BETHEL, VERMONT

MIDDLE WHITE RIVER AND THIRD BRANCH WATERSHEDS

STREAM GEOMORPHIC ASSESSMENT and RIVER CORRIDOR PLAN

2013-2014
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1.0 EXECUTIVE SUMMARY

In February, 2013 the White River Partnership (WRP), as part of a project funded by the Vermont Agency of Natural Resources Ecosystem Restoration Grant Program, engaged Redstart to conduct a Phase 2 Stream Geomorphic Assessment (SGA) in Bethel, Vermont, and to produce a Phase 2 SGA report and River Corridor Management Plan (RCMP). The assessment area included portions of the Third Branch; Third Branch tributaries Camp Brook and Gilead Brook; the Middle White main stem; and Middle White tributaries Cleveland Brook, Locust Creek, and Lilliesville Brook (overview map in Fig. 1 below).

The WRP is a community-based, non-profit organization whose mission is to bring together people and local communities to improve the long-term health of the White River and its watershed in central Vermont. The Town of Bethel corridor planning project builds on sixteen years of community-based efforts undertaken by the WRP and partners throughout the White River watershed. Key partners in Bethel have included riparian landowners, the Bethel Conservation and Planning Commissions and Selectboard, Whitcomb elementary and high schools and Verdana Ventures, the Vermont Law School, the Vermont Youth Conservation Corps, the Vermont Agency of Natural Resources Department of Fish & Wildlife, Watershed Management Division and River Management Program, Two Rivers-Ottauquechee Regional Commission, local water-quality monitors and other volunteers active with the 'Tween (Mid-White) Stream Team, the White River National Fish Hatchery, the White River Natrual Resources Conservation District, the Connecticut River Watershed Council and Joint Commissions, the USDA Forest Service, and Trout Unlimited.

Stream Geomorphic Assessment and River Corridor Planning

Fluvial (= flow-related) geomorphology (geo = earth, morphology = shape) is the study of the physical river forms and processes that explain many of the current conditions observed in streams. Streams have a natural tendency to maintain equilibrium between the amount and power of water moving through the system and the amount and type of sediment being carried by that water. With significant changes in the landscape and development patterns in the last 200 years, many streams in Vermont, including the White River, Third Branch and many of their tributaries, have been confined to deeper, straighter channels and lost access to historic floodplains. Additional stress has come from changes in precipitation timing and patterns, particularly notable in flash flooding in portions of Bethel in 2007 and 2008, as well as substantial impacts from Irene in 2011.

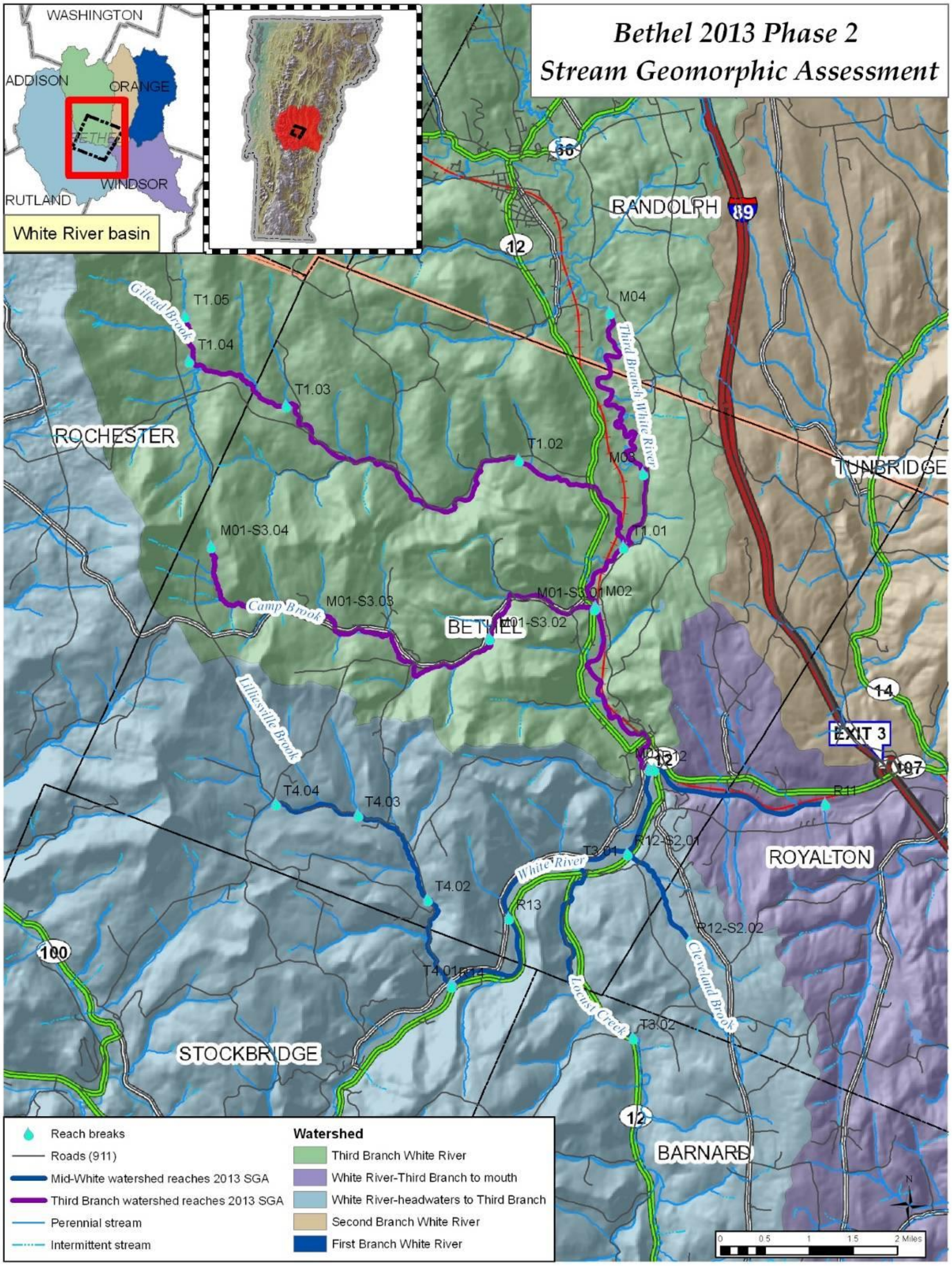


Figure 1. Overview map for Town of Bethel 2013-14 stream geomorphic assessment and corridor planning.

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

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

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

Assessment summary

Eighteen reaches (a reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form) comprising roughly 36 linear miles of stream in Bethel were included in Phase 2 assessment. These eighteen reaches included portions of the Third Branch (~7.5 miles), Third Branch tributaries Camp and Gilead Brooks (~14 miles), the Middle White main stem (~6.5 miles), and Middle White tributaries Cleveland Brook, Locust Creek, and Lilliesville Brook (~8 miles). Based on field assessment of current physical conditions these streams were divided into 38 segments (a segment is a relatively homogenous section of stream, within a reach, that differs from other portions of the reach based on parameters other than those mentioned above for reach classification; e.g., degree of floodplain encroachment, presence/absence of ledge or waterfalls spanning the stream bed, presence/absence of vegetated riparian buffers and general corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, or degree of channel alterations). Two segments (the upstream ends of Camp and Gilead Brooks) were excluded from full geomorphic assessment, per protocols, due to impoundment by beavers.

Impacts from Tropical Storm Irene (August 2011) were highly evident throughout the assessment area in Bethel, and no reaches were rated in Good geomorphic condition (indicating only Minor current adjustments). Town-wide, 26 of 36 fully assessed stream segments (72%) were indicated in Poor geomorphic condition (undergoing Extreme current adjustments) while 10 of 36 segments (28%) were in Fair condition (Major current adjustments). Distribution of these assessments was remarkably similar in the assessed streams of the mid-White and Third Branch basins (Table 1).

Table 1. Distribution of geomorphic condition ratings for fully assessed stream segments in the Bethel 2013 Stream Geomorphic Assessment. Two segments were excluded from full geomorphic assessment.

