximity of these features to Turnpike Rd., would make this area a concern in a flood event. Soils in this area are highly erodible, although a good portion of the banks is rip-rapped. The significant amount of riprap and berming in this segment may increase the likelihood of continued bed degradation. The presence of active incision in the next downstream segment suggests that headcuts could migrate upstream rapidly, although these structures may limit further upstream migration and will probably make arresting headcuts in this segment unnecessary. There is also an elevated risk for outflanking of these structures due to deposition just upstream of each of these culverts (channel constriction decreases stream power and sediment transport). The structural integrity of these culverts is thus a concern (Fig. 44). Replacement of these structures, however, has a high potential for initiating significant changes in channel evolution and bed elevations in particular; these factors need to be weighed carefully in comparison with the potential costs of damages due to outflanking and erosion.

Figure 44. Indications of scour undermining this culvert make the possibility of upstream migration of headcuts a concern for structural integrity. Sediment deposition above – not as heavy at this culvert as some others in the study – indicates a structure may not be adequately sized to transport sediment as well as water at bankfull flows.

Table 18. Blood Brook Segment M08D Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08D (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08D (4)	Plant stream buffer	High	High	Y	Benefits bank stabilization and deters spread of invasives
M08D (18)	Remove berms	Low	Low	Y	Gain of floodplain access minimal; may impact land use (residential)
M08D (25)	Replace structures	Low	Low	N	Needs evaluation on a case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking

6.1.7 Preliminary project identification: Reach M09 – Blood Brook mainstem, Old Orchard Ln. to headwaters of Blood Brook mainstem

Reach M09 begins just above Old Orchard Lane and continues for 12,260 ft (2.32 mi.) to the head of Blood Brook (Fig. 45). It drains 1.94 sq. mi. and was divided into three segments during Phase 2 assessment. The lowest segment (M09A) includes 7,260 ft. (1.38 mi.) of stream to just upstream of Birch Hill Ln. and was characterized by multiple road crossings and significant road and development impacts. It was typed as a C channel dominated by cobble substrate and a weak riffle-pool bed form. The mid-reach segment, M09B, includes 3,220 ft. (0.61 mi.) up to the beginning of wetland influences between 1655 and 1720 Turnpike Rd.; it was characterized as a B-type channel dominated by a cobble substrate, with multiple ledge and waterfall grade controls and exemplary buffering. Bed form varied between riffle-pool and step-pool. There was an old beaver impoundment in the middle of this segment that was not holding water. The upper segment (M09C) of this reach is 1,780 ft. (0.34 mi.) in length and was dominated by a broad valley and wetlands created by beaver activity. This upper segment was not further evaluated due to the wetland and impoundment influences, per Phase 2 protocols.

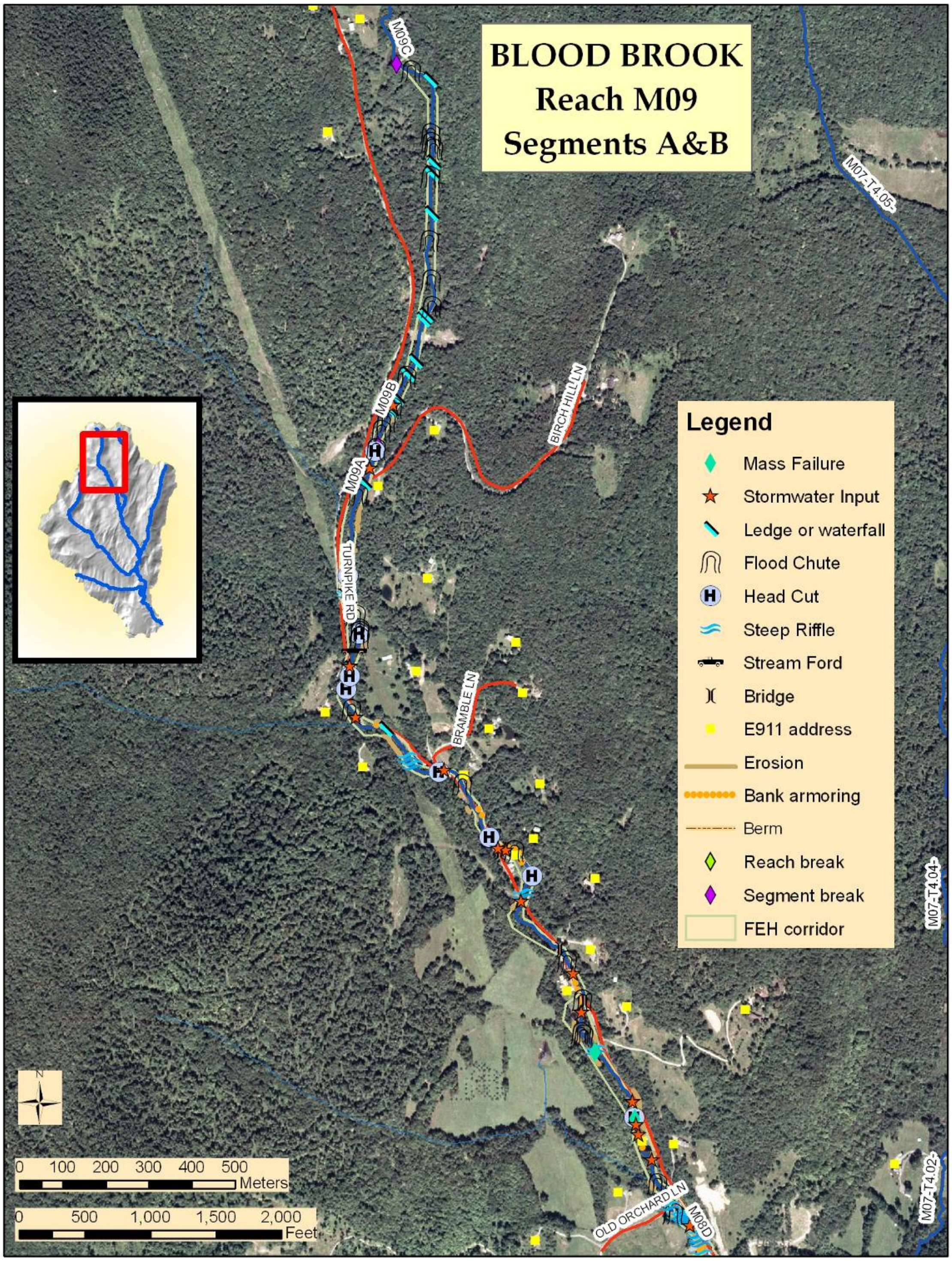


Figure 45. Reach map for Blood Brook mainstem reach M09 segments A and B (segment C was excluded from full Phase 2 analysis due to the influence of wetlands and impoundments).

Table 19. Blood Brook Segment M0A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M09A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; attenuation asset
M09A (4)	Plant stream buffer	High	High	Y	Primarily augmentation; transpiration benefits
M09A (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures; unnecessary in upstream portions due to natural grade controls
M09A (25)	Replace structures	Low	Low	N	Case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking
M09A (36)	Potential restoration/ protection project	High	High	N	Information gathering: Between Old Orchard and Bramble Lns.; may warrant active restoration; encroachment limits possibilities

Issues in segment M09A included road encroachment and channel constrictions, and giving a high priority to river corridor protection and to limiting further encroachment is recommended. More than 50% of the reach is considered straightened by virtue of its maintenance in relation to road and development encroachments as well as bulldozing of the lowest portion (below Bramble Ln.) after the 1973 flood. Although the stream still has access to a narrow floodplain, its incision ratio of 1.7 along with numerous nickpoints, tributary rejuvenation, and two mass failures in the segment indicate active downcutting processes. The very lower end of segment M09A was noticeably incised (Fig. 46).


Figure 46. Segment M09A was noticeably incised, limiting access to historic floodplain.

With numerous ledge and bedrock grade controls located above this portion of the stream, sediment transported out of the headwaters is being deposited in this segment but is likely minimal due to retention in wetlands and impoundments upstream. Fourteen stormwater inputs were documented within this segment, representing a significant increase in direct hydrologic inputs to the stream. Buffer widths in M09A generally exceeded 25 ft., but they were predominantly less than 50 ft. on the left bank, and this segment had a subdominant buffer width of less than 50 ft. on the right bank as well. With a significant increase in water inputs in this segment, it is important to remember that wooded buffers not only enhance bank stability but also dramatically affect the timing and delivery of water to the stream through transpiration (noticeable in hardwood areas by how quickly the stream drops back down after a summer rainstorm in comparison with a winter rain after leaves have dropped).

Sediment from erosion (of 5-20% of each of the banks) and mass failures within the segment is currently augmented by contributions from tributary rejuvenation. This area can play an important role as an attenuation asset for both sediment and water, and it will be important to maintain access by the stream to floodplain for it to fulfill that function. The bedrock above will limit upstream migration of headcuts, but the lower portions of the segment may require monitoring. The stream in this segment passed through 8 culverts, all of which constrict the channel to some degree, and a few of which cause significant constrictions, which can actually contribute to sediment storage; it can also increase risks of outflanking and erosion of surrounding areas in floods (Fig. 47). Fourteen flood chutes were noted in this segment during field assessments.

Figure 47. Substantial deposition above an undersized culvert in segment M09A has begun to obstruct the inlet. Such a situation provides sediment storage and flow attenuation, but it increases risks of outflanking and erosion hazards.

Replacement of such a structure needs to be carefully evaluated regarding potential impacts of bed elevation changes and initiation of channel adjustment processes.

Similar to the situation in reach M08 downstream, replacement of these structures may have a high potential for initiating significant changes in channel evolution and bed elevations. These factors need to be weighed carefully in relation to potential costs of damages due to outflanking and erosion, as well as potential impacts of bed elevation changes on infrastructure and private property up and downstream, and whether grade controls may be necessary if replacements are deemed necessary or desirable.

Segment M09B was rated in good condition on rapid geomorphic, and reference on rapid habitat, assessment scores, and it offers a benchmark in this watershed for buffers in a healthy condition, as well as excellent possibilities for protecting the relatively intact corridor from encroachment and development to avoid potential land use conflicts and erosion hazards. The presence of bedrock and ledge grade controls naturally limits upstream migration of bed degradation processes (Fig. 48). There is one old abutment in the segment that presents a channel, but not a flood-prone, constriction. This structure could be removed but that would likely entail little change in stream conditions or channel equilibrium.

Figure 48. Segment M09B was rated in good condition on the Rapid Geomorphic, and reference on the Rapid Habitat, Assessment in Phase 2.

Table 20. Blood Brook Segment M09B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M09B (1,2,3)	Protect river corridor	High	Low	Y	Does not play significant role in flow or sediment load attenuation
M09B (27)	Remove structure	Low	Low	Y	Little impact on equilibrium conditions

6.1.8 Preliminary project identification: reach M03-T1.01 – Bragg Brook, Blood Brook confluence to Simpson Rd.

Reach M03-T1.01 is the most-downstream reach for Bragg Brook. This reach drains a watershed of 1.21 sq. mi. and extends roughly 2,100 ft. (0.40 mi.) from the Bragg Brook confluence with Blood Brook to a series of grade controls in a steeper and more confined valley roughly 375 ft. downstream of Simpson Rd. (Fig. 49). The reach was divided into two segments during Phase 2 field assessment.

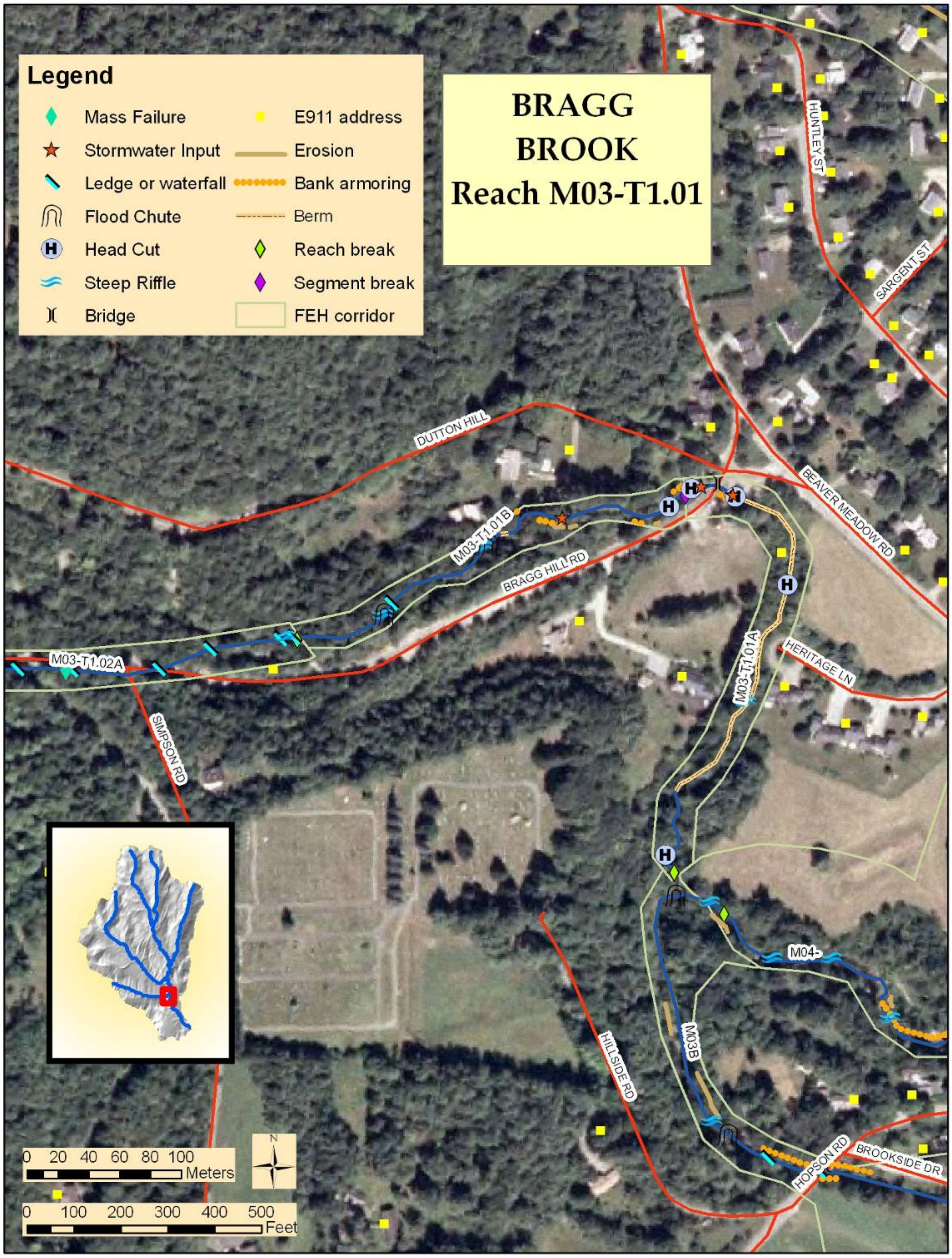


Figure 49. Reach map for Bragg Brook reach M03-T1.01.