	Geomorphic condition		
	Fair	**Poor**	**Total**
Mid-White and tribs	4	11	15
	27%	73%	100%
Third Branch and tribs	6	15	21
	29%	71%	100%
Town-wide	10	26	36
	28%	72%	100%

Current physical conditions on the assessed streams in Bethel indicate:

1) The White mainstem and most of the Third Branch in Bethel are deeply entrenched and considerably straightened, significantly increasing the force of water contained within the channel in flood situations

2) There are few grade controls to limit downcutting of stream beds in high flows, and despite significant aggradation in many areas Tropical Storm Irene exacerbated or left streams with a complete loss of access to historic floodplains throughout the assessed reaches. Exceptions to this complete loss of access to historic floodplain were noted on portions of Cleveland Brook (downstream of Cleveland Brook Rd), Locust Creek (upstream of Rhoades Hill Rd along Rte. 12) and to a lesser degree the portion of the White mainstem by the old Power Station and former Blueberry Hill dam site (behind Vermont Castings and the Bethel-Royalton Police Barracks)

3) Heightened stream power in these entrenched channels will mean elevated impacts in flood situations until this stream power can be offset by re-establishing access to floodplains (where stream power can be dissipated) and/or re-establishing more extensive meanders (so that the channel slope can be reduced, also helping to dissipate stream power)

4) Tributary streams in assessed portions of Bethel are frequently able to rebuild meanders and access to floodplains through a combination of debris jams and sediment retention in areas where these materials are available and these type of stream dynamics are not in conflict with investments in the corridor

5) Although some coarse sediments and large woody debris (representing vital resources for offsetting heightened stream power and regaining greater channel stability) are being recruited along the banks of the mainstem and from the

tributaries, widespread encroachment on streams and numerous undersized structures have led to repeat conflicts between stream dynamics and investments in stream corridors. This has frequently resulted in removal of these materials from the channel, exacerbating the impacts of heightened flows

6) The larger mainstem reaches of the White and Third Branch, due primarily to the size of the channel, are less able to actually rebuild access to floodplains (though partial debris jams and sediment deposition make highly valuable contributions to re-establishment and extension of meanders). Channel evolution in these portions of the assessment area will thus primarily entail widening (generally through heightened erosion and mass failures) and establishment of new floodplains at lower elevations than historic floodplains

7) Extensive presence of fine sands and gravels along the White and Third Branch mainstems (largely the legacy of profound influences from glacial Lake Hitchcock) give these streams a high capacity for establishing more stable channel conditions relatively quickly in areas where channel evolution processes (including widening and rapid stream relocations) are not in conflict with investments in the stream corridor

Project recommendation summary

Project prioritization for this 2014 River Corridor Plan for Bethel features (in order of descending priority):

- Watershed (largely municipal) strategies
- Buffer establishment and protection
- Reach-scale corridor protection projects: Third Branch reach M03, Gilead Brook reach T1.01, White River mainstem reach R12
- Reach-scale restoration projects: Gilead Brook reaches T1.02 and T1.01

Due to the extensive presence of fine sands and gravels along the White and Third Branch mainstems, Very High to Extreme sensitivity of streams throughout the Phase 2–assessed area indicates good possibilities for success of passive geomorphic projects which allow the river to utilize its own energy and watershed inputs to reestablish meanders, fuller access to floodplains, and self-maintaining equilibrium conditions over time. Typical passive projects focus on river corridor protection, primarily preventing or limiting further corridor encroachments and limiting channel alterations (such as bank armoring or dredging) that interfere with channel evolution. Implementation may involve incentive approaches (e.g., river corridor easements), regulatory approaches (e.g., zoning overlays), or ideally a combination of approaches.

Due to the widespread extent of stream instability following the impacts of Tropical Storm Irene, project prioritization for this version of a River Corridor Plan for the Town of Bethel places a high priority on municipal initiatives. Implementing best management practices on a watershed scale will greatly increase possibilities for successful localized project implementation, and adaptive management that monitors the results of these practices can shift the priorities of future updates or revisions of the Corridor Plan.

Municipal initiatives

Floodplain and River Corridor Planning and Protection

- River Corridor Protection overlay adoption by reference, in conjunction with National Floodplain Insurance Program (NFIP) maps, as comprising the Bethel Flood Hazard Overlay District in the Bethel Zoning Ordinance (last amended 2008), helping prevent or limit further development or encroachments in stream corridors
- River Corridor Protection overlays are a refinement of belt-width corridors and are recommended as a scientifically based method that uses the size, inherent sensitivity, and current adjustment processes of the stream to determine and map levels of risk and appropriate setbacks (FloodReadyVT- River Corridors FAQs 2014). The data needed to inform this process were collected for the eighteen reaches assessed in this study. Belt-width corridors approximate the extent of lateral adjustments likely to occur over time in a meandering stream, generally a minimum of 3-4 times the stream channel width on each side of the stream
- Fifty foot setback for streams draining less than 2 square miles. Encroachments on small streams play a particularly large role on tributaries to the White mainstem and Third Branch; setbacks, River Corridor Protection zones, or other belt-width corridors provide not only flood protection for land and structures adjacent to the stream but accommodation of stream processes that will help break a cycle of impacts being amplified and passed to downstream reaches.
- Identify existing structures and encroachments in the NFIP flood zones as well as the River Corridor Protection zone; include this information in Hazard Mitigation Plan updates and the Flood Resiliency chapter of Town Plan updates
- Consider a public information meeting for landowners in these zones to clarify emergency response options, recent changes in FEMA funding options for buyouts and elevation of structures in NFIP mapped zones, and regulatory requirements and insurance options for the different zones in the Flood Hazard Overlay District
- Given the extent of road encroachments and damages over time in Bethel, a municipal approach to limiting further development in stream corridors is a highly cost-effective method of not only reducing future conflicts and damages but also minimizing impacts on existing encroachments.

Road-Stream Crossing Retrofits and Replacements

- Bethel, Stockbridge, Barnard, Randolph and Royalton have all adopted Vermont Agency of Transportation 2013 Bridge and Culvert Standards (FloodReadyVT 2014). Vermont Stream Alteration Permit standards now specify structure sizes of 100 percent of “bankfull width” (i.e., the 1.5-2 year peak flow, or what has colloquially been the “high spring flow” in the past). FEMA will only fund a structure replacement to the size specified in the Town-adopted standards. Town adoption of the 2013 Bridge and Culvert Standards (or a higher standard), ensures no funding gap between the FEMA reimbursement and the funding needed to meet the Stream Alteration permit requirements.

- Due to the slope and geology of very narrow valleys along Camp and Lilliesville Brooks in particular (but Cleveland Brook and Locust Creek as well) it is recommended that Bethel, Stockbridge and Barnard consider adopting higher standards (120 percent bankfull sizing for replacements) along these streams
- Obtain digital bridge and culvert inventories, through the Vermont Online Bridge and Culvert Inventory Tool (VTCulverts 2014) at a minimum but preferably also using River Management/Fish & Wildlife data collection protocols (VT-RMP_ApxG 2009) to permit use of Culvert Screening Tools for prioritization
- Capital budget planning with geomorphic compatibility included in prioritization discussions with structure owners on replacement schedules

Drainage and Stormwater Management

- Management of overland flow and keeping entry points well vegetated
- Seek opportunities to increase on-site infiltration and retention times
- Priority areas (due to more notable cumulative impacts) on tributaries

Additional priority strategies

Buffer Establishment and Protection and Integrated Reach-scale Corridor Protection and Restoration Strategies

With 72% of the assessed stream segments in Bethel historically incised, it will likely be necessary (or at least highly beneficial) to implement reach-scale projects with multiple coordinated strategies (probably requiring multiple partners or organizations) to restore better floodplain function and meander geometry.

Four reaches were identified as high priorities for reach-scale protection and/or restoration strategies, listed in order of priority:

1 M03 Third Branch from east of Gilead Brook Rd. to Beanville (south Randolph)

2 T101 Gilead Brook from Third Branch to farm bridge downstream of Messier Rd.

3 T1.02 Gilead Brook from Mitchell Dr. to bridge at Schoolhouse Rd.

4 R12 White River from Third Branch at Peavine Park to Tozier’s on Rte. 107

Buffer projects identified during preparation of this Corridor Plan are prioritized for inclusion with high-priority reach-scale corridor protection and/or restoration projects and then as stand-alone planting projects. Buffer establishment and protection are thus preferentially recommended on these high-priority reaches.

The high-priority stream reaches and segments above were prioritized based on their ability to enhance flood resilience, attenuate high flows and store sediment and nutrients, and most quickly and cost-effectively begin to move the stream network toward more stable conditions.

Additional stream reaches or segments with buffer projects recommended for stand-alone implementation included:

M01 (Third Branch)	Marsh Meadow buy-out site: consider wooded trail, close buffers. Augment buffers at Peavine Park, consider educational sign about importance of buffers. Seed and plant point bar upstream of Peavine Blvd. bridge. Athletic fields and just upstream. Ag fields in upstream portions of reach.
M02 (Third Branch)	Right bank upstream Findley Rd. bridge. Both banks upstream Gilead Brook mouth.
R11 (White)	Right bank downstream of River St. bridge.
T4.01A (Lilliesville Brook)	Assess plantings already installed in downstream portion of segment (upstream of Peavine Blvd.) before augmenting.
T1.01D (Gilead Brook)	Seed sources exist but buffers need augmentation- especially base of tributary from Messier Rd.
T4.02A (Lilliesville Brook)	Augment buffer at upstream end of field across from 2289 Lilliesville Brook Rd.
M01-S3.02A (Camp Brook)	Primary areas lacking buffers are road embankments; investigate Better Back Roads design guidelines. Opportunity near 1523 Camp Brook Rd.
T3.01C (Locust Creek)	Area surrounding Barnard TH-80 bridge

Adequate buffers will play an important role in reach-scale strategies and may be able to precede implementation of other strategies. It should be noted however that the high erodibility of soils in most of the assessment area, as well as the high degree and extensive nature of channel instability following Irene, should be clearly acknowledged in buffer design; plantings in most areas are recommended for low-cost stock and adequate setbacks to anticipate the possibility of rapid erosion with consequent impacts to plantings.

Five additional reaches or segments were also prioritized from the perspective of moving toward greater stream stream stability but are much more constrained in possibilities for protection and/or restoration due to current levels of development along these streams:

T4.01A	Lilliesville Brook upstream of River Rd.
T4.03	Lilliesville Brook between Lilliesville and Lympus (Brink Hill Rd. upstream to 4-corners at Gay Hill, Dartt Hill, Campbell and Lilliesville Brook Roads)
T3.01A	Locust Creek from White mainstem to ~0.15 mi. upstream of Rte. 12-Old Rte. 12 intersection
M01-S3.02B	Camp Brook from ~0.5 mi. upstream of Sugar Hill Rd. to Pond Rd.
M01	Third Branch from Bethel village upstream to Camp Brook

The intractable nature of this situation reinforces the recommendation of municipal corridor protection to limit further development in close proximity to streams as the top priority recommendation of this Corridor Plan. Realistically, greater long-term stream stability in these areas may only come about with a reduction in current levels of development along these streams. Addressing undersized bridges and culverts in a number of these areas can greatly benefit stream dynamics, public safety and infrastructure maintenance costs.

Funding options for replacement of private bridges will be one of the most pressing and challenging issues for reach-scale restorations, particularly on Lilliesville, Camp and Gilead Brooks, and it is highly recommended that an effort be made to contact structure owners and compile information on how such replacements were funded post-Irene (if such a document does not now exist). It is further recommended that a summary report of the compiled information be provided to the Bethel Town Manager, Selectboard and Planning Commission.

A more complete table of prioritized projects can be found in Section 6.2 (Project Prioritization) of this report. A “catalogue” of projects, with varying priorities, can be found for each reach with the reach descriptions in Section 6.1, and a consolidated catalogue is found in Appendix 6. A full list of assessed bridges and culverts, findings of the assessments, and potential for retrofitting culverts that impede passage for fish and other aquatic organisms can be found in Appendix 8. Primary analyses leading to the project recommendations are found in Section 5.1.3, Existing Sediment Regime Departure Analysis (summarized in tables at the end of the section), and Section 5.2, Sensitivity Analysis.

2.0 INTRODUCTION

When Tropical Storm Irene swept through Vermont in August 2011, large scale and rapid changes occurred in many portions of the state and incurred hundreds of millions of dollars in damages. Bethel was particularly hard hit, and portions of VT Rte. 107 along the White River mainstem were some of the last roadway sections in the state to be restored to full service. While this was a particularly dramatic event, flooding is a major and natural driver in ongoing processes of stream channel evolution – one that both affects and is affected by the landscape in which the channel is located.

Estimates in Windsor County, Vermont (where Bethel is located) indicate that flooding from 1960-2012 accounted for only 7% of the total number of natural hazard events but nearly 92% of the reported monetary damages from those events (Hazards & Vulnerability Research Institute 2013).The data and planning processes presented here aim to broaden our understanding and help break an escalating cycle that requires an increasing level of investment to rebuild and/or protect property, livelihoods and ecosystems from damage and hazards caused by flooding, erosion and nutrient loading.

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

Stream Geomorphic Assessment (SGA) is part of a science-based process that can help elucidate these relationships and make communities more flood resilient, and by "combining it with knowledge from local landowners, we can develop sound plans for restoring and protecting important streams while respecting the concerns and interests of the local community" (WRP 2013).

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

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

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

Figure 2. This sediment plume entering Long Island Sound from the mouth of the Connecticut River was evident in satellite imagery nearly a week after Irene had moved through the state of Vermont, indicating tremendous amounts of erosion and sediment export in response to the storm. (*Photo credit: NASA 2011*)

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

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

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

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

2.1 PROJECT OVERVIEW

In February, 2013 the White River Partnership (WRP), as part of a project funded by the Vermont Agency of Natural Resources Ecosystem Restoration Grant Program, engaged Redstart to conduct a Phase 2 Stream Geomorphic Assessment (SGA) in Bethel, Vermont, and to produce a Phase 2 SGA report and River Corridor Management Plan. The assessment area included portions of the Third Branch, Third Branch tributaries Camp Brook and Gilead Brook, the

Middle White main stem, and Middle White tributaries Cleveland Brook, Locust Creek, and Lilliesville Brook (overview map in Fig. 1 in the Executive Summary).

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

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

> The Vermont Agency of Natural Resources initiated planning efforts to improve or maintain water quality at a watershed level in the 1960's….
>
> In the 1970s basin planning was conducted in Vermont to address point sources of pollution....The White River Basin Plan was completed in 1975, and contained several conclusions and recommendations…still relevant today…. (including) a recommendation for an assessment of stream bank erosion…and revegetation for disturbed stream bank areas….
>
> The collaborative process in the White River Basin began with the work of the White River Partnership. The Partnership formed in 1995 as a group of local citizens interested in preserving the quality of life in the White River Basin. It has become a forum for bringing together the community, local, State, and federal government agencies, and their resources to protect common interests.
>
> To identify common interests or concerns in the community, the Partnership held a series of public forums in 1996. The public forum results and public input during the basin planning process provided…primary concerns…as follows:
>
> - Stream channel instability and streambank erosion
> - Lack of awareness of water quality problems
> - Extent and quality of public access to recreational opportunities on the water
> - Impacts to fisheries

Many of the cooperators present at the 1996 forums have now been involved with restoration efforts in the watershed for more than a decade and a half, and the work of WRP "Stream Teams" and follow-up public forums and input from local landowners in 2007 indicated that these concerns have remained consistent over time. (The White River Basin Tactical Plan (VT-ANR WMD 2013) includes an extensive list of Watershed Partners, pp. 10-13). Cumulative experience has indicated that including upstream and downstream dynamics in the planning process is crucial to increasing the likelihood of successful project implementation as well as providing a means to optimize the benefits and minimize the costs of future projects. The White River Partnership has thus worked with the Vermont River Management Program to conduct stream geomorphic assessments and incorporate the results into River Corridor Plans.

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

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

In preparation for Phase 2 work, review of the original Phase 1 data for the Third Branch and the Middle White mainstem was conducted in 2012 by the White River Partnership along with River Scientist Gretchen Alexander and other members of the Vermont River Management Program. This work prioritized 18 reaches (a reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form) comprising roughly 36 linear miles of stream in Bethel for inclusion in Phase 2 assessment. These 18 reaches included portions of the Third Branch (~7.5 miles), Third Branch tributaries Camp and Gilead Brooks (~14 miles), the Middle White main stem (~6.5 miles), and Middle White tributaries Cleveland Brook, Locust Creek, and Lilliesville Brook (~8 miles). Assessment work in Bethel followed heightened interest from members of the Bethel community following heavy impacts from Tropical Storm Irene in 2011.

As of 2013 the White River Partnership listed the following completed River Corridor Plans in other portions of the White River basin, based on Stream Geomorphic Assessments and knowledge from local landowners (WRP 2013):

Ayers Brook River Corridor Plan (2007)
Upper White River Corridor Plan (2008)
Tweed River Corridor Plan (2008)
Town of Sharon River Corridor Plan (2010)

The White River Tactical Plan (VT-ANR WMD 2013) notes that:

> Stream geomorphic assessments (SGA) provide the basis for stream alteration regulatory decisions, technical assistance for fluvial conflict resolution, stream corridor protection and restoration, flood hazard mitigation and water quality protection. The assessment data is critical to prioritization of riparian and fluvial process-related water quality restoration and protection projects, project design alternatives analyses, and project design criteria. SGA provides insight into the social, economic and ecological interrelationships between people and fluvial systems and as such, it is also a valuable educational tool.