Table 21. Bragg Brook Segment M03-T1.01A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.01A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but downstream end important; attenuation asset
M03-T1.01A (4)	Plant stream buffer	High	High	Y	Primarily upstream portion; will aid flood mitigation also
M03-T1.01A (15)	Arrest headcuts	Low	Low	Y	Currently more nickpoints; significant deposition moving from upstream and natural grade controls in next segment; monitor for threats to structures, further loss of floodplain
M03-T1.01A (18)	Remove berm	High	High	Y	Downstream section; could restore some critical floodplain function; need to assess Heritage septic impacts
M03-T1.01A (25)	Replace structure	High	Low	N	Weigh potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking; ideally linked to floodplain restoration downstream

Segment M03-T1.01A comprises roughly 980 ft. at the base of the reach and was typed as an E gravel planebed system, based on Phase 2 cross-section data indicating a very low width/depth ratio. Similar to segment M08C on Blood Brook, however, this w/d ratio is likely related to confinement in a built environment, and the low sinuosity of the segment is not typical of meandering E-type streams. The upstream portion of this reach, M03-T1.01B, was field-assessed as a C gravel planebed stream. Both of these field assessments were in contrast to Phase 1 preliminary reference typing as a B-type stream, an assessment that was likely related to artificial confinement created by a long berm in the downstream segment. The Phase 1 assessment was updated to reflect a C reference type, emphasizing the important point that under reference conditions, floodplain access would be available to the stream in this portion of the watershed. This access is currently restricted by a 790-foot-long berm that prevents the stream from reaching its floodplain even in very high water (Fig. 50).

Figure 50. A high berm on the left bank of segment M03-T1.01A prevents the stream from accessing the floodplain.

Analysis of soil maps overlaid on topographic maps indicates that this berm has likely disconnected Bragg Brook from a much broader floodplain to the east of the current location of the stream, and that extensive development in this area is situated on an alluvial fan or on convergent post-glacial deltaic deposits at the base of several streams within the Blood Brook watershed (Fig. 51). Glacio-fluvial soils beneath Huntley and Sargent Streets and Beaver Meadow Rd. in this same area, in addition to the extensive alluvial soils, are primarily fine-grained sands and silts that are highly erodible and characterize naturally unstable and shifting portions of stream channels.

Headcuts were noted in reach M03-T1.01A, indicating that the stream is degrading, but an incision ratio of 1.5 and an entrenchment ratio of 2.7 indicate some floodplain access. Straightening and confinement of the stream channel in M03-T1.01A contributed to the breakdown of reference streambed features; those characteristics, combined with subsequent deposition, classify most of the segment as having a plane bed and diminished aquatic habitat. With sediment from mass failures and erosion farther upstream still moving through the stream channel, as well as natural grade controls present upstream, headcuts and nickpoints are likely to wash out or be checked from further upstream migration. Headcutting should be monitored, however: primary issues would be threats to infrastructure and further loss of floodplain access. The top section of this segment had a buffer only 5-25 ft. in width, and sometimes less, on the left bank. The most-downstream section of the segment was less developed and had a forested buffer exceeding 100 ft. on both sides. Potential exists for the removal of portions of the berm in the lower segment's forested area to regain some floodplain access. This is downstream of residential developments, should not have an impact on town infrastructure, and may restore some of the vital floodplain access that this lower portion of Bragg Brook has lost. The septic system for the Heritage condominium development may be impacted and would need to be assessed regarding these impacts.

The Bragg Hill Rd. bridge near the top of the segment is sized at 62% of bankfull width, but the alignment of the structure with the stream channel reduces the effective width and contributes to this structure being both a channel and floodplain constriction, indicating potential structure risk and/or channel avulsion in a flood event. Replacement of the structure could initiate changes in bed elevation and/or bank stability, however, and may require consideration of property protection and possible channel bed stabilization; ideally this would be coordinated with floodplain restoration measures downstream of the structure.

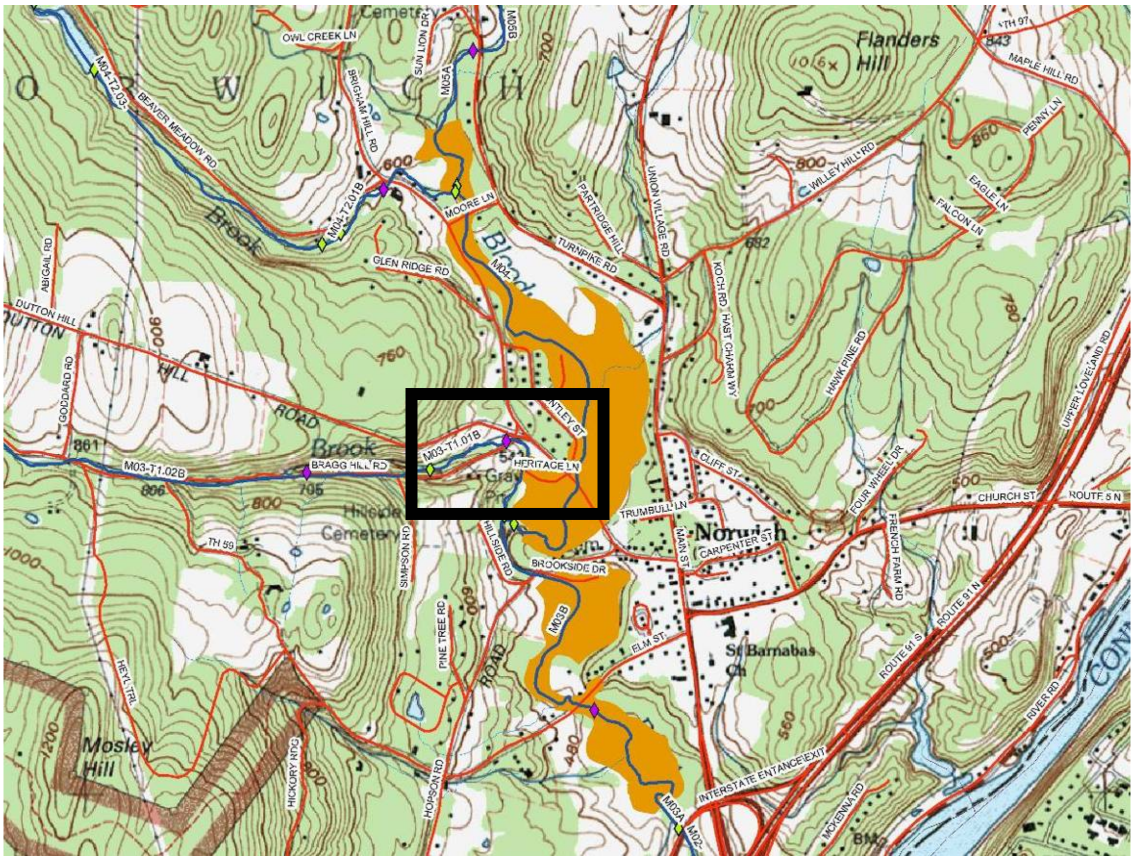


Figure 51. Alluvial soils (indicated by orange solid polygon at center) and steep valley walls above convergent streams in the downstream portions of the Project area suggest the presence of an alluvial fan in this area. The base of Bragg Brook (reach M03-T1.101, within the bounding rectangle) has been disconnected from this former floodplain by the berm pictured in Fig. 50.

The upper segment of this reach (M03-T1.01B) showed less evidence of degradation (incision ratio 1.2, entrenchment ratio 4.9) and streambed disruption, with some riffle-pool structure evident and aggradation occurring as bed load sediments move downstream from mass failures in the next-upstream reach. One headcut was noted in the lower portion of the segment, but there is a ledge grade control present in the upper section. Encroachment exceeded 20% of the segment but was concentrated in the downstream section, and dominant buffer widths were 26-50 ft. on both banks. With a natural grade control present and aggradation occurring, channel evolution in this section of the stream is likely to entail lateral migration and widening as the stream attempts to reestablish equilibrium in the narrow valley; corridor protection is highly recommended.

Table 22. Bragg Brook Segment M03-T1.01B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.01B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; attenuation asset
M03-T1.01B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, natural regeneration; will aid flood mitigation; transpiration benefits

6.1.9 Preliminary project identification: reach M03-T1.02 – Bragg Brook, Simpson Rd. to bridge upstream of 369 Bragg Hill Rd.

Reach M03-T1.02 extends just past a new bridge put in upstream of 369 Bragg Hill Rd. during mid-October, 2006 (Fig. 52). It drains 1.17 square miles and has a channel length of 5,210 ft. (0.99 mi.). The entire reach was typed as a B channel with cobble-dominated substrates and a relatively steep gradient (>4%), and it was divided into two segments during Phase 2 assessment. The lower segment (M03-T1.02 A, 1,350 ft. or 0.26 mi.) was dominated by ledge grade controls and was largely in reference condition, except for sediment inputs from mass failures on its steep left corridor. These mass failures appear related to a one-time break in a water line leading from town wells near the Connecticut River to a 3-million-gallon holding tank on Dutton Hill Road, upslope of this reach, in the late 1970s (pers. comms., Andy Hodgdon, Norwich Road Foreman, December 2006 and January 2007). The largest mass failure extended upslope 70 feet and was approximately 15-20 feet deep (Fig. 15, Sec. 5.1.3a).

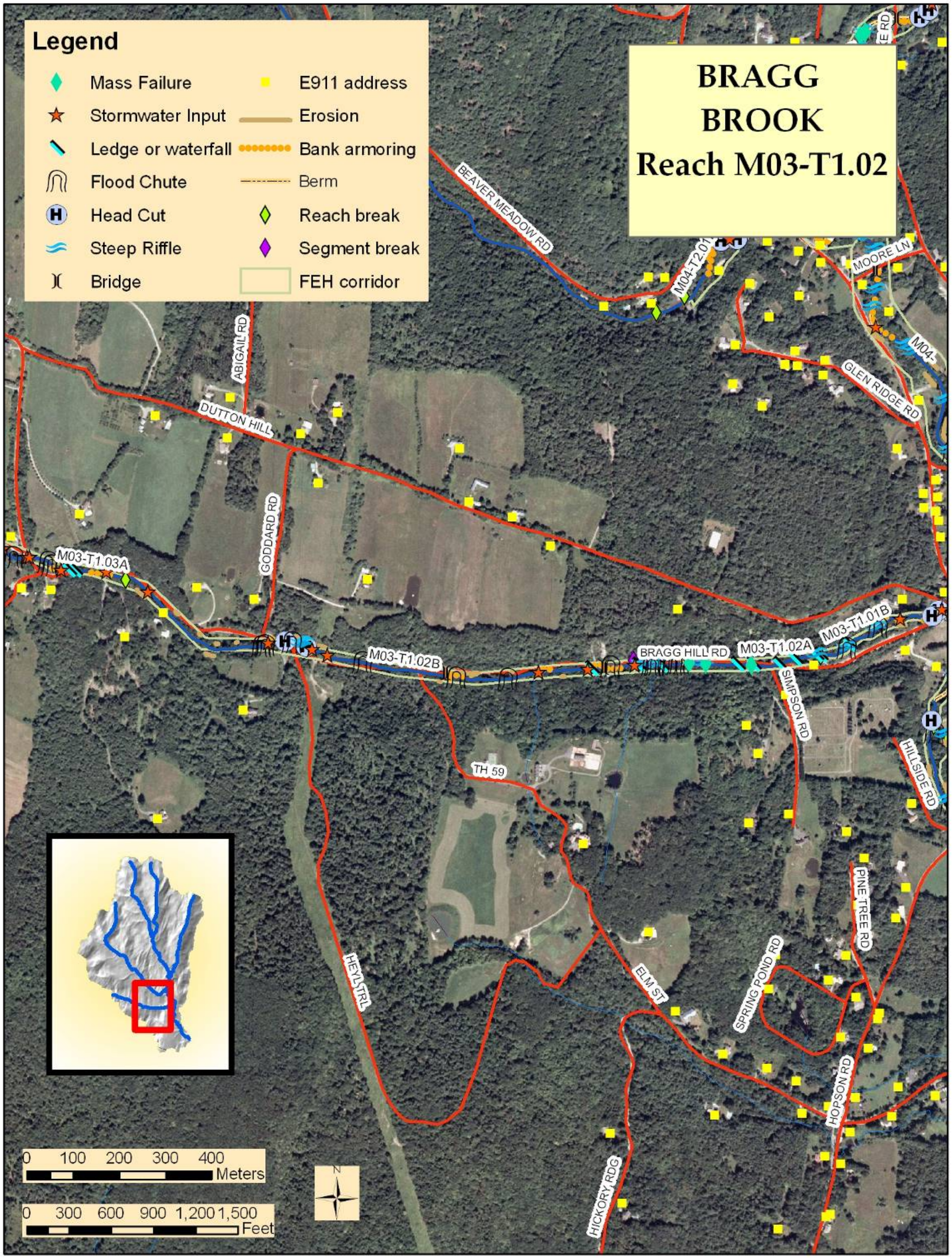


Figure 52. Reach map for Bragg Brook reach M03-T1.02.

Table 23. Bragg Brook Reach M03-T1.02 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.02A (1,2,3)	Protect river corridor	High	Low	Y	Natural transport reach, not attenuation asset; flood hazard avoidance
M03-T1.02A (4)	Plant stream buffer	Low	Low	Y	Mostly along road encroachments
M03-T1.02B (1,2,3)	Protect river corridor	High	Low	Y	Natural transport reach, not attenuation asset; flood hazard avoidance
M03-T1.02B (4)	Plant stream buffer	High	High	Y	Primarily upstream portion; will aid flood mitigation also
M03-T1.02B (25)	Replace structures	High	High	N	Weigh potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking; ideally linked to floodplain restoration downstream

Although the slopes above segment M03-T1.02A have largely stabilized, the large flow increase and sediment inputs related to the water line rupture appear to be impacting Bragg Brook significantly. Waterfall and ledge grade controls immediately upstream of the mass failures were likely a saving grace for upper portions of the stream, limiting rapid upstream migration of headcuts at the time of the rupture. A relatively low incision ratio of 1.2 in segment M03-T1.02A indicates that the series of ledge grade controls downstream also provided a measure of stability for the channel bed there. Field assessments also noted a number of flood chutes associated with these grade controls, however, likely indicating higher erodibility of the banks in relation to the bed in these areas. These conditions indicate potential for channel avulsions in high-water events, as well as lateral migration related to localized increases in deposition above these grade controls at both low- and high-flow levels.

The upstream segment (M03-T1.02B) had a relatively high incision ratio of 2.0. This may be related to adjustment processes occurring in response to the water line break downstream, with headcuts migrating upstream as the stream tried to match the lowered elevation of the streambed downstream. There are waterfall and ledge grade controls above the entry point of the discharge, however, which would serve to limit such migration. Incision in this reach may also be related to stressors including six stormwater inputs noted in the segment, localized flow increases and sediment reduction below three culverts and one bridge noted as channel constrictions, and frequent encroachment from Bragg Brook Rd., which comes right to the streambank in several areas (Fig. 53).

Figure 53. Road encroachment and channel constrictions such as this culvert in segment M03-T1.02B can combine to create localized increases in stream power and decreases in sediment load that increase the likelihood of downcutting processes.

Both segments of reach M03-T1.02 are natural transport reaches, and the steep gradient and confined valley setting mean that the stream is not likely to exhibit a high degree of lateral migration under reference conditions. Primary recommendations for these areas are corridor protection to prevent or mitigate flood hazards and maintenance or establishment of wooded buffers whenever possible.