With this background, tremendous thanks to all the cooperators who have contributed to development of this assessment and River Corridor Plan, and hopes for a lasting contribution to harmonious interaction with the complex relationships involved, Redstart's work on this is humbly offered here.

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The entire town of Bethel lies within the White River basin, with southern portions of the town draining directly into the White mainstem (oriented along an east-west axis) and the Third Branch of the White (oriented along a north-south axis) draining most of the northern portion of Bethel; the confluence of these two watersheds lies at the heart of Bethel village (Fig. 3). The upper White mainstem drains a bit more than 270 sq. mi. into Bethel, with just 5% (15 sq. mi.) of that area actually located within Bethel. The Third Branch watershed drains nearly 137 sq. mi. into Bethel, with about 18% (25 sq. mi.) of that area located within the town bounds.

Downstream of its confluence with the Third Branch the White mainstem enters a new drainage (White River-Third Branch to mouth), but the section of the White mainstem from the Tweed confluence in Stockbridge to the First Branch confluence in Royalton (or thereabouts), including portions of the “White River - headwaters to Third Branch” and “White River - Third Branch to mouth” watersheds, is colloquially known as the “mid-White”. Fieldwork for this study in 2013 included just one reach at the upstream end of the 125 sq. mi. “Third Branch to mouth” drainage of the White, with roughly 2% (a bit over 2 sq. mi.) of that drainage located in Bethel.

Roughly 4.1 sq. mi. of the northeast corner of Bethel is located within the drainage basin of the Second Branch of the White; none of this drainage was included in the 2013 Phase 2 assessment and corridor planning included in this report.

Elevations on the western side of Bethel are significantly higher than the ridge forming the eastern boundary of the drainages feeding into Bethel, with Mount Cushman (2743 ft.) near the upstream end of Gilead Brook; Rochester Mountain (2953 ft.) near the head of Camp Brook, and Mount Lympus (2485 ft.) above the head of Lilliesville Brook.

Quarry Hill (~1400 ft.) and Christian Hill (~1300 ft.) are high points on the ridge that divides the Third and Second Branch basins on the eastern side of Bethel.

Vulture Mountain (~1520 ft.) and the Delectable Mountain ridge (~2050 ft.) are summits that form part of the southern bounds of the drainages feeding into Bethel.

Deer Mountain (~2150 ft., NW) and Fish Hill (~1350 ft., NE) are high points on the northern bounds of the Third Branch basin just outside of Bethel.

The confluence of the White mainstem and Third Branch in Bethel village is at roughly 520 ft., with a USGS benchmark above the Third Branch at 573 ft. representing one commonly cited elevation of Bethel village. The Third Branch is at about 600 ft. as it enters Bethel from Randolph on the northern boundary, and the White mainstem is at about 575 ft. as it flows into Bethel from Stockbridge along the southern boundary.

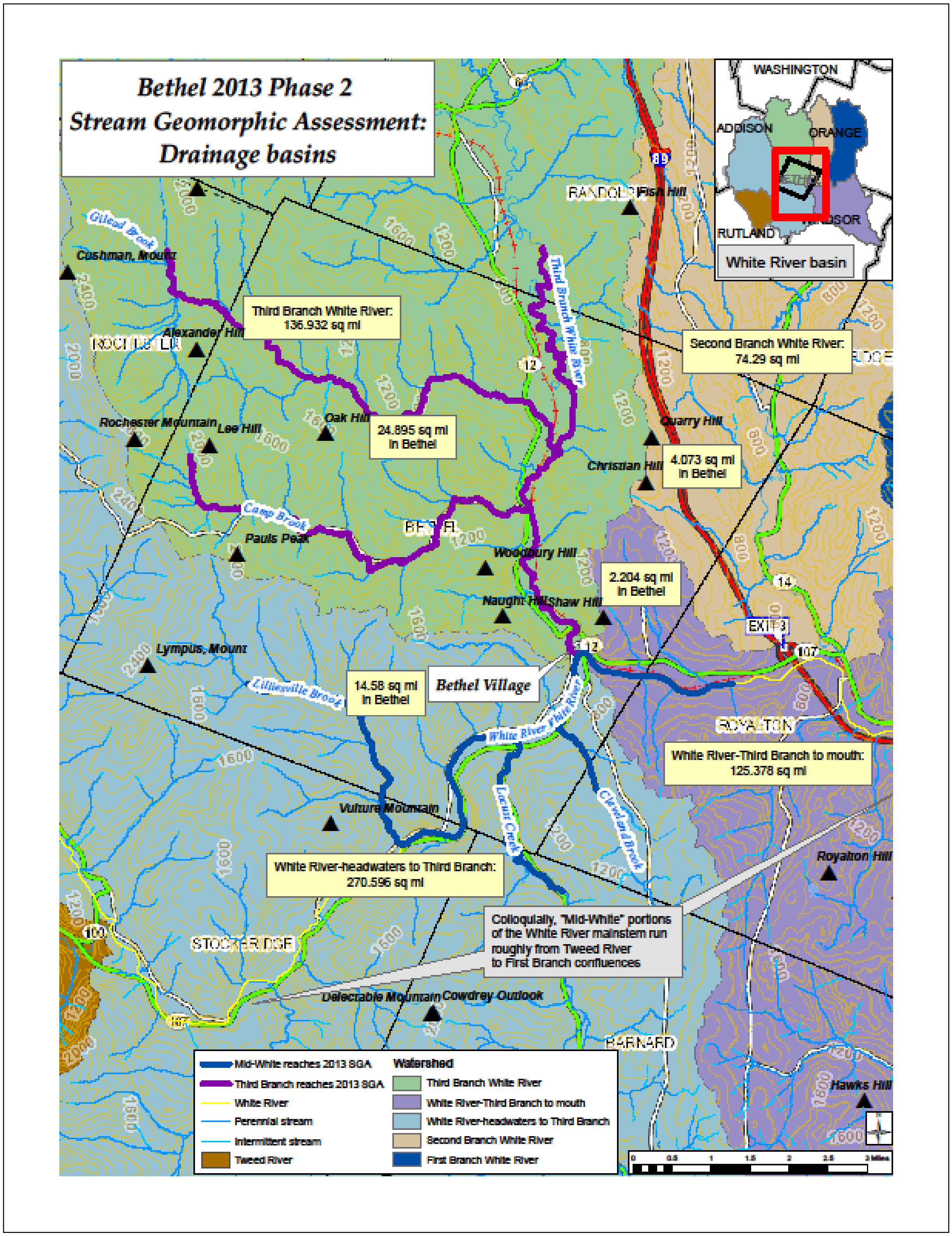


Figure 3. Bethel drainage basins.

3.1.2 Political jurisdictions

The 2013-14 Phase 2 assessment and corridor planning project of the White River and tributaries reported here was delineated by township, with the study area being defined primarily by reaches located in or flowing into the town of Bethel (Fig. 3 basins; Fig. 1 overview). The study area also included small portions of the towns of Rochester (Gilead Brook reaches T1.03 and T1.04), Stockbridge (White mainstem reach R13 and Lilliesville Brook segment T4.01A), Barnard (Locust Creek segments T3.01B, C and D), Royalton (White mainstem reach R11 and Cleveland Brook segments R12S2.01B and C), and Randolph (Third Branch reach M03).

The portion of Third Branch reach M03 in Randolph lies within Orange County; all other assessed areas are located in Windsor County. All assessed areas are within the 30-town coverage area of the Two Rivers-Ottauquechee Regional Commission.

3.1.3 Land use history and current general characteristics

Bethel lies at the convergence of four different biophysical regions, giving the area a diverse mix of climate, geology, topography, soils, natural communities, and human history (Thompson and Sorenson 2000; Fig. 4). Overall the town is characterized by the influences of the Green Mountain regions in the western two-thirds of the town and by the Piedmont regions in the eastern third of town. Since the northeastern corner of town lies largely in the Second Branch basin (not assessed in the 2013 Phase 2 assessment), the area described in this report is predominantly influenced by the Green Mountain regions.

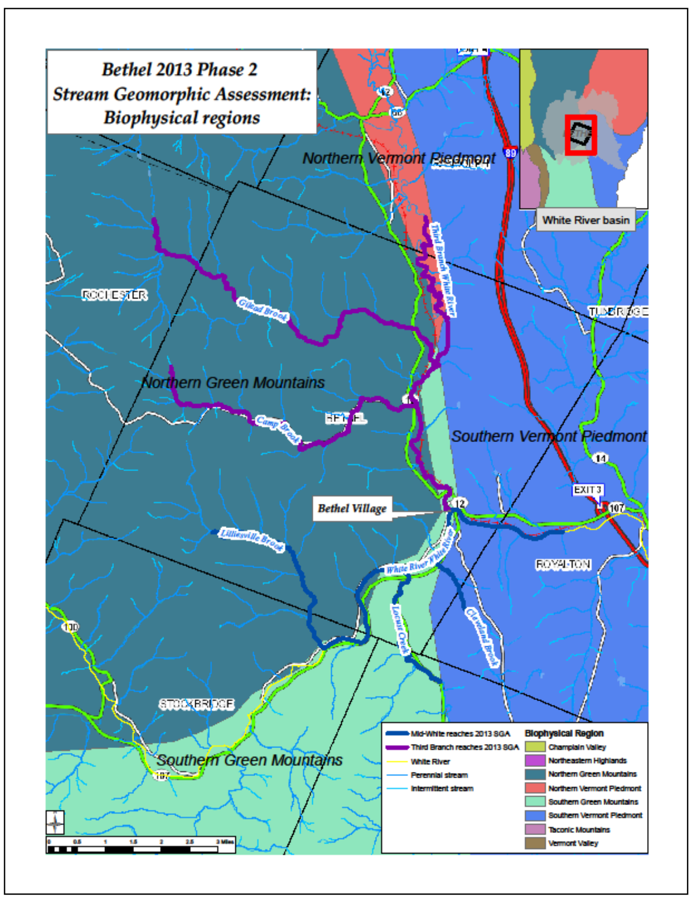


Figure 4. Biophysical regions in Bethel.

While there are distinct differences in these different biophysical regions, particularly in terms of geology and climate, there is a common dominant matrix of Northern Hardwood forest throughout Bethel with agricultural use concentrated along the Third Branch valley and the narrower floodplains of the White mainstem and other tributaries (especially Gilead Brook and Locust Creek). Due in large part to the geology and topography of the Green Mountain regions, primary land uses there (both historically and currently) have tended toward more extensive uses including timber harvesting, hunting and recreational uses, while more intensive agricultural and commercial/industrial uses have been focused more in the Piedmont regions and the major drainages of the White mainstem and Third Branch regions influenced by the soils deposited along the margins of glacial Lake Hitchcock (discussed further below in sec. 3.2, Geologic setting). A major climatologic influence from the Green Mountains biophysical regions is the distinctly higher precipitation regime associated with orographic effects as air lifts across the Green Mountains and higher ridges to the west of town, which can contribute to heavy downpours feeding the streams and rivers that flow into Bethel as well as generally higher annual precipitation averages on the western edge.

Native American use in the Bethel area included a long history of primarily non-intensive land use and travel ways linking the Connecticut River valley with points north and west, with more concentrated use along larger floodplains and a few lakes and ponds in the region (Thompson and Sorenson 2000; USFS 2001; Mavor and Dix 1989; pers. comm., Donna Roberts and John Moody, Winter Center for Indigenous Traditions). Lakes and ponds in Bethel are primarily small in size, with Ansel Pond representing the only named lake or pond appearing on USGS topographic maps of the area, but expanded use of the travel ways along floodplains has had profound effects on the streams in Bethel - particularly through the legacy of the railroads that were originally laid out through town in the latter half of the 1800s (Herwig et al 2006; Drysdale 2006; Parsons 2010; UNH Dimond 2014 – Figs. 5 and 6). Today some of the largest "ponds" in Bethel are in the disconnected floodplain oxbows of the Third Branch, along the tracks but outside of the current stream corridor (and separated from it by elevated embankments).

Channel straightening and restriction of access to floodplains that accompanied the building of the railroads (through elevated embankments and bank armoring) are crucial to understanding the current entrenched nature of much of the stream network in Bethel. The White River mainstem retains a unique status as the longest undammed major tributary of the Connecticut River, in part due to the fact that a number of former dams along the river were not rebuilt following the extensive damages of the 1927 flood that heavily impacted Vermont (Johnson 1928; see reach R11 description in Ch. 6.1 of this report for picture and notes on the former power dam downstream of the Bethel/Royalton town line). Despite the widespread damage to infrastructure caused by the '27 flood, however, both of the major rail lines in Bethel (White River Railroad, aka 'Peavine' railroad, and Central Vermont Railway along the Third Branch) were rebuilt after the flood (Drysdale 2006; Parsons 2010). The Peavine remained a primary form of transportation between Bethel and Rochester into the 1920s, and the line was not discontinued until the recession of the 1930's and the advent of better roads and more extensive automobile use contributed to closure in 1933; the tracks were torn up in 1938 but replaced by roads in nearly the same location (Fig. 6). Bed erosion and downcutting in response to channel straightening (such as that associated with the elevated railbeds along both the White and Third Branch mainstems) and subsequent loss of floodplain access is further discussed in Sec. 5.1, Departure Analysis; relative lack of grade controls to limit this downcutting in Bethel are discussed in Sec. 3.3, Geomorphic Setting.

The Central Vermont Railway along the Third Branch is now the New England Central Railroad and is still active but has declined in use since a peak in the 1980s; the track is maintained to relatively high rail standards (Parsons 2010).

Figure 5. This section of a 1926 USGS topographic map covering the town of Bethel shows the former location of the White River Railroad jammed in along the White mainstem toward Stockbridge, as well as the Central Vermont Railway laid out along the Third Branch (headed north toward top of map) where it's elevated railbed (as of 2013) still significantly reduces the extent of available floodplain.

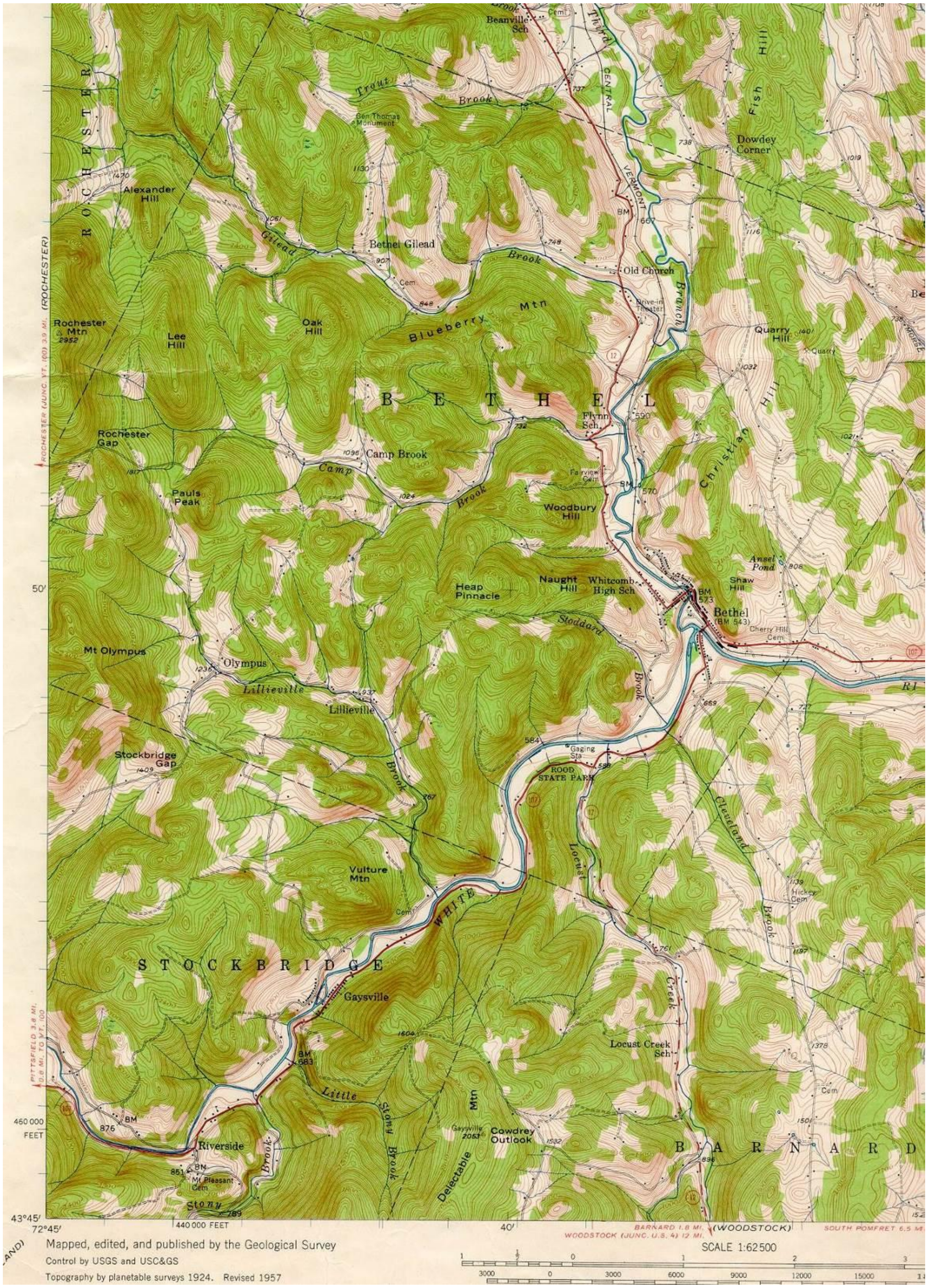


Figure 6. This section of a 1957 USGS topographic map covering the town of Bethel shows the former location of the White River Railroad (tracks torn up in 1938) largely replaced by roads (Peavine Blvd. in Bethel/ River Rd. in Stockbridge, not named on this map) along the White mainstem going toward Stockbridge. Open areas (tan rather than green) indicate that 1800s deforestation in Bethel was likely not as extensive as in many other areas of Vermont, particularly on the western side of town (Green Mountains biophysical regions).