Physical dictates of stream equilibrium entail a balance between stream power and sediment load (Fig. 54). When stream power is increased and/or contained within an incised channel, erosive power is also increased.

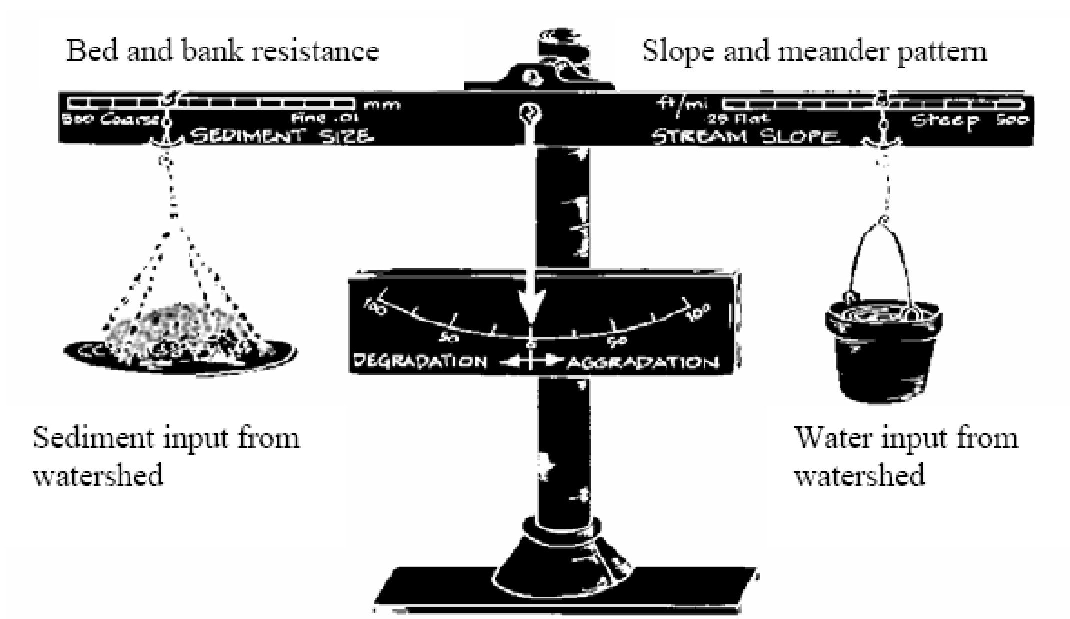


Figure 54. The channel balance (Lane 1955).

Where the bed is resistant to erosion (such as the grade controls in reach M03-T1.02), the banks will become subject to elevated levels of erosion.Wooded buffers can significantly increase bank stability but can be difficult to maintain in areas where road encroachment is extremely close to the stream. Maintenance work on the Blood Brook mainstem in 2007 involving the Norwich road crew, Vermont Youth Conservation Corps, and Two Rivers-Ottauquechee Regional Commission utilized Better Backroads program recommendations for including planting stock within bank stabilization installations. Norwich road Foreman Andy Hodgdon has also worked with geotextile fabrics and rubberized backings for reducing failure of riprap and other bank stabilization efforts, but it is important to remember that this will increase impacts on downstream reaches, and it further emphasizes a critical need for maintaining or restoring floodplain access where possible. In addition, outflanking of undersized bridges and culverts in a narrow valley with significant encroachments can have very different results than might be expected in a broader floodplain, as evidenced by catastrophic channel avulsions in small streams similar to Bragg Brook during July 2007 storms in central Vermont (Fig. 55). Town bridge and culvert replacements in Norwich are more appropriately sized to transport sediment as well as water in high flows, and various collaborators at the state level have been working to develop sizing guidelines that are expected to be released in 2008. Norwich may wish to explore options for ensuring private installations meet similar guidelines.

Figure 55. This road was taken out by a small, unnamed tributary of Ayers Brook in Randolph, Vermont, when the stream avulsed and cut a new channel in an intense thunderstorm during July 2007. The woman at the center of the photo is indicating the post-flood width of the stream by her armspan.

6.1.10 Preliminary project identification: Reach M03-T1.03 – Bragg Brook, bridge upstream of 369 Bragg Hill Rd. to Bragg Brook headwaters

Reach M03-T1.03 extends 5,780 ft (1.09 mi) from 369 Bragg Hill Rd to the head of the Bragg Brook watershed (Fig. 56), and drains a watershed of 0.59 square miles. It was broken into three segments during Phase 2 assessment: M03-T1.03A is 1,868 ft (0.35 mi); M03-T1.03 B includes 2,714 ft (0.51 mi); and M03-T1.03 C covers 1,198 ft (0.23 mi). The downstream segment (M03-T1.03 A) is characterized by human development and diminished buffers and is highly recommended for river corridor protection planning and limitation of further encroachment. This segment is a highly sinuous, slightly entrenched C (or possibly E)-channel in some places, though road encroachment contributes to overall characterization as primarily a moderately entrenched B type. The middle segment (M03-T1.03 B) has a less developed setting with frequent ledge and waterfall grade controls. This segment alternates between a B-type and a steeper, entrenched A-type channel. The upper segment (M03-T1.03 C) is dominated by impoundments and was not further evaluated, in accordance with Phase 2 protocols (VTANR 2007d).

Table 24. Bragg Brook Reach M03-T1.03 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M03-T1.03A (1,2,3)	Protect river corridor	High	High	Y	Attenuation asset limited due to confinement and alternating channel type, but important: high in the watershed
M03-T1.03A (4)	Plant stream buffer	Low	Low	Y	Check results of 2007 plantings on Blood Brook for applicability to roadside plantings
M03-T1.03A (26)	Replace structures	High	Low	Y	Town has inventory and replacement schedule; flood hazard avoidance
M03-T1.03A (36)	Potential restoration/ protection project	High	Low	N	Information gathering: needs cost/benefit analysis; narrow valley may mean minimal floodplain gain

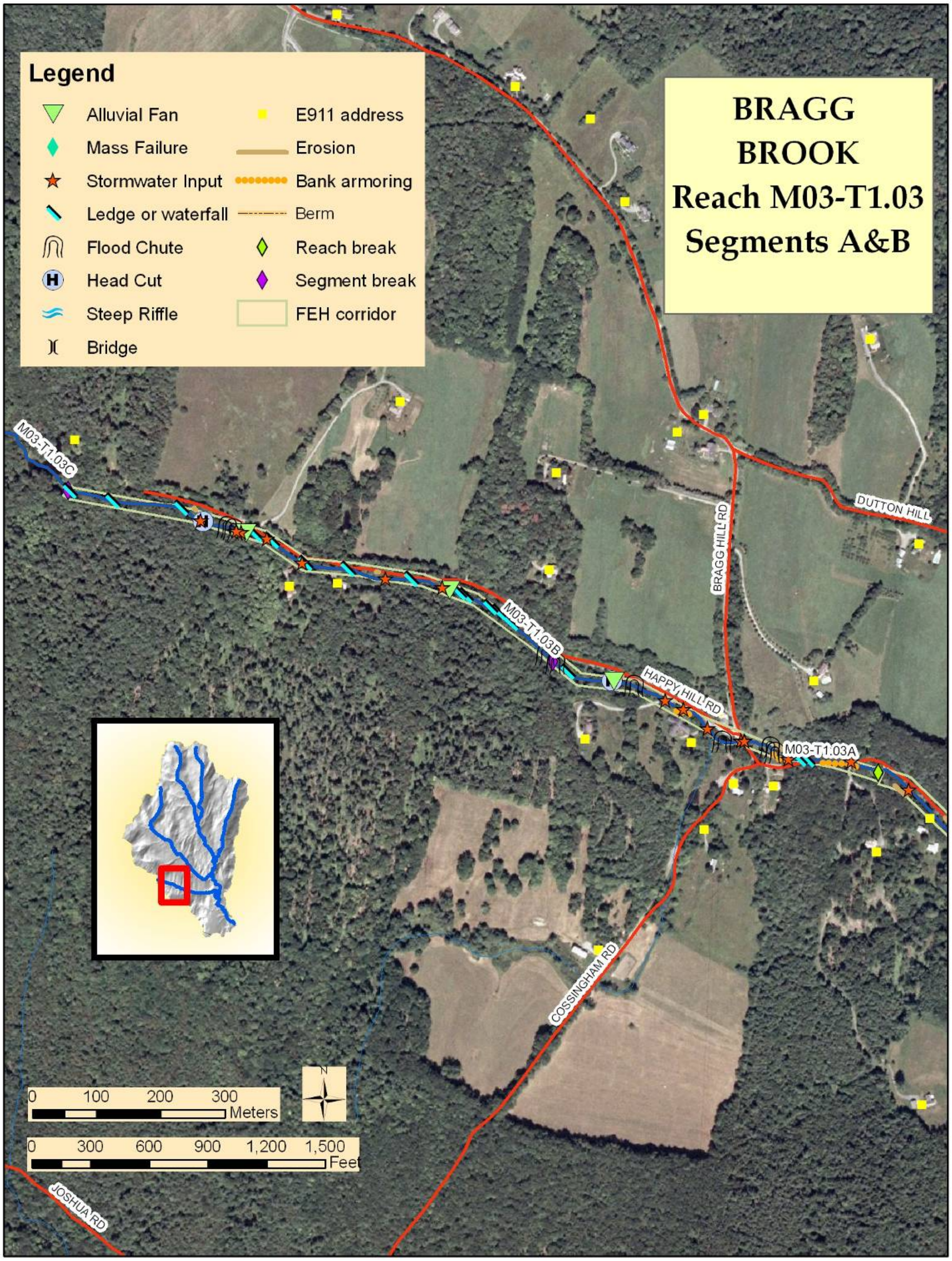


Figure 56. Reach map for Blood Brook mainstem reach M03-T1.03, segments A and B (segment C was excluded from full Phase 2 analysis due to the influence of wetlands and impoundments).

Downstream segment M03-T1.03 A was dominated by gravel substrates in a riffle-pool setting at cross-section locations, contributing to its designation as a subreach with different stream dynamics than the upstream portions. Small areas of moderate slope (<2%) and significant deposition (appearing as small alluvial fans) occur periodically in the segment, alternating with steeper sections that are often bedrock-controlled. Indications are that this area can play some role as an attenuation asset for sediment storage and flow moderation, despite the narrowly confined valley setting. However, an incision ratio of 1.8 indicates downcutting, and encroachments were severe along more than 20% of the segment (Fig. 57), restricting access to floodplain and limiting these functions. Five flood chutes and tributary rejuvenation were noted. Nickpoints noted in the reach are likely related to this downcutting, but are in close proximity to grade controls and would be checked from upstream migration. Buffers were noted as predominantly <5 ft on the left bank and <25 ft on the right bank along the segment, with subdominant buffers of 26-50 ft on both banks. Joint projects in 2007 (along Blood Brook) between town road crews and Vermont Youth Conservation Corps workers, in coordination with TRORC and the Better Backroads program, may have applicability for roadside plantings if maintenance or repairs are scheduled along this segment. Maintenance with hard armoring increases the stream power and transport capacities of the segment and limits the extent of available floodplain, processes that are augmented by 7 stormwater inputs documented in the segment. Five culverts and one bridge in segment M03-T1.03A were noted as floodprone constrictions, and four of the culverts were noted as channel constrictions. The newest town installations were a 6-foot bridge and a 10-ft box culvert, significant upgrades from the culverts they replaced; remaining culverts are sized from 2 – 3.5 ft.

Figure 57. Encroachments along more than 20% of segment M03-T1.03A contribute to an increase in stream power.

Segment M03-T1.03B is largely bedrock-controlled, and an incision ratio of 1 indicates minimal downcutting in this portion of the stream. The reference sediment regime in this portion of the reach is a transport type, and buffers were relatively intact but somewhat diminished with a 26- to 50-ft buffer width dominant on the left bank and subdominant on the right bank; the right bank dominant buffer exceeds 100 feet. Seven stormwater inputs were documented in this segment, in addition to the seven noted in the next downstream segment, suggesting there are elevated hydrologic inputs being transferred downstream.Encroachment was noted along >20% of the channel, suggesting an increase in stream power as well. In addition, multiple impoundments and beaver activity are likely to reduce the sediment inputs in this portion of the watershed, but no mass failures or tributary rejuvenation were noted in this segment and only minimal erosion was observed. Three culverts in the segment were noted as both flood prone and channel constrictions and likely contribute further to sediment transport reductions and localized increases in stream power, as scour was noted beneath each. Deposition above these constrictions was not noted, however.

Table 25. Bragg Brook Reach M03-T1.03B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M03-T1.03B (1,2,3)	Protect river corridor	Low	Low	Y	Primarily flood hazard mitigation; transport reach, not an attenuation asset
M03-T1.03B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, natural regeneration; buffers generally good
M03-T1.03B (26)	Replace structures	Low	Low	Y	Town has inventory and replacement schedule; flood hazard avoidance

6.1.11 Preliminary project identification: Reach M04-T2.01 – Charles Brown Brook, Blood Brook confluence to Norwich Pool

Reach M04-T2.01 is the most downstream section of Charles Brown Brook, beginning at its confluence with Blood Brook and continuing upstream to the dam below the Norwich Pool. This short reach drains 5.64 square miles. It is only 1,760 ft (0.33 mi) long, but was segmented into two subreaches because of reference stream type differences (Fig. 58). The segments also differed in corridor encroachment and grade control characteristics. The lower subreach, M04-T2.01A, was typed as a B channel dominated by cobble substrates, while the upstream segment, M04-T2.01B, was characterized as a C channel with a cobble substrate.

Segment M04-T2.01A extends roughly 1040 ft (0.20 mi) upstream to just above a bridge on Beaver Meadow Rd. A 10-foot waterfall accounts for the large majority of elevation change in this segment, and the rest of the segment is a c subslope (<2 %). An old mill foundation and significant walling of the channel below this indicate that the artificial valley created by this confinement is of a long-standing historical nature, and the segment was designated a subreach with a modified Bc cobble riffle-pool reference type. A plane bed structure noted in fieldwork is likely to be related to adjustment processes subsequent to bulldozing both above the waterfalls and below this segment (on the Blood Brook mainstem) following the 1973 flood, as well as the store and release regime at the Norwich Pool impoundment in the next reach upstream.

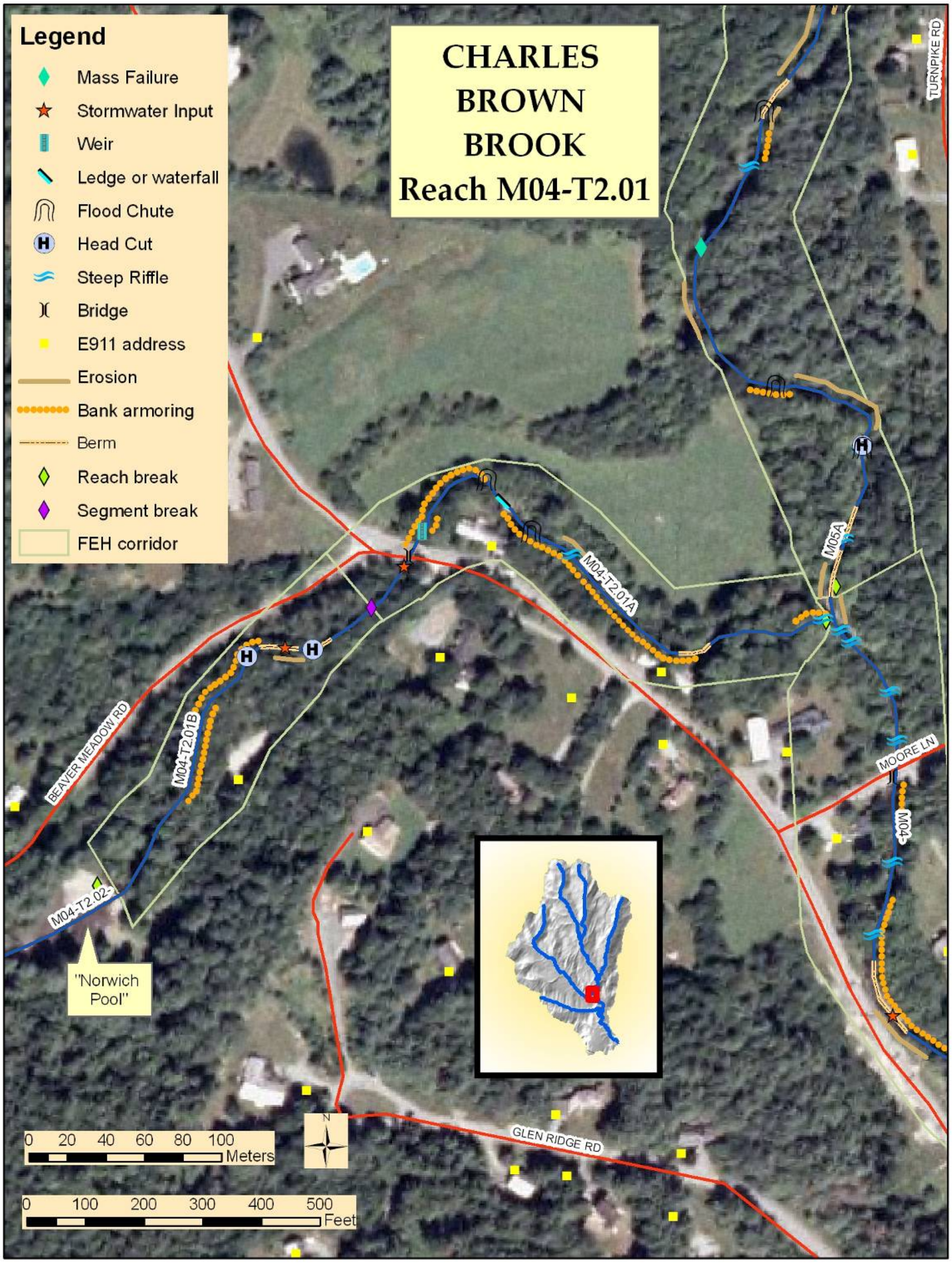


Figure 58. Reach map for Charles Brown Brook Reach M04-T2.01.

Table 26. Charles Brown Brook Segment M04-T2.01A Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M04-T2.01A (1,2,3)	Protect river corridor	High	High	Y	Important attenuation asset on LB
M04-T2.01A (4)	Plant stream buffer	High	High	Y	Ag lands may have funding opportunities
M04-T2.01A (15)	Arrest headcuts	High	High	Y	Currently has check dam in good shape, but could pose loss of floodplain upstream and threats to bridge
M04-T2.01A (15)	Replace structure	Low	Low	Y	Low priority; primarily a floodprone constriction and outflanking may be helpful to downstream properties and infrastructure
M04-T2.01A (36)	Potential restoration/ protection project	High	High	N	Information gathering: may require active measures, but could potentially restore critical floodplain; remove LB armoring below bridge

Buffers were predominantly <25 ft on both banks along the segment, with 50-100 ft buffers present near agricultural fields on the left bank. An incision ratio of 1.3 indicates some downcutting and loss of floodplain, but the bedrock controls present in this segment limit bed degradation and increase erosive powers on the banks. Headcutting upstream of the falls is quite possible, however, and a check dam has been placed in the upstream portion of the segment to limit upstream migration. This grade control was in good shape at the time of 2006 Phase 2 work but is a log structure that requires maintenance (Fig. 11, Sec. 5.1.2).

Corridor encroachment in M04-T2.01A is significant on the right bank, with houses perched above heavily riprapped banks just downstream of the falls and at the falls (Fig. 59), and there is extensive armoring on both banks of the segment (roughly 25% of the left bank and 40% of the right bank). Windrowing of stone in the downstream portion of the segment has effectively created a berm that may deflect some high flows from development on the right bank but does not of itself restrict much floodplain access. The bridge at the upstream end of the segment is sized at 117% of reference channel width but was noted as a floodprone constriction. Outflanking of this structure in a flood may allow the stream to access the floodplain off the left bank downstream, however, but could affect development and infrastructure on the right bank downstream as well. The left bank floodplain represents a highly valuable attenuation asset for both flow and sediment storage in a flood; river corridor protection is highly recommended for this area. This same area may represent an opportunity for restoring floodplain access through more active measures as well, with the value of such an effort amplified by the magnitude of encroachments in the right bank corridor.

Figure 59. Corridor encroachments come right to the stream bank in segment M04-T2.01A.

Table 27. Charles Brown Brook Segment M04-T2.01B Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M04-T2.01B (4)	Plant stream buffer	Low	Low	N	Ideally linked to potential enhancement of floodplain access off left bank
M04-T2.01B (15)	Arrest headcuts	High	High	Y	Currently downstream check dam in good shape, but could pose loss of floodplain and damage to Norwich Pool
M04-T2.01B (36)	Potential restoration/ protection project	High	High	N	Information gathering: may require active measures, but could potentially restore critical floodplain

The upper segment (M04-T2.01B) had better buffers, with 50-100 widths dominant on the right bank and subdominant on the left bank, but road encroachment on the left bank meant the dominant buffer on that side was less than 25 feet. Store and release damming of the Norwich Pool upstream, along with lack of natural grade controls, contributes to periodic sediment starving of this segment and then larger inputs of sediment and water when the impoundment is flushed out seasonally. This segment was bulldozed after the dam had breached following the 1973 flood as well (pers. comms., former selectboard member Linda Cook, August 2006 and Town Road Foreman Andy Hodgdon, December 2006). It is difficult to identify exactly how these factors affect channel dimensions and adjustment processes, but an incision ratio of 1.2 indicates that loss of floodplain through downcutting has likely been limited by the installation of a check dam just downstream of this segment (Fig. 58) and/or mitigated by aggradation following periodic flushing of the pool. Plane bed features noted in the segment are likely due to a combination of these factors and the bulldozing, which left many coarser bed sediments windrowed along the banks, creating a berm off the right bank in the midsection of the segment and contributing to bank armoring in the upstream portion of the segment. The sum effect of channelization appears to be increased stream power and sediment transport, with the bulk of impacts transferred downstream. The maintenance of the Pool and the substantial development and infrastructure off the right bank downstream indicate that equilibrium conditions may be more easily achieved by protecting and accessing the floodplain downstream of this section of the stream. Encroachment from Beaver Meadow Rd off the left bank appears to restrict potential access to floodplain downstream and offers a focus area for project implementation.

6.1.11 Preliminary project identification: Reach M05-T3.01 – New Boston Brook, confluence with Blood Brook mainstem to upstream end of "the crooked half mile"

This reach extends from the confluence of New Boston Brook and Blood Brook and continues upstream to the top of what is known as the "crooked half mile" on New Boston Road (Fig. 60). This reach drains 2.79 square miles, is 3302 feet (0.63 mi) in length, and was left unsegmented during assessment. It was characterized by a narrow valley confinement, but classed as a Cb type stream (b subscript for 2-4% slope, steeper than a typical C stream), due to its access to the narrow floodplain. The stream is moderately to severely encroached upon by New Boston Road, and an unusual situation arises from the fact that the valley and floodplain have been somewhat broadened by road construction. At the top of the reach, the landscape broadens into a wide valley. Extensive wetlands and mulitple impoundments constructed by both humans and beavers upstream of this reach are likely retain many sediments that might otherwise become part of the sediment load of this reach; the reduction of sediment load may be contributing to increased stream power in this reach. Although there is access to the floodplain in this reach, it is very narrow; concerns have more to do with retaining access to the floodplain upstream of this reach and minimizing impacts transferred out of this area to downstream reaches.

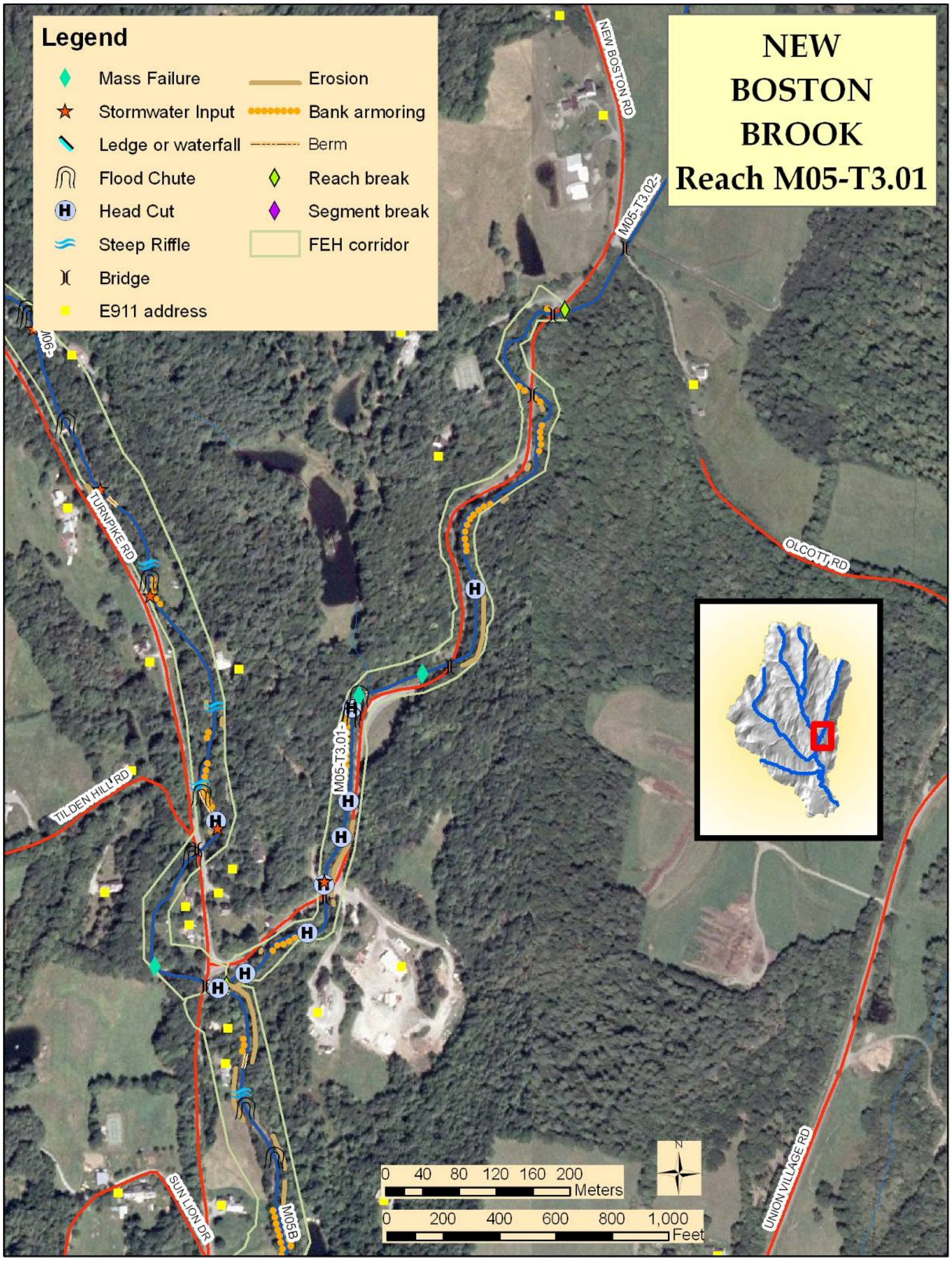


Figure 60. Reach map for New Boston Brook Reach M05-T3.01.

Table 28. New Boston Brook Segment M05-T3.01 Projects and Practices Table used throughout the step-wise project identification process (VTANR, 2007b, Ch. 6 step numbers).

River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M05-T3.01 (4)	Plant stream buffer	Low	Low	N	Difficult conditions close to stream; low cost stock
M05-T3.01 (15)	Arrest headcuts	High	High	Y	Currently mid-reach check dam in good shape, but could pose loss of floodplain and damage to infrastructure
M05-T3.01 (25)	Replace structures	Low	Low	Y	Cost/benefit analysis: will require consideration of infrastructure protection and possible channel bed stabilization; risks of outflanking impacts may be lower
M05-T3.01 (34)	River corridor protection at downstream reach and Restore incised reach with bed forms and floodplain features	High	High	N	Bed forms and floodplain features need to be in equilibrium with higher power of channelized reach; erosion conflicts likely to increase until this occurs; corridor protection downstream to attenuate increased flows

An incision ratio of 1.7 is indicative of downcutting, and exposed lodgement till, numerous nickpoints, two mass failures, and tributary rejuvenation were noted in M05-T3.01. Erosion was noted on less than 5% of the reach on the right bank, but 5-20% of the left bank. The right bank erosion was primarily limited to the most downstream crossing of this reach on New Boston Road, where surface water runoff was causing bank erosion and a head cut was forming in the stream (Fig. 61). Mass failures in this reach (Fig. 62) were located close to culverts listed as constrictions that also exhibited scour downstream of these structures, indicative of localized increases in stream power. A log check dam upstream of these mass failures was in good shape at the time of 2006 Phase 2 assessments. With no natural grade controls evident in this reach, this weir appears to play an important role in limiting upstream migration of headcuts and reduction of risks to infrastructure, but it should be noted that this type of installation requires maintenance.

In addition, the overall effects of migration of incision processes into upstream reaches are more difficult to assess in terms of the stream dynamics in this portion of the watershed. Given the extent of downcutting currently exhibited here and further downstream, the stream in this area may need to be recruiting sediments from upstream sources to retain or rebuild floodplain access.

Figure 61. (Left) Norwich Conservation Commission volunteer Jonathan Frishtick extends a measuring rod near bank erosion located just above a headcut in the downstream portion of New Boston Brook.

Figure 62. (Right) Mass failures in reach M05-T3.01 were located near culverts also exhibiting scour downstream of the structure, indicative of localized increases in stream power (photo courtesy TRORC).

One bridge and three culverts are located in this reach. They all represent some channel constriction, ranging from 49% - 69% of reference channel width, and all were listed as floodprone constriction.. None of these structures was fully aligned with the channel, reducing the effective width of the structure for sediment and flow transport. An old abutment within the reach was a significant channel constriction but not a floodprone constriction, as it would flood during major flood events. Although it appears there are localized increases in streampower associated with these structures, the sensitivity of the stream bed to degradation indicates a need to carefully assess the potential for initiating significant changes in channel evolution and bed elevations if these structures are replaced. These factors need to be weighed carefully in comparison with the potential costs of damages due to outflanking and erosion. In several portions of this reach, the road actually broadens available floodplain and high flows are likley to run over these surfaces; although this would attenuate flows through lateral movement, it may also intesify stream power over these smooth surfaces. In other areas that are more deeply incised or entrenched, an outflanked structure is likely to significantly undermine the road. These issues are outside the scope of this plan and best left to the Road Foreman and qualified engineers; many have already been considered in the Town's structure inventory and prioritization process (pers. comm., Andy Hodgdon, Norwich Road Foreman, Dec. 2006).