Interestingly, the changing transportation history of Bethel (with major arteries along the streams of the watershed) appears to parallel population trends in the town (Fig. 7), with peaks experienced during the period when both rail lines were operating in Bethel and again after the completion of Interstate I-89. While Bethel has always had a relatively diffuse settlement pattern, increasing population since the completion of I-89 in the 1970s has also been accompanied by an increasing use of a road system that frequently shares narrow valleys with streams in this topographically rugged town. US Census figures in 2010 indicated 72% of reporting workers in Bethel travelled to work outside of town, with an average commute time of 23 minutes (Vermont Indicators Online 2010).

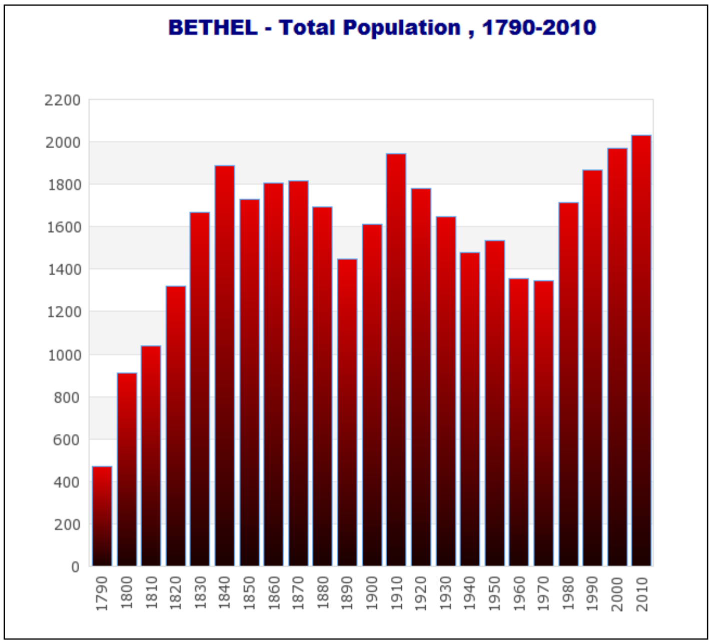


Figure 7. Population peaks in Bethel parallel the heydays of stream-based millpower (mid-1800s) and the railroad (early 1900s) plus the completion of Interstate I-89 (finished in the Bethel area ca. 1970) (Vermont Indicators Online 2010).

Many communities in east-central Vermont experienced peak populations during the mid-1800s, and initial settlement patterns in Bethel in the 1800s focused on agricultural use of the White mainstem, Third and Second Branch valleys but also included relatively dense settlements clustered particularly at key junctures in the narrow valleys along the tributaries (Fig. 1 overview map). As in much of New England, stream power played a large role in the location and development of these villages by supplying power for sawmills, grist mills, manufacturing facilities and other uses. In Bethel, Beers Atlas of Windsor County (1869) indicates a grist mill and three sawmills on Gilead Brook; five sawmills on Camp Brook; three sawmills on Lilliesville Brook; and one sawmill at the base of Locust Creek. The majority of these mills are indicated on the Atlas with associated dammed ponds or stream diversions. There was little evidence of these former impoundments or associated buildings observed during the 2013 Phase 2 assessments.

Historical photographs (UVM Landscape Change 2011) and topographic maps (UNH Dimond 2014; Fig. 6) indicate that deforestation in Bethel was likely not as extensive as in many areas of

Vermont during the 1800s, especially in the western portions of town (Green Mountains biophysical regions) that are characterized by more mountainous topography and predominantly thinner, more acidic soils than the Piedmont regions to the east. Most bottomlands and many lower slopes were cleared however, but as in most of Vermont the landscape largely reforested through much of the 20th century and as of the turn of the 21st century the White River basin upstream of Bethel was 90% forested and the Third Branch basin was more than 80% forested (Table 2, 1990s data; Fig. x represents a simplified 4-class version of these land cover/land use classes).

The Third Branch basin hosts a more extensive agricultural base (8% land cover/land use) than the White mainstem basin (2.5%). Both basins are characterized by diffuse settlement patterns accompanied by a network of transportation infrastructure, but while in the Third Branch basin agricultural use is followed by "urban" land cover/ land use (5%) the White basin actually upstream of Bethel actually has more water (3.7%) than "urban" land use (3.3%); Table 2). "Urban" in a four-class context (Fig. 8) refers to not only densely developed areas, but roads, infrastructure, suburbs, and large-lot residential development as well; roads and infrastructure account for most of the "urban" landuse in both the White and Third Branch basins (Table 2; Figure 8).

Table 2. Land cover/land use data for the White River mainstem (upstream of and including Bethel) and Third Branch basins, derived from 1990s satellite imagery. Shading indicates groupings portrayed by four-class system (UVM-SAL 2002) in Fig. 8.

	White	Third Branch
FORESTED TOTAL	***90.42%***	***84.65%***
CONIFEROUS FOREST (generally evergreen)	61.55%	56.29%
MIXED CONIFEROUS-BROADLEAF FOREST	16.39%	16.73%
BROADLEAF FOREST (generally deciduous)	12.12%	10.52%
FORESTED WETLAND	0.31%	0.84%
BRUSH OR TRANSITIONAL BETWEEN OPEN AND FORESTED	0.06%	0.26%
AGRICULTURAL TOTAL	***2.52%***	***7.95%***
Hay/rotation/permanent pasture	1.46%	4.89%
Row crops	1.04%	2.99%
OTHER AGRICULTURAL LAND	0.02%	0.06%
"URBAN" TOTAL	***3.30%***	***4.67%***
TRANSPORTATION, COMMUNICATION AND UTILITIES	2.82%	3.97%
RESIDENTIAL	0.43%	0.66%
INDUSTRIAL	0.00%	0.00%
COMMERCIAL, SERVICES AND INSTITUTIONAL	0.02%	0.02%
OUTDOOR AND OTHER URBAN AND BUILT-UP LAND	0.00%	0.00%
BARREN LAND	0.02%	0.01%
WATER	***3.71%***	***2.56%***
NON-FORESTED WETLAND*	**0.05%**	**0.17%**
	100.00%	100.00%