6.2 PROJECT PRIORITIZATION

Due in large part to its geologic setting, the Blood Brook corridor planning Project area tends to be highly sensitive and responsive to changes in watershed inputs. Passive geomorphic restoration projects, which leverage these inputs and the river's own energy to facilitate a return to equilibrium conditions, are thus recommended for prioritization due to the likelihood of rapid stream evolution. Lower investments associated with this approach are often desirable considering an inherent degree of uncertainty in the success of engineered approaches in an active system. That said, however, there are significant constraints to be considered in a relatively developed watershed such as Blood Brook. Widespread development has already occupied significant portions of historic floodplains, and key attenuation assets are a dwindling resource in many portions of the watershed. Due to significant development pressures, highest priority in this watershed is thus recommended for protection of these assets and adoption of belt-width corridors as a basis for reducing flood hazards and land-use conflicts. The Fluvial Erosion Hazard 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 pre-defined width or similar method and can be implemented through a variety of approaches (VTANR, 2007a).

Sediment regime departure analysis (see esp. Sec. 5.1.4 of this report) suggests that restoration of floodplain in upper portions of the watershed will be important to establishing equilibrium conditions and reducing flood hazards and erosion conflicts in downstream reaches. Although it is not as high in the watershed as would be ideal, reach M04 near the Norwich playing fields and Huntley Meadows contains valuable floodplain assests for attenuating both flow and sediment inputs as well as mitigating flood impacts on the center of town, and these areas are recommended as a high priority for corridor protection.

Due to significant existing encroachment, the least limited opportunities higher in the watershed (and best possibilities for passive approaches) on the Blood Brook mainstem appear from the base of segment M08D into segment M08C downstream of Needham Rd., and in segment M05A above the Moore Ln. bridge. Segment M05A will play a role in attenuating inputs from New Boston Brook as well and would benefit from protection of key assets in the floodplain above the confluence with Charles Brown Brook. Reach M04 contains valuable floodplain assests for attenuating both flow and sediment inputs as well as mitigating flood impacts on the center of town.

Although generally more expensive to implement, more active approaches may be warranted to ensure or restore floodplain access due to the significant limitations already in place on many of this watershed's historic floodplains. Project implementation in segment M05A on Blood Brook might explore a combination of active and passive approaches, with windrowed stone close at hand to be restored to the channel. Segment M03-T1.01A at the base of Bragg Brook plays an important flow and sediment load attenuation role for that stream, though it enters the lower portions of the watershed and thus plays a smaller role in overall watershed dynamics. Removal of a portion of the berm that has cut Bragg Brook off from its former floodplain may help mitigation and restoration efforts there without endangering development and infrastructure. The potential alluvial fan in the downstream portion of segment M08A and the top of M07B indicates that this area has likely played a major flow attenuation and sediment storage role historically, but restoring these functions at this point in time may require active measures due to considerable encroachments. This is an area where the Town of Norwich may wish to explore a cost/benefit analysis of relocation of portions of Turnpike Rd., including a careful reassessment of damages after the 1973 flood in this area and a high potential for similar impacts in the future.

Significant incision that has already limited floodplain access throughout the watershed will mean that attenuation of flows high in the watershed will be especially important for minimizing potential impacts and damages as these streams recruit sediments to rebuild floodplains. Cumulative direct stormwater inputs to streams need to be considered in transport reaches as well, even though these often appear to be "just a little stream" in the upstream portions of the watershed. Although the complex dynamics of wetlands and impoundments precluded a full geomorphic assessment of most of New Boston Brook, it is clear that the extensive wetlands in that portion of the watershed play a critical role in flow and sediment attenuation. Channel incision beneath undersized culverts along New Boston Brook as well as significant downcutting due to stormwater inputs on highly erodible soils along the valley walls indicate the potential for increasing hydrologic inputs incrementally without realizing the cumulative impacts. Attention to sizing of culverts to ensure transport of both sediment and water and stormwater management that ensures percolation and distribution over well vegetated surfaces can help mitigate these impacts. Due to the pervasive nature of these issues in the Blood Brook watershed, Norwich may wish to consider these issues at a town-wide scale as well.

With these considerations in mind, Table 29 lists potential projects in the Blood Brook corridor planning Project area in order of recommended priority. It is important to bear in mind that buffer establishment and augmentation would be an important component of any of these projects due to the composition of boundary materials in the basin. This prioritization should be considered preliminary and will need to be adjusted based on further information and community interest. Maps of the potential project areas follow the table and are referenced in the table.

Table 29. Potential project prioritization for the Blood Brook corridor planning Project area

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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 loss of floodplain access, escalating erosion conflicts due to adjustments	FEH and belt-width based corridor planning, culvert sizing recommendations and/or requirements for private installations in addition to town's inventory and prioritization	Feasible, process largely developed Priority high; developmen t pressures in watershed likely to continue	Flood hazard reduction, fit with NCC & 'Open Spaces' priorities	Policy development and implementa-tion; technical background largely developed	Depends on options chosen; see VTANR links in Literature cited section of this report: Municipal guide	Town of Norwich, TRORC, VTANR-RMP
2	M04 Fair – High (Fig. 63)	Still has floodplain access	Passive; protect corridor	Feasible	Flood mitigation for downtown	Easement transactions	Land use conversion minimal; Flood insurance	Town of Norwich, abutting landowners

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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	M08C Fair – High (Fig. 64)	Still has floodplain access, high in watershed; road encroachment; as floodplain rebuilds may cause flood threats to road, house in corridor	Passive; Protect corridor; may need to arrest headcuts to limit further incision, loss of floodplain and threats to road and upstream structures	Feasible; has floodplain access; decent buffer already; high watershed priority		Flood hazards to house and road, increased risk of outflanking of downstream bridge; installation of temporary grade control if needed	Flood insurance	

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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
4	M05A Poor –Very High (Fig. 65)	Bulldozed and windrowed after '73 flood, effectively bermed Corridor encroachments: development off banks and downstream	Corridor protection, especially hayfield in floodplain above Charles Brown confluence; remove windrow on right bank upstream, place larger stone back in stream	Feasible, but impacts on downstream development need careful assessment; high priority for watershed dynamics but implement-ation tricky		Easement transactions or compensation on ag lands; removal of berm, replacement of stone in stream	Permit further erosion at mass failures off right bank on upstream end; buffer augmentation and flood hazards on ag lands	Investigate CREP, EQIP and similar options, Town of Norwich, VT ANR-RMP

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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	M04-T2.01A&B Fair – High (both segments) (Fig. 66)	Beaver Meadow Rd encroachment and bridge limits access to floodplain off left bank downstream	Ensure access to left bank floodplain in flood flows: a) if bridge outflanks and b) remove LB armoring below bridge and restore floodplain access/meanders	Needs detailed elevation analysis off left bank of bridge at Beaver MeadowRd; high priority, attenuation for M05A	May offer some property protection or damage mitigation for down-stream properties in flood	Elevation analysis, grade changes if necessary; removal of armoring; easement transactions, compensa-tion on ag	Buffer augmentation and flood hazards on ag lands	Investigate CREP, EQIP and similar options, Town of Norwich, VT ANR-RMP
6	M03-T1.01A Fair – Very High (Fig. 67)	Cut off from likely historic floodplain; straightening, encroachment May impact Heritage septic in flood	Remove berm below potential development impacts	Feasible; limited floodplain gain, enters watershed low	Could tie to trail system	Berm removal	Buffer augmentation on upstream end and near confluence with Blood Brook mainstem	NCC (trail system), Heritage Condo assoc.

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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
7	M03A&B (A) Poor – Extreme (B) Fair – Moderate (Fig. 68)	Incised, now widening; lacking buffers by hayfields	Plant buffer	Feasible; 'low-hanging fruit' High reach priority, low watershed priority	Commun-ity project, could tie to trail system; ecological benefits for CT River	Low-cost planting stock	Buffer establishment would need wide setback (belt-width): vertical instability; trail permissions	Likely CREP project, NCC (trail system), school groups
8	M07A Fair – High (Fig. 69)	Road, development and ag encroach-ments, bulldozing and straightening	Floodplain access/ meander construction	Feasible; Mid range priority, may rise if repeated conflicts; success may be linked to prior mitigation upstream	High visibility, potential education benefits	Site engineering and construction	Ag lands would not need permanent conversion, but would need earthworks and buffer establishment, maintenance	Norwich Farms, Town of Norwich, CREP, VTANR-RMP

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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
9	M08A & M07B Fair – High (both segments) (Fig. 70)	Possible alluvial fan, inherent stream instability Road, development and ag use encroach-ments	Floodplain access/ meander construction and/ or road relocation to higher elevations outside corridor	Costly, may be difficult to implement and soil/slope capabilities need to be assessed Mid range priority, may rise with repeated conflicts; high priority for watershed dynamics	May offer reduced mainte-nance costs in long term; high risk of repeated flood impacts	High; needs cost/ benefit analysis in relation to high risk of repeated flood impacts Possible easement and/or compensa-tion costs	Site engineering and earthworks, buffer establishment and maintenance (buffers could be done independ-ently)	Town of Norwich, VTANR-RMP

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	Reach/ Segment Condition-Sensitivity	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitment	Potential Partner Commitments
10	M08B Fair – High (Fig. 70)	Bridge alignment and conjunction with adjoining driveway restrict floodplain access	Replace bridge and realign to no longer route stream to opposite valley wall	Linked to possible road relocation in M08A & M07B; otherwise increases flood hazard risks to Turnpike Rd Lower priority unless road relocation becomes more feasible	May offer reduced mainte-nance costs in long term; high risk of repeated flood impacts	Bridge replacement, floodplain access and meander establishmen t	Road and structure relocation and/or realignment: site engineering and construction costs	Town of Norwich, VTANR-RMP

Blood Brook Corridor Planning Prioritized Project and Strategy Summary								
Project #	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
11	M09A Fair – High (Fig. 71)	Increased hydrologic inputs; road, development encroachments, bulldozing and straightening	Floodplain access/ meander development, buffer augmentation	Buffers feasible; other pieces more difficult: numerous encroach-ments in a narrow valley; valuable for attenuation high in watershed		Planting stock; other pieces could be largely passive but would likely entail flood hazard risks for roads, culverts, driveways; monitoring for headcuts		

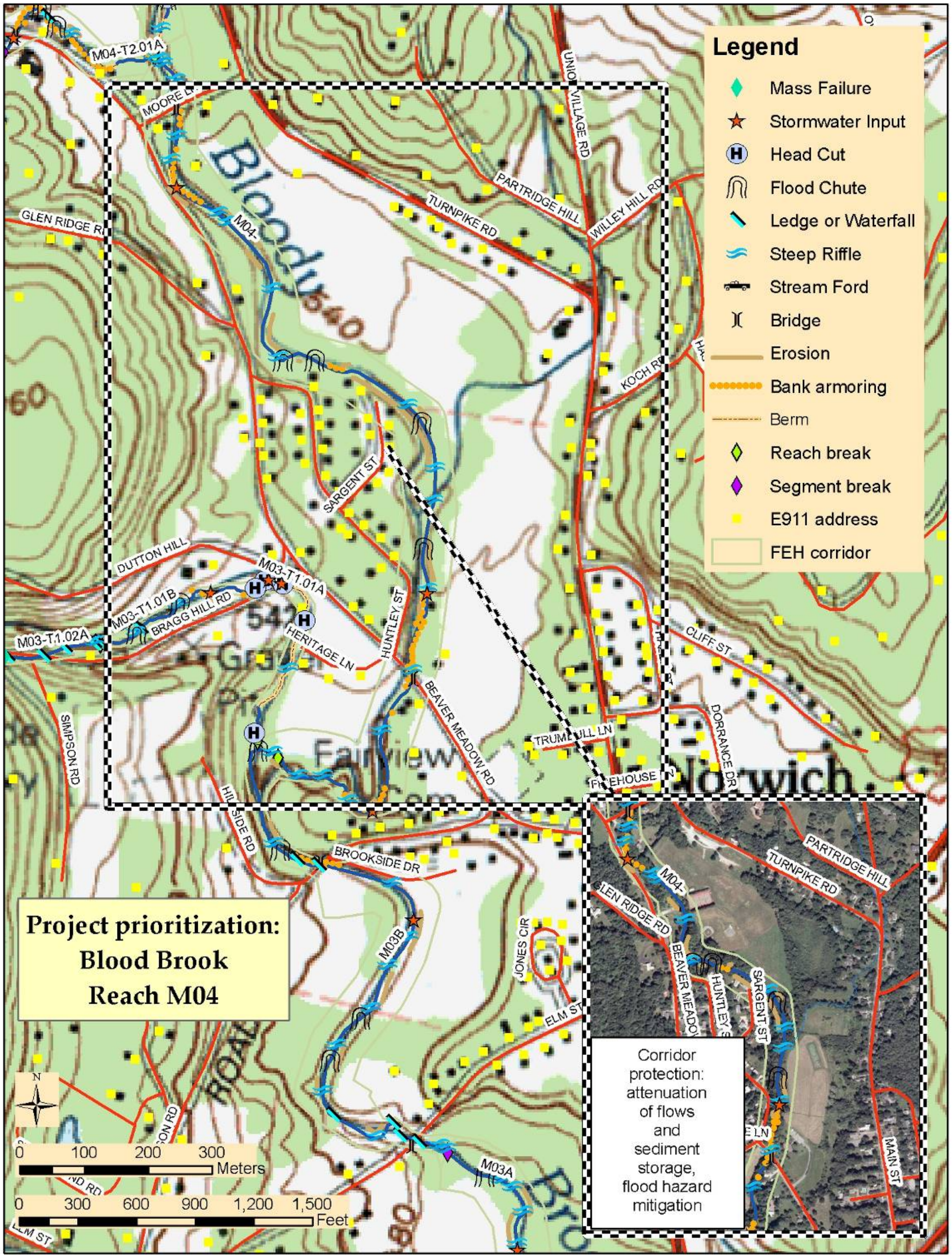


Figure 63. Project prioritization: Segment M04, Blood Brook by Norwich playing fields and Huntley Meadows

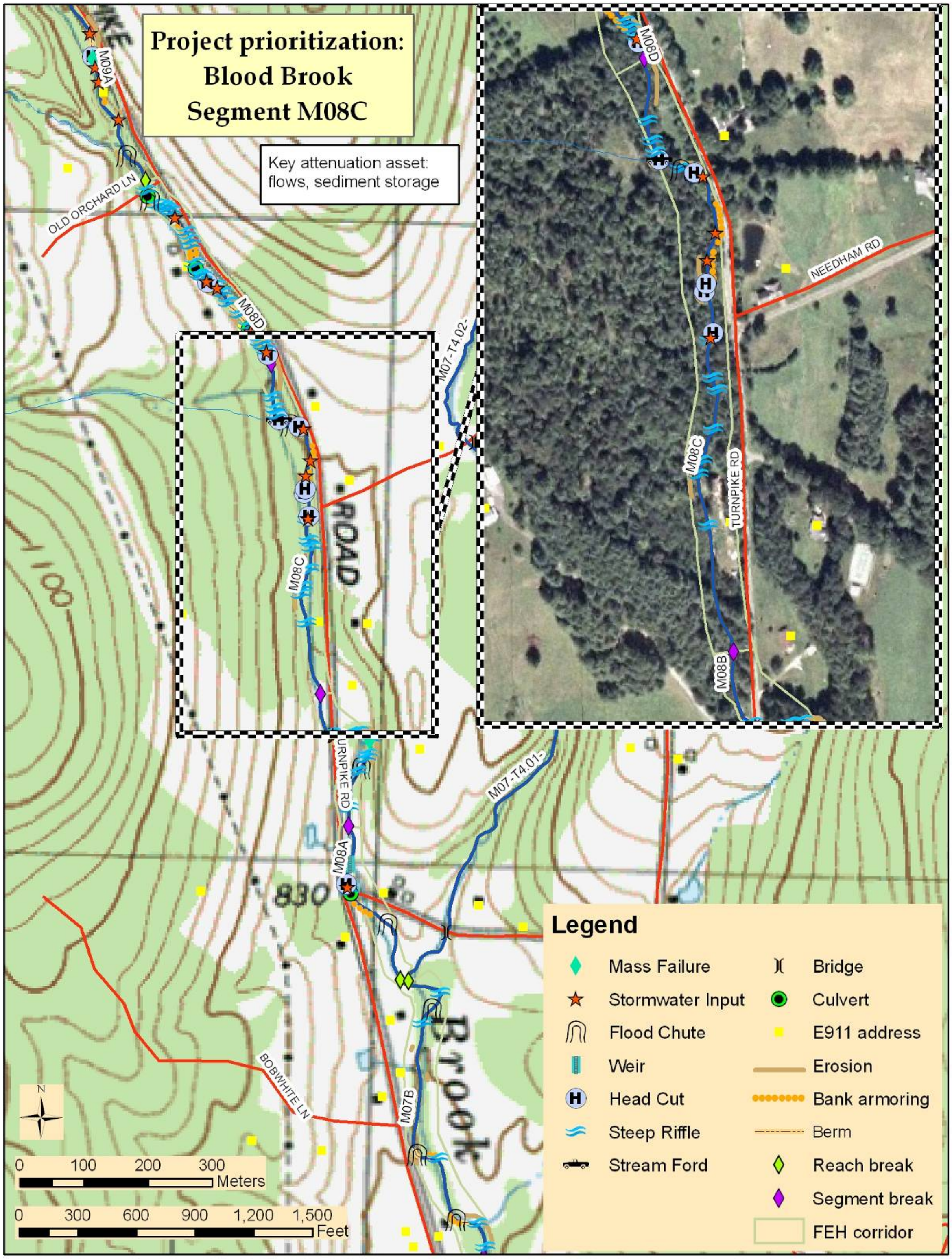


Figure 64. Project prioritization: Segment M08C, Blood Brook by Turnpike/Needham Rd intersection

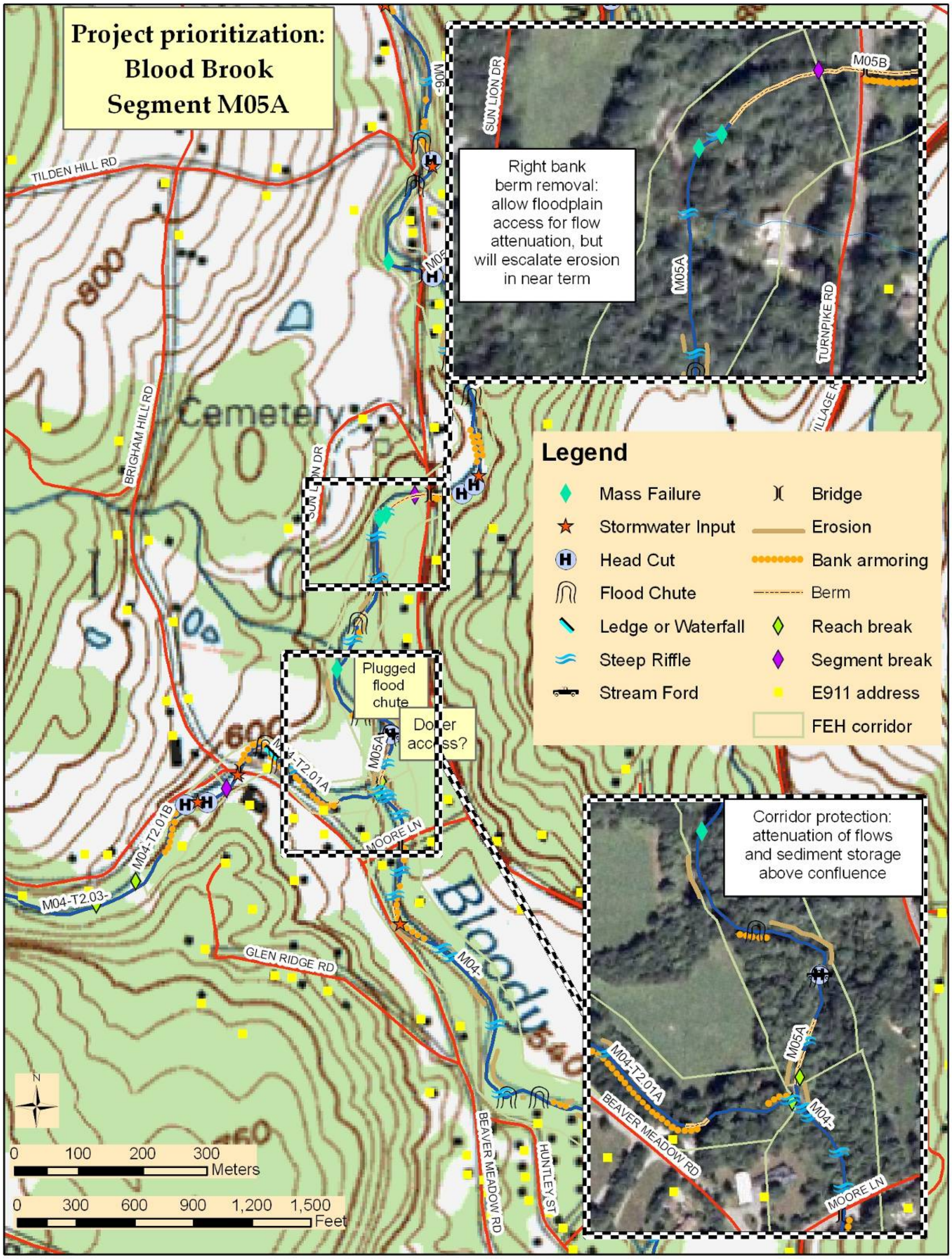


Figure 65. Project prioritization: Segment M05A, Blood Brook from Moore Ln. to Sun Lion Rd.

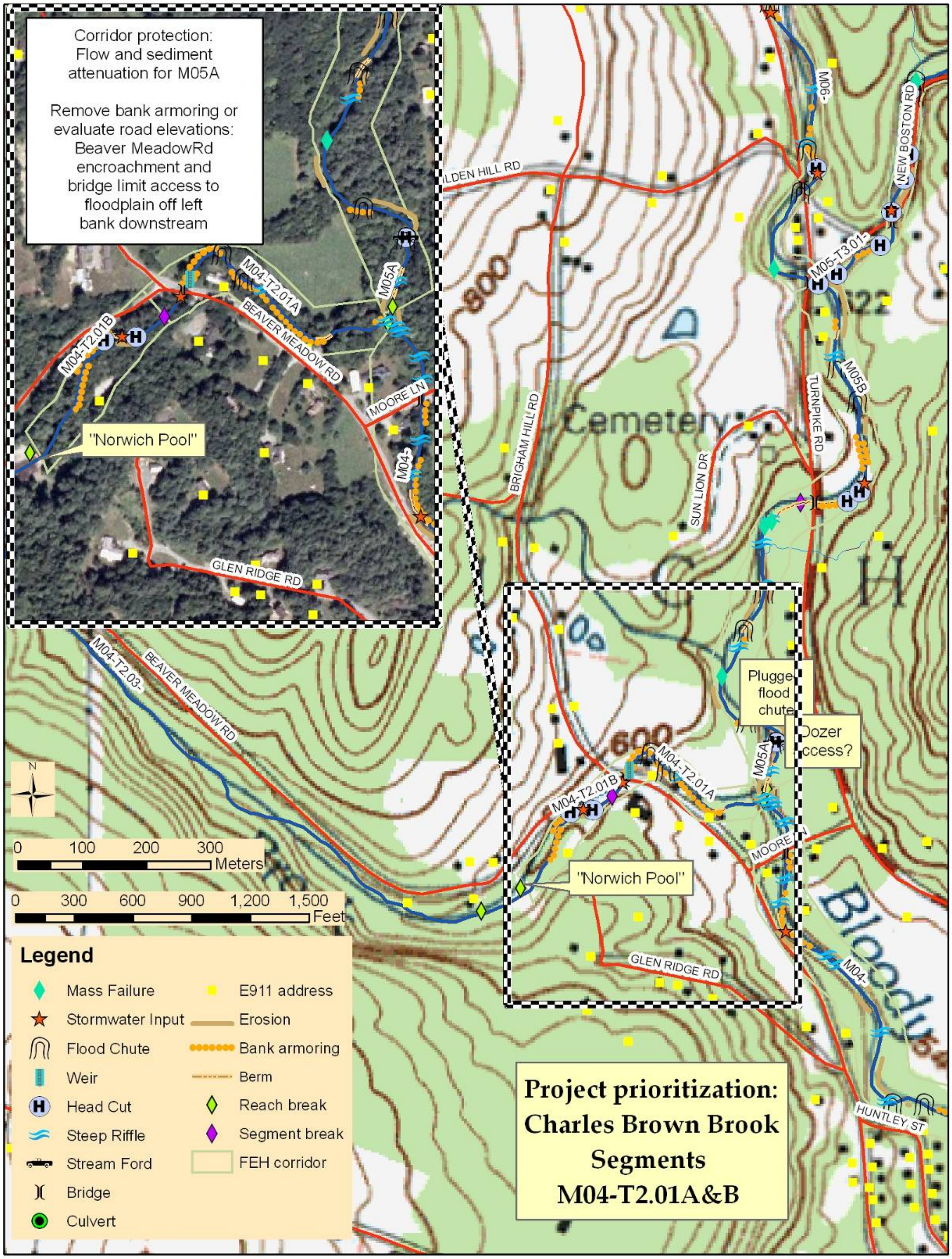


Figure 66. Project prioritization: Segments M04-T2.01A&B, Charles Brown Brook from Blood Brook confluence to Beaver Meadow Rd. downstream of the Norwich Pool

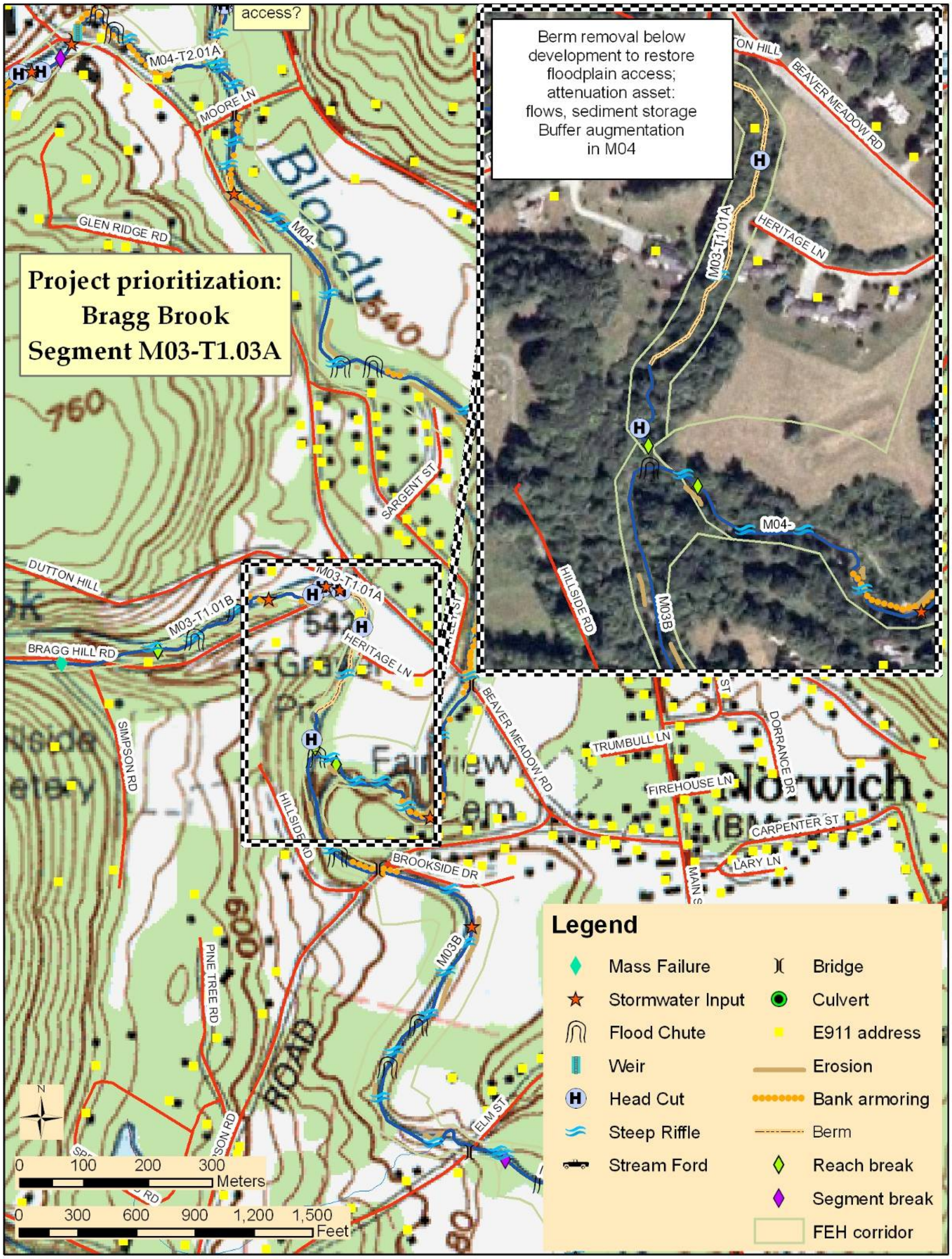


Figure 67. Project prioritization: Segment M03-T1.01A, Bragg Brook below Heritage Ln.