**non-forested wetland may be classed as urban, ag, or forest in the 4-class typing*

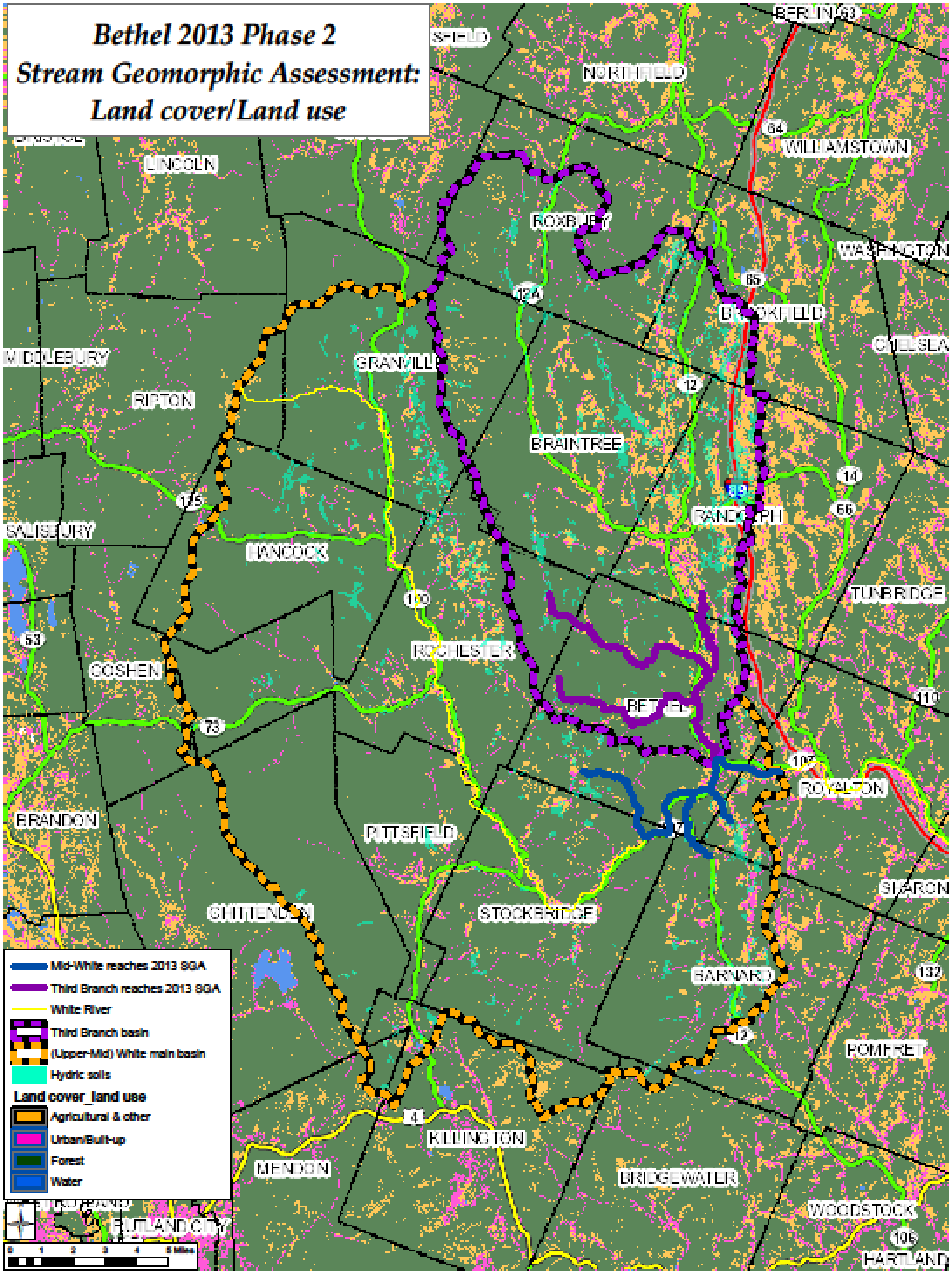


Figure 8. Four-class land cover/land use map (UVM-SAL 2002) for the White mainstem (upstream of and including Bethel) and Third Branch watersheds, with hydric soils (SSURGO 2008). Areas of "urban" and agricultural lands intersecting with hydric soils may indicate potential loss of historic wetlands (discussed in sec. 5.1.1, *Hydrologic regime stressors*).

Protected lands comprise roughly 82,200 acres (46.7% of the basin land area) in the White mainstem basin upstream of Bethel, with about 85% of this (69,876 ac.) in the Green Mountain National Forest (VCLD 2009; Table 3).

In the Third Branch basin protected lands comprise roughly 7,539 acres (~8.6% of the basin land area), with about 68% of this (5,134 ac.) on State of Vermont lands (primarily state forests and some wildlife management areas).

Table 3. Protected lands by ownership type for the basins feeding into the Bethel Phase 2 study area.

	Third Branch		White Main		Grand Total	
	Acres	Pct	Acres	Pct	Acres	Pct
Municipal	420.2	0.5%	740.5	0.4%	1160.7	0.4%
Federal	1.9	0.0%	70153.3	39.9%	70155.2	26.6%
State	5133.7	5.9%	7664.5	4.4%	12798.2	4.9%
Private organization	1983.6	2.3%	3641.9	2.1%	5625.5	2.1%
Protected Total	**7539.4**	**8.6%**	**82200.2**	**46.7%**	**89739.6**	**34.1%**
Basin Total	87636.9	100.0%	175876.8	100.0%	263513.7	100.0%

Protection mechanisms vary on these properties and only 8-9% of the protected lands (in each basin as well as the combination of both basins) are protected from conversion of natural land cover, though the protected status generally indicates the land will not be developed (development being roughly equivalent to the "urban" land use category in the four-class system denoted in Fig. 8, which tends to contribute to the greatest impacts on overall stream health). Land use on lands not mandated to maintain natural cover or manage for biodiversity conservation may range from low intensity timber harvest to more intensive resource extraction (but barring permanent conversion) or agricultural use. Forest cover strongly influences the rate and intensity at which water is delivered to the stream network (further discussed in Sec. 5.1.1, Hydrologic regime stressors).

Protected lands within the Town of Bethel include 667 acres in the Third Branch basin and 472 acres in the White mainstem basin, with roughly half of those lands protected by private easements (Table 4). The majority of non-private protected lands in both basins is comprised of portions of the Bethel Town Forest, and the State of Vermont Agency of Natural Resources owns roughly 41 acres of stream bank access in three different parcels along the White. None of these lands are mandated to maintain natural cover or manage for biodiversity conservation.

Table 4. Protected lands within the Town of Bethel in the Phase 2 study area

	Third Branch		White Main		Grand Total	
	acres	pct	acres	pct	acres	pct
BETHEL SCHOOL FOREST	17.2	2.6%		0.0%	17.2	1.5%
BETHEL TOWN FOREST	277.8	41.6%	196.1	41.5%	473.9	41.6%
PRIVATE EASEMENTS	372.1	55.8%	235	49.8%	607.1	53.3%
WHITE RIVER STREAM BANK		0.0%	40.9	8.7%	40.9	3.6%
Grand Total	**667.1**	**100.0%**	**472**	**100.0%**	**1139.1**	**100.0%**

Although the heyday of the railroad in Bethel is past and the Depot now houses a bar, downtown Bethel maintains an active commercial district at the junction of the White and Third Branch and extending up Rte. 12 (Pleasant St.) and along Rte. 107 in both directions from the village. Many vital services are found within town, and Bethel Mills (building supplies), GW Plastics, and Vermont Castings (stoves) are among a number of significant employers in town. Bethel Mills owns and operates the only dam still existing in the Phase 2 study area, a 17-ft. concrete hydro-electric dam constructed atop a natural waterfalls in the late 1930s (Bethel Mills 2013). The generating plant was undergoing repairs at the time of Phase 2 work in 2013.

Despite the number of businesses in town, 2000 U.S. Census figures (Vermont Indicators Online 2010) indicated only 11% of the reporting work force in Bethel working at home or walking to work, and commuters reported an average commute of 23 minutes. With a high degree of mobility in the current economy of Bethel, and an increasing population (see Fig. 7) extending a pattern of diffuse settlement, roads are a focal point for residential concerns and municipal and state budgets.

The deeply dissected landscape of both the White mainstem and Third Branch basins leaves many roads and streams sharing narrow valleys that are hard pressed to accommodate both, leading to recurrent conflicts between infrastructure location and inevitable stream processes. Rte. 107 (running tight along the White mainstem south and west of Bethel) is one of a limited number of east-west highways in Vermont, and the time and money invested in its repair following Irene (further discussed in this report in Sec. 6.1 description for reach R12) indicate the priority given to road maintenance. Gilead Brook and Camp Brook both experienced extensive channelization following infrastructure conflicts in Irene, and numerous bridges along Lilliesville Brook and Locust Creek incurred significant effort and costs for repair or replacement as well. Although one bridge along Locust Creek was taken out of service following Irene, the large majority of these areas have had numerous repeat flood damages requiring significant investments (notably in 1927, 1973, 2007 and 2008) but have continued to be rebuilt or replaced with the same or similar dimensions and locations.

3.2 GEOLOGIC SETTING

Although both the White mainstem and Third Branch basins overall are dominated by glacial till, the geologic influence of glacial Lake Hitchcock heavily influences both the mainstems of those two streams plus a large proportion of the valleys of most tributaries assessed during the 2013 Phase 2 work in Bethel (Fig . 9). Lake Hitchcock formed as an impoundment behind large volumes of glacial deposits in central Connecticut that dammed the Connecticut River valley. At its maximum extent, the lake body stretched from Rocky Hill, CT for 200 miles northward to the mouth of the Nulhegan River in Bloomfield, VT, and as far west as the Upper White mainstem in Pittsfield/Rochester and the Third Branch in Braintree. Sediments in and along the edges of the glacial Lake tend to be dominated by the stratification of fine silts, sands and gravels that settled out differentially in the still waters of the Lake as glacial streams fed into it.