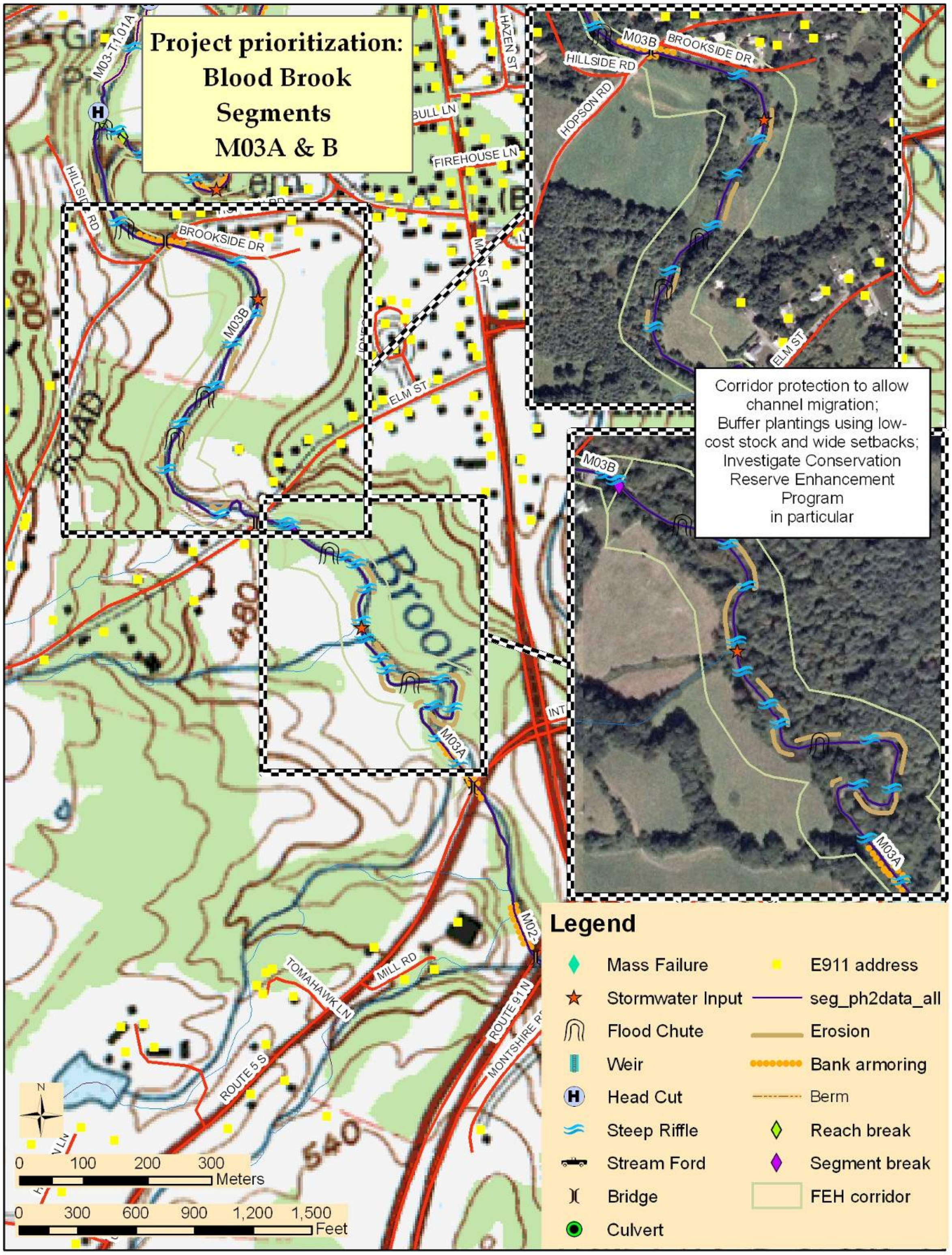


Figure 68. Project prioritization: Segments M03A&B, Blood Brook from Rte. 5 to Brookside Dr.

Figure 69. Project prioritization: Segment M07A, Blood Brook downstream of Bobwhite Ln.

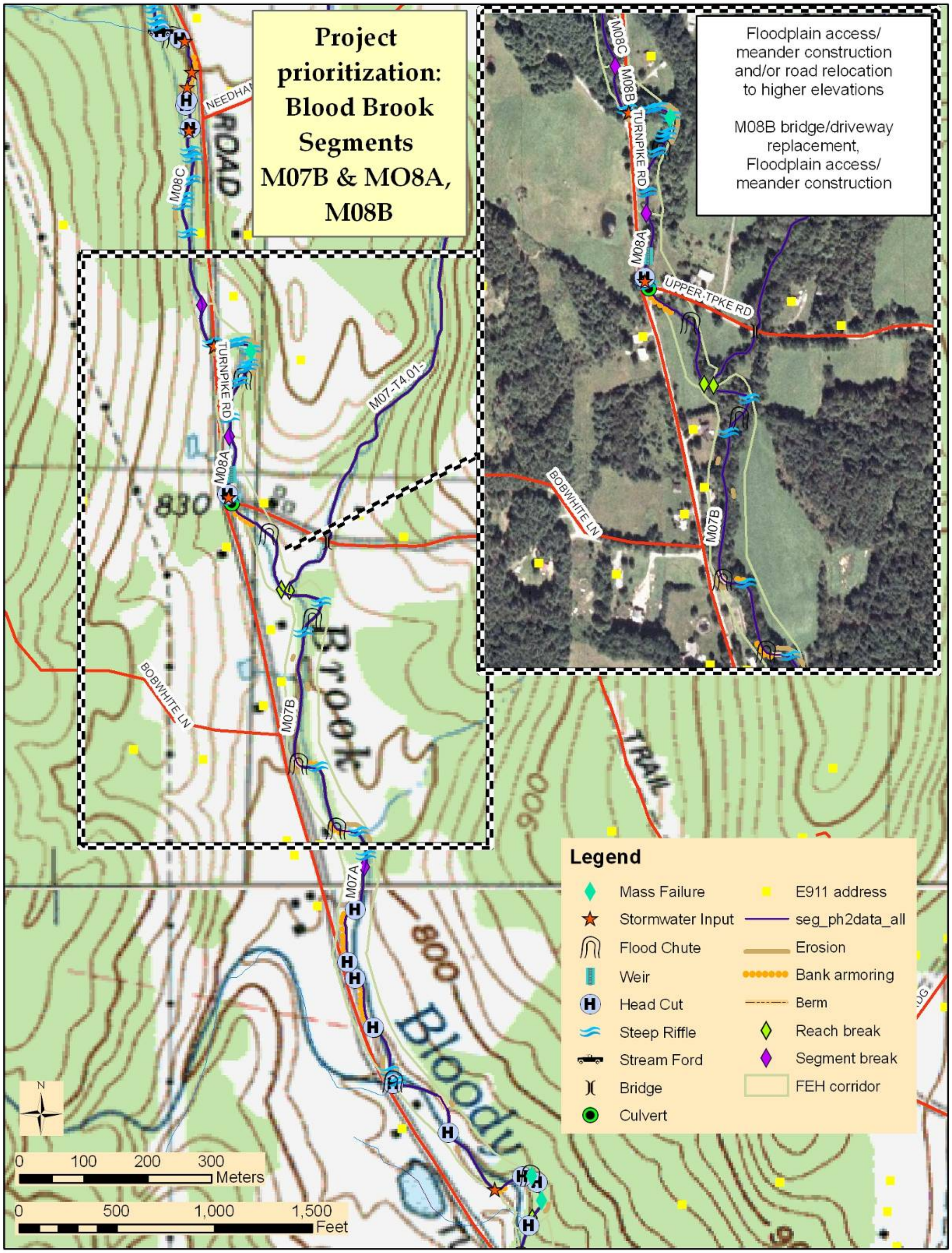


Figure 70. Project prioritization: Segment M07B & M08A, segment M08B, Blood Brook downstream of Bobwhite Ln. to bridge 1000 feet upstream of Upper Turnpike Rd.

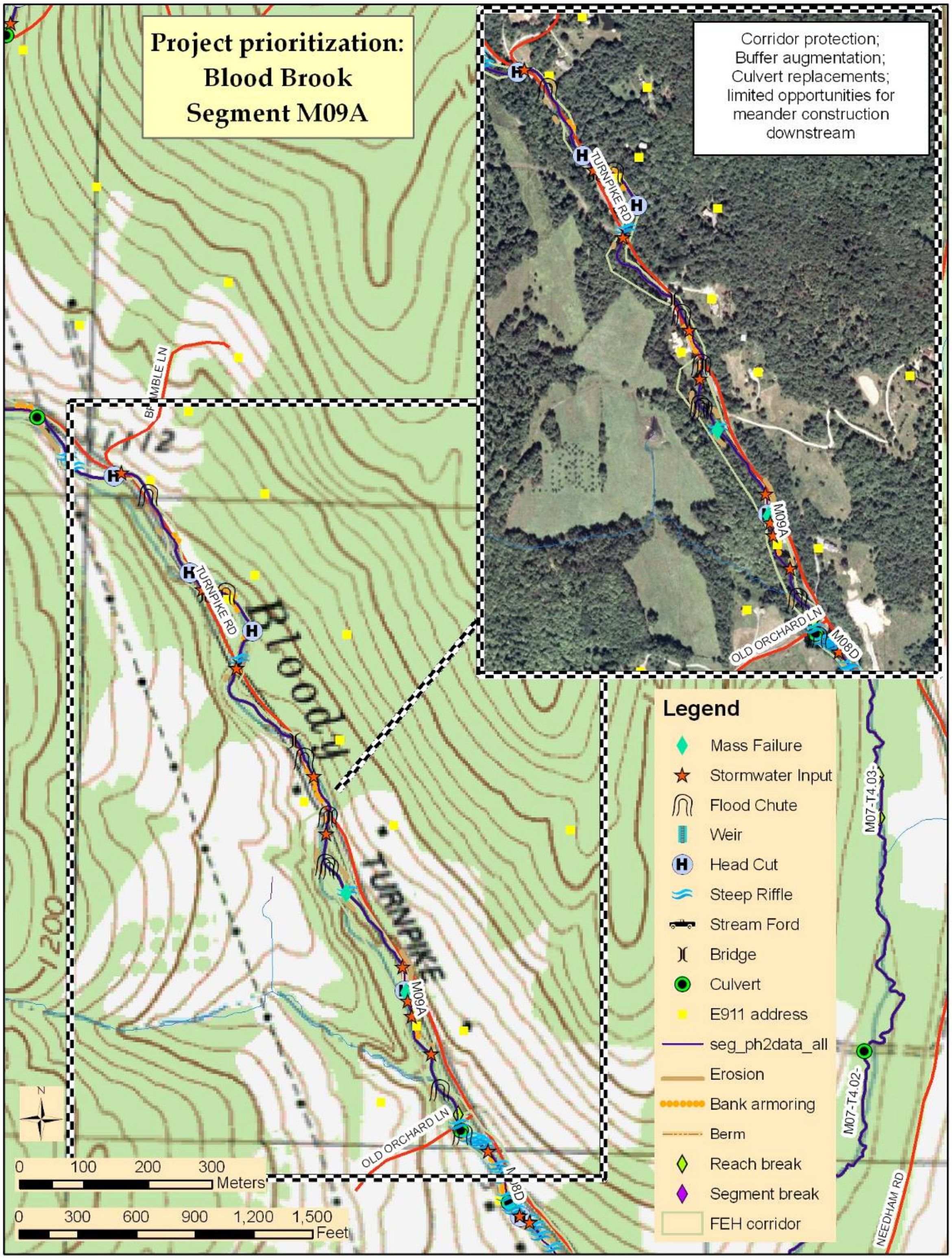


Figure 71. Project prioritization: Segment M09A, Blood Brook, Old Orchard Ln. to Bramble Ln.

7.0 PROJECT AND PROGRAM RECOMMENDATIONS

7.1 STATE AND MUNICIPAL ACTIONS

Several strategies can be used by 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 fluvial erosion hazard 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 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 (SFHA). The SFHAs and other risk premium zones that affect participating communities are depicted on Flood Insurance Rate Maps. The Mitigation Division within 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 Flood Insurance Rate Maps to a digital format that can be more easily overlaid with other maps through Geographic Information Systems (GIS) and similar technologies. These map updates finished a review and adoption process in Windsor county in 2007, including Norwich and the Blood Brook watershed, and can be found through FEMA's Map Service Center (http://www.fema.gov/msc.fema.gov).

Fluvial erosion hazard (FEH) mapping offers a science-based approach that uses the geomorphic data collected in Phase 1 and 2 to rate erosion hazards in the zone along the river based on the predicted movement of the river. Flash flooding is more common in Vermont than inundation flooding, particularly in watersheds such as Blood Brook where historic floodplain access has been limited. The FEH approach is highly recommended for Norwich for its more refined delineation of belt-width corridors and added measure of protection. Model ordinances, guidance documents and information about both the NFIP and FEH programs in Vermont is available through the VT ANR River Management Program (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).

7.2 STORMWATER MANAGEMENT

Although the Blood Brook watershed may not appear to be an "urban" setting, the watershed is relatively developed in a dispersed settlement pattern heavily oriented to the stream valleys. Stormwater management should be considered for rural areas because hydrology and sediment regimes can be altered by direct inputs 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 Norwich can be proud of the care and efforts exhibited by Road Foreman Andy Hodgdon and his crew. In addition, 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. The Norwich road crew has coordinated efforts with this program as well as the VT Dept. of Fish & Wildlife in the past.

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, it is important to expand this focus to incorporate upstream and downstream impacts in project consideration. 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.

7.3.1 Short-term

The following short-term actions are recommended in this preliminary Blood Brook Corridor Plan:

Review of the draft plan by Two-Rivers-Ottauquechee Regional Commission, the Norwich Conservation Commission, Town Planner Phil Dechert, VT DEC River Management Program, and other interested parties during Feb. 2008

Particular review of the Fluvial Erosion Hazard zones mapped in conjunction with this project and coordination between TRORC, Town Planner Phil Dechert, and VT DEC River Management Program Fluvial Erosion Hazard Program Coordinator Kari Dolan regarding options for incorporation of these zones into the town planning process

Draft revision to incorporate feedback

Incorporation of the desired information into TRORC's pre-disaster mitigation plan and subsequent support of that plan

Continued support of the bridge and culvert inventory and prioritization process maintained by the Town of Norwich

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

Adjustments to the draft will be reviewed in conjunction with TRORC and VT ANR River Management Program personnel to focus on the most promising projects consistent with return of the Blood Brook watershed to equilibrium conditions.

7.3.2 Long-term

With the bulk of the Blood Brook corridor planning Project area in Stage II to 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, the critical issues for long-term stability in the Blood Brook watershed will involve identifying and protecting key attenuation assets that allow for floodplain access and reestablishment of river meander patterns to facilitate diffusion of stream power under high flow conditions as well as sediment and nutrient storage within the watershed. An alternatives delineation 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. This strategy does not resolve, but postpones existing land use conflicts, 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 by means of dredging, berming, and 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 preferred only where land use conflict is high and conversions are highly unlikely; permitting and cost issues are significant.

Active restoration attempts to restore rivers to a geomorphic state of dynamic equilibrium using human constructed meanders, flood plains, and stabilized banks. These types of 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 re-vegetation is essential to this approach, along with long term protection of the river corridor. 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). 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. Active restoration may be appropriate in conjunction with passive restoration in a number of circumstances within this watershed however, particularly 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 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 techniques, so that flood plain access can be insured elsewhere within the watershed while preserving critical functions of nutrient and storage sediment within the watershed.

Most 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 upstream reaches. This approach will increase the likelihood of successful project implementation in downstream reaches. While permitting and zoning requirements are often perceived as an onus for a property owner, it is also important to remember the costs borne by downstream property owners in a flood, the substantial investments in infrastructure maintained as a community, and the obligations of ensuring the safety of all.

8.0 ASSESSMENT AND MONITORING RECOMMENDATIONS

8.1 RECOMMENDATIONS FOR FUTURE STREAM GEOMORPHIC AND PHYSICAL HABITAT ASSESSMENT

Phase 1 assessment of the Blood Brook watershed included many other streams in addition to those included in this plan. That assessment rated these tributaries for a number of impacts in accordance with VTANR geomorphic assessment protocols, and recommendations for any future assessments would be referenced to that report. Of note in that report was the unnamed tributary located between Needham, Turnpike and Upper Turnpike roads, and the patterns of development in this area and its impacts on stream dynamics may be worth assessment in the future if significant changes occur. Preliminary analysis in conjunction with the preparation of this plan did not indicate significant impacts at this time, but the general recommendations for seeking attenuation assets and benefits high in the watershed would be applicable.

Vermont Fish & Wildlife fisheries biologists have been very active in efforts to develop bridge and culvert sizing recommendations as well as guidelines for enhancing passage for fish and other aquatic organisms, with information due to be released in 2008. Bridge and Culvert survey data collected by TRORC as well as the inventory maintained by the town road crew have much of the information needed to prioritize and implement recommendations that come out of these efforts, and options might be explored to restore connectivity with the Connecticut River that appears significantly disrupted by the structures under Rte. 5 and Interstate 91 at the base of the watershed.

8.2 RECOMMENDATIONS FOR MONITORING OF ASSESSED REACHES AND IMPLEMENTED PROJECTS

Due to the erodibility of bed materials in portions of the Project area, potential aggravation of loss of floodplain access if further incision were to occur, and temporary nature of such installations it is recommended that log check dams installed on the Blood Brook mainstem (segment M08A), Charles Brown Brook (segment M04-T2.01A), and New Boston Brook (reach M05-T3.01) be monitored at least annually. It was not clear to the preparers of this report who had installed these grade controls and what sort of monitoring or maintenance regimes are in place. The installation on New Boston Brook is probably important to maintenance of infrastructure in the narrow valley along this portion of the stream, but the relatively undeveloped corridor upstream of this reach presents fewer constraints to channel evolution and this area may be able to supply sediment loads important to rebuilding floodplains and re-establishing equilibrium with increased stream power in incised reaches downstream.

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

- Assessment of management strategies in light of project implementation and further geomorphic assessments
- Revision of reach and watershed scale management options
- Updates on financial and technical resources available to interested parties
- Public outreach and education concerning these efforts

Literature cited

Evans, R.A., 2002. An ecosystem unraveling? In: B.P. Onken, R. Reardon and J. Lashomb (Editors), Proc of the 3rd Hemlock Woolly Adelgid in the Eastern United States Symposium. NJ Agricultural Experiment Station, Rutgers University, East Brunswick, NJ, pp. 23-33.

Cronon, W. (1983). Changes in the land: Indians, colonists, and the ecology of New England. New York: Hill and Wang.

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

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, MA.

NCC, 2004. Open Space Priorities Informal Plan, Norwich Conservation Commission and Norwich Special Places.

Redstart, 2007. Blood Brook Watershed, Norwich, VT, Phase 2 Geomorphic Assessment, Redstart Forestry & Consulting, Corinth, VT.

Schumm, S., 1977. The Fluvial System. John Wiley & Sons, New York.

Schumm, S., 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publication. In: W.R. Publication (Editor), Littleton, CO.

Thompson, E.H. and Sorenson, E.R., 2000. Wetland, Woodland, Wildland: A guide to the natural communities of Vermont. Vermont Department of Fish and Wildlife and The Nature Conservancy; Montpelier, VT. Distributed by University Press of New England, Hanover, NH.

TRORC, 2006. Blood Brook Watershed, Norwich, VT, Phase 1 Geomorphic Assessment, Two Rivers-Ottauquechee Regional Commission, Woodstock, VT.

USDA-FS, 2000. Upper White River Watershed Assessment. Part I. USDA Forest Service, Rochester, VT.

UVM-SAL, 2002. Land Cover/Land Use Dataset for Vermont. University of Vermont Spatial Analysis Lab, Burlington, VT.

VTANR, 2003. Alternatives for River Corridor Management: Toward resolving river and land use conflicts in an economically and ecologically sustainable manner. Vermont Agency of Natural Resoures, Dept. of Evironmental Conservation River Management Program.

VTANR, 2007a. Municipal Guide to Fluvial Erosion Hazard Mitigation. Vermont Agency of Natural Resoures, Dept. of Evironmental Conservation River Management Program. 17 pp.

VTANR, 2007b. Vermont Agency of Natural Resources River Corridor Planning Guide - Draft, Vermont Agency of Natural Resources River Management Program, Waterbury, VT.

VTANR, 2007c. Vermont Agency of Natural Resources Stream Geomorphic Assessment Protocol Handbooks. Vermont Agency of Natural Resources.

VTANR, 2007d. Vermont Stream Geomorphic Assessment Phase 2 Handbook: Field Protocols. Vermont Stream Geomorphic Assessment Protocol Handbooks. Vermont Agency of Natural Resources, Waterbury, VT, 83 plus Appendices pp.

VTANR, 2007e. Vermont Stream Geomorphic Assessment Protocol Appendices. Vermont Agency of Natural Resources.

Appendix A. Consolidated reach/segment Projects and Practices (technically feasible project identification) table

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03A (1,2,3)	Protect river corridor	High	High	Y	Some land already conserved Attenuation asset Extremely sensitive – linked to mitigation of upstream impacts
M03A (4)	Plant stream buffer/ fencing?	High	Low	Y	Wide buffer, low-cost stock Further measures need watershed strategies (>5yr)
M03A (25)	Replace structure	Low	Low	Y	Modification more likely; overflow culverts? Flood mitigation, may not significantly increase attenuation assets
M03B (1,2,3)	Protect river corridor	High	High	Y	Limited but important opportunities – ag lands
M03B (4)	Plant stream buffer/ fencing?	High	High	Y	Mixed cost – High sensitivity and grade controls mean bank impacts are elevated in bedrock areas Further measures need watershed strategies (>5yr)
M03B (25)	Replace structure	Low	Low	Y	Hopson Rd.; flood mitigation, may not significantly increase attenuation assets

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M04-0 (1,2,3)	Protect river corridor	High	High	Y	Huntley Meadows, playing fields important attenuation assets; importance accentuated due to right bank development and infrastructure
M04-0 (4)	Plant stream buffer	High	Low	Y	Wide buffer, low-cost stock Further measures need watershed strategies
M04-0 (26)	Replace structure	Low	Low	Y	Replaced 1989; blocks floodplain, but no further geomorphic incompatibilities
M05A (1,2,3)	Protect river corridor	High	High	Y	Attenuation asset High sensitivity – linked to mitigation of upstream impacts
M05A (4)	Plant stream buffer	High	Low	Y	Augmentation; buffers generally >50 ft., almost always >25 ft.
M05A (18)	Remove berms	Low	Low	Y	Upstream and downstream ends of segment need to be evaluated carefully for impacts to development and infrastructure; mid-segment section is short and not likely to gain much more floodplain access
M05A (34)	High priority river corridor protection at downstream reaches and Restore incised reach with bedforms and floodplain features	High	High	N	Assess RB floodplain restoration and possible impacts on development at base of Charles Brown Brook, Moore Ln.; assess placement of windrowed stone into stream

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M05B (1,2,3)	Protect river corridor	High	High	Y	Only limited opportunities in upstream portion – encroached
M05B (4)	Plant stream buffer	High	High	Y	Mixed cost – High sensitivity
M05B (15)	Arrest head cuts	High	Low	Y	Monitor: Currently nickpoints; exposed till; may eventually wash out as sediment slugs from upstream move into reach
M05B (26)	Replace structure	Low	Low	N	Looks new; partially blocks floodplain, but no further geomorphic incompatibilities
M06-0 (1,2,3)	Protect river corridor	High	High	Y	Current opportunities very limited due to encroachment; risk of flood damage may recommend cost-benefit analysis of road relocation
M06-0 (4)	Plant stream buffer	High	Low	Y	Ag lands may have funding opportunities
M06-0 (25)	Replace structures	High	High	Y	Needs evaluation on a case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M07A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M07A (4)	Plant stream buffer/ fencing	High	High	Y	Ag lands may have funding opportunities
M07A (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures
M07A (18)	Remove berm	Low	Low	Y	Short section (90 ft.); gain of floodplain access likely to be minimal
M07A (36)	Potential restoration/ protection project	High	High	N	Information gathering: Sigler ag lands; may warrant active restoration
M07B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M07B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation; limited areas <25ft., mostly by road
M07B (36)	Potential restoration/ protection project	High	High	N	Information gathering: Sigler ag lands; may warrant active restoration

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited primarily due to road encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08A (4)	Plant stream buffer/ fencing	High	High	Y	Ag lands may have funding opportunities
M08A (15)	Arrest headcuts	High	High	Y	Currently has check dam in good shape, but could pose loss of floodplain and threats to road
M08A (36)	Potential restoration/ protection project	High	High	N	Information gathering: may be linked to culvert replacement at Turnpike/Upper Tpk., but will require consideration of property and infrastructure protection and possible channel bed stabilization
M08B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation; buffers generally good, reach vertically unstable
M08B (36)	Potential restoration/ protection project	High	High	N	Information gathering: may be linked to bridge replacement at Turnpike/Upper Tpk., but will require consideration of property and infrastructure protection

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08C (1,2,3)	Protect river corridor	High	High	Y	Important attenuation asset
M08C (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, roadside and recently cut banks by residential development; buffers generally good, reach vertically unstable
M08C (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures
M08D (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; risk of flood damage may recommend cost-benefit analysis of road relocation
M08D (4)	Plant stream buffer	High	High	Y	Benefits bank stabilization and deters spread of invasives
M08D (18)	Remove berms	Low	Low	Y	Gain of floodplain access minimal; may impact land use (residential)
M08D (25)	Replace structures	Low	Low	N	Needs evaluation on a case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking

Blood Brook mainstem					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M09A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; attenuation asset
M09A (4)	Plant stream buffer	High	High	Y	Primarily augmentation; transpiration benefits
M09A (15)	Arrest headcuts	High	High	Y	Currently more nickpoints, but could pose loss of floodplain and threats to structures; unnecessary in upstream portions due to natural grade controls
M09A (25)	Replace structures	Low	Low	N	Case-by-case basis, weighing potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking
M09A (36)	Potential restoration/ protection project	High	High	N	Information gathering: Between Old Orchard and Bramble Lns.; may warrant active restoration; encroachment limits possibilities
M09B (1,2,3)	Protect river corridor	High	Low	Y	Does not play significant role in flow or sediment load attenuation
M09B (27)	Remove structure	Low	Low	Y	Little impact on equilibrium conditions

Bragg Brook					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.01A (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but downstream end important; attenuation asset
M03-T1.01A (4)	Plant stream buffer	High	High	Y	Primarily upstream portion; will aid flood mitigation also
M03-T1.01A (15)	Arrest headcuts	Low	Low	Y	Currently more nickpoints; significant deposition moving from upstream and natural grade controls in next segment; monitor for threats to structures, further loss of floodplain
M03-T1.01A (18)	Remove berm	High	High	Y	Downstream section; could restore some critical floodplain function; need to assess Heritage septic impacts
M03-T1.01A (25)	Replace structure	High	Low	N	Weigh potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking; ideally linked to floodplain restoration downstream
M03-T1.01B (1,2,3)	Protect river corridor	High	High	Y	Opportunities limited due to encroachment, but important; attenuation asset
M03-T1.01B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, natural regeneration; flood mitigation, transpiration benefits

Bragg Brook					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.02A (1,2,3)	Protect river corridor	High	Low	Y	Natural transport reach, not attenuation asset; flood hazard avoidance
M03-T1.02A (4)	Plant stream buffer	Low	Low	Y	Mostly along road encroachments
M03-T1.02B (1,2,3)	Protect river corridor	High	Low	Y	Natural transport reach, not attenuation asset; flood hazard avoidance
M03-T1.02B (4)	Plant stream buffer	High	High	Y	Primarily upstream portion; will aid flood mitigation also
M03-T1.02B (25)	Replace structures	High	High	N	Weigh potential for channel evolution and need for property protection and channel bed stabilization in comparison with risks due to outflanking; ideally linked to floodplain restoration downstream
M03-T1.03A (1,2,3)	Protect river corridor	High	High	Y	Attenuation asset limited due to confinement and alternating channel type, but important: high in the watershed
M03-T1.03A (4)	Plant stream buffer	Low	Low	Y	Check results of 2007 plantings on Blood Brook for applicability to roadside plantings
M03-T1.03A (15)	Replace structures	High	Low	Y	Town has inventory and replacement schedule; flood hazard avoidance
M03-T1.03A (36)	Potential restoration/ protection project	High	Low	N	Information gathering: needs cost/benefit analysis; narrow valley may mean minimal floodplain gain

Bragg Brook					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M03-T1.03B (1,2,3)	Protect river corridor	Low	Low	Y	Primarily flood hazard mitigation; transport reach, not an attenuation asset
M03-T1.03B (4)	Plant stream buffer	Low	Low	Y	Primarily augmentation, natural regeneration; buffers generally good
M03-T1.03B (15)	Replace structures	Low	Low	Y	Town has inventory and replacement schedule; flood hazard avoidance

Charles Brown Brook					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M04-T2.01A (1,2,3)	Protect river corridor	High	High	Y	Important attenuation asset on LB
M04-T2.01A (4)	Plant stream buffer	High	High	Y	Ag lands may have funding opportunities
M04-T2.01A (15)	Arrest headcuts	High	High	Y	Currently has check dam in good shape, but could pose loss of floodplain upstream and threats to bridge
M04-T2.01A (15)	Replace structure	Low	Low	Y	Low priority; primarily a floodprone constriction and outflanking may be helpful to downstream properties and infrastructure
M04-T2.01A (36)	Potential restoration/ protection project	High	High	N	Information gathering: may require active measures, but could potentially restore critical floodplain; remove LB armoring below bridge
M04-T2.01B (4)	Plant stream buffer	Low	Low	N	Ideally linked to potential enhancement of floodplain access off left bank
M04-T2.01B (15)	Arrest headcuts	High	High	Y	Currently downstream check dam in good shape, but could pose loss of floodplain and damage to Norwich Pool
M04-T2.01B (36)	Potential restoration/ protection project	High	High	N	Information gathering: may require active measures, but could potentially restore critical floodplain

New Boston Brook					
River Segment (step #)	Project	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps and other Project Notes
M05-T3.01 (4)	Plant stream buffer	Low	Low	N	Difficult conditions close to stream; low cost stock
M05-T3.01 (15)	Arrest headcuts	High	High	Y	Currently mid-reach check dam in good shape, but could pose loss of floodplain and damage to infrastructure
M05-T3.01 (25)	Replace structures	Low	Low	Y	Cost/benefit analysis: will require consideration of infrastructure protection and possible channel bed stabilization; risks of outflanking impacts may be lower
M05-T3.01 (34)	River corridor protection at downstream reach and Restore incised reach with bed forms and floodplain features	High	High	N	Bed forms and floodplain features need to be in equilibrium with higher power of channelized reach; erosion conflicts likely to increase until this occurs; corridor protection downstream to attenuate increased flows