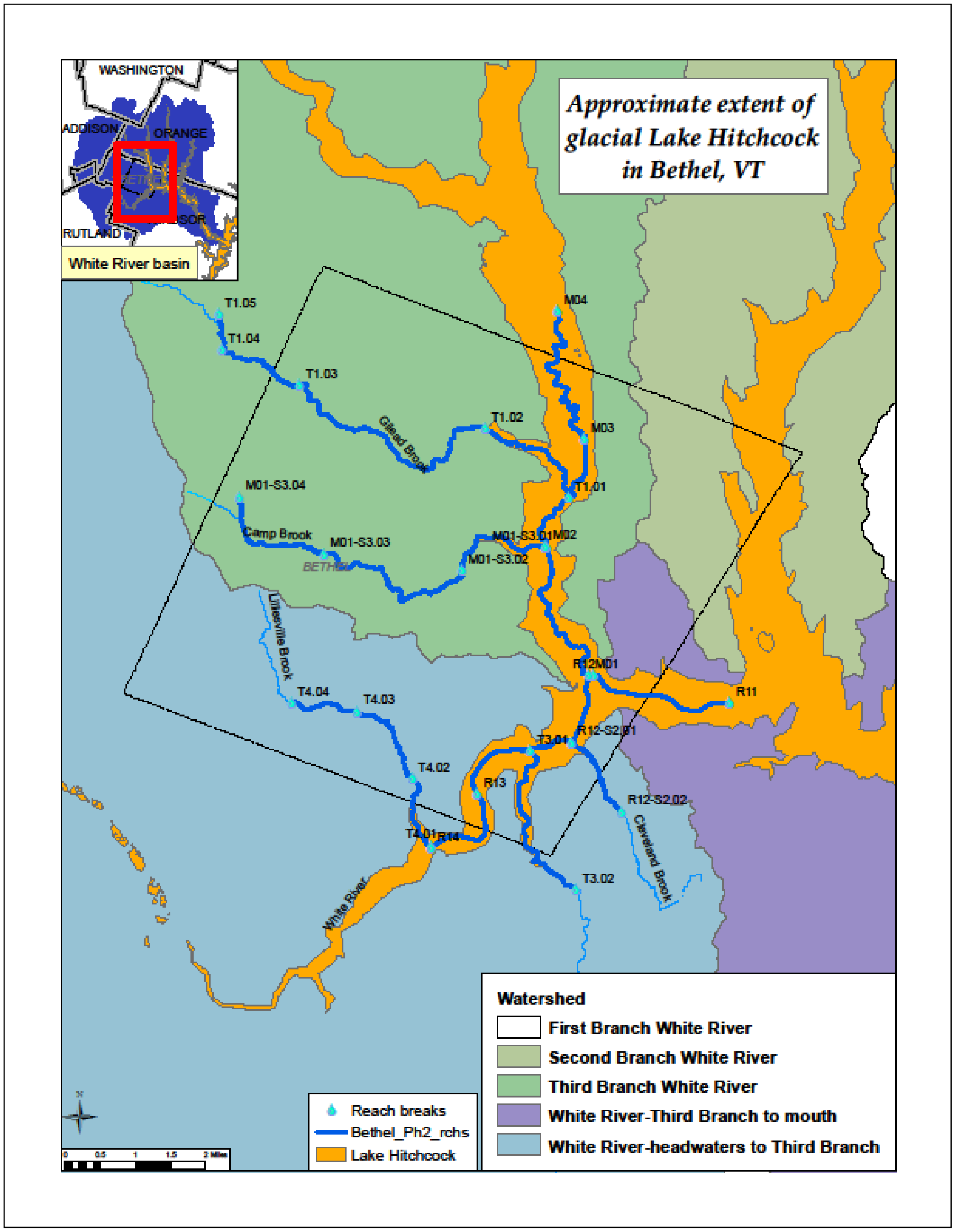


Figure 9. Extent of glacial Lake Hitchcock in the Bethel region.

Alluvial soils have deposited within the valleys of both the White mainstem and Third Branch over time, but glaciolacustrine soils (silts, pebbly sands, lake sands and gravels; Fig. 10) have left a profound legacy of extremely deep, highly erodible sediments in both the White mainstem and Third Branch basins in Bethel. Even along the narrow tributary valleys of the Phase 2 study area the valleys themselves are dominated by glacial outwash and unconsolidated tills, with bedrock exposures primarily comprising a limited number of extremely steep areas outside of the valleys.

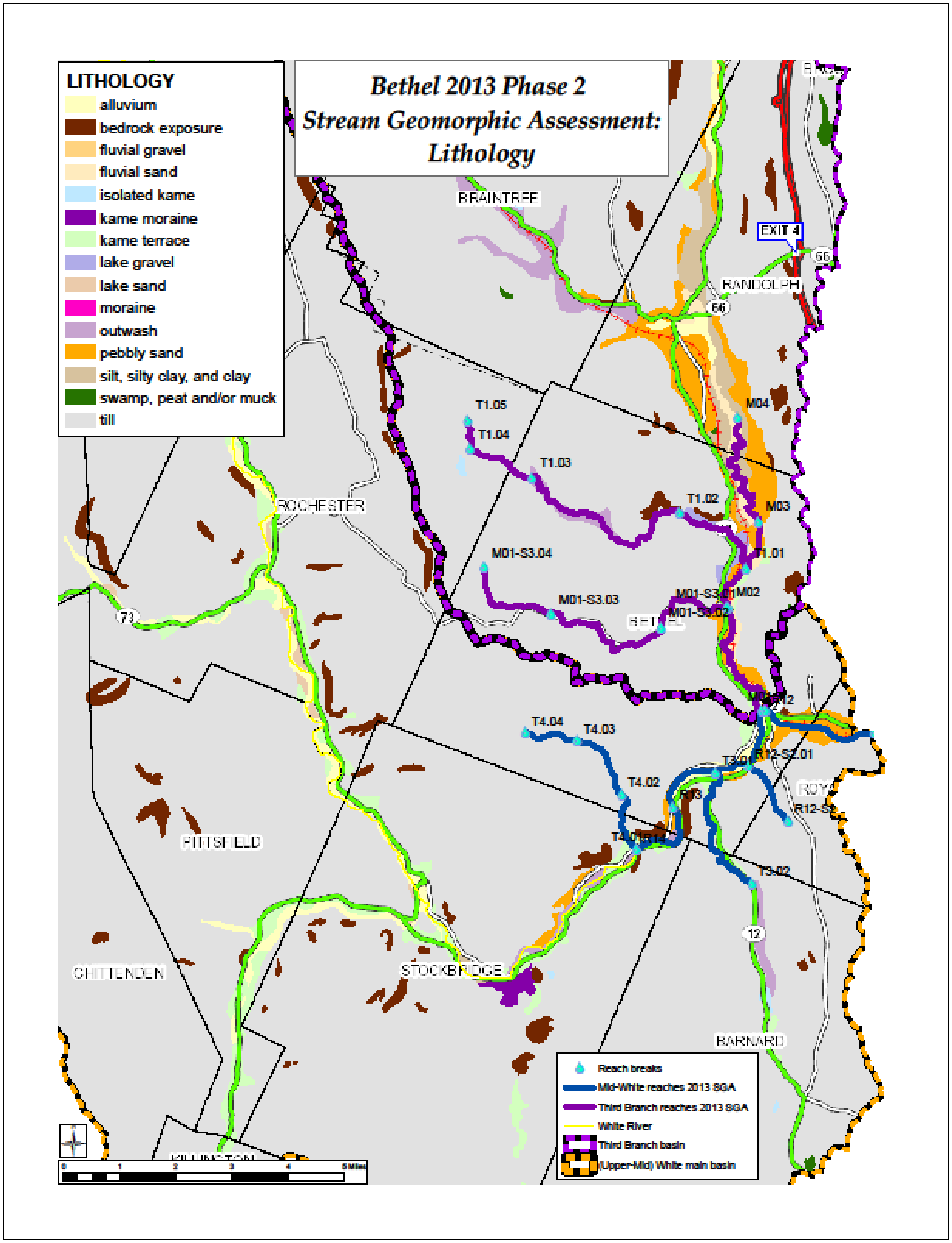


Figure 10. Surficial geology (lithology) of the Bethel region.

Due to the highly erodible nature of the valley walls and stream beds, in combination with minimal presence of grade controls that might limit downcutting, the large majority of streams assessed during the 2013 Phase 2 work in Bethel indicated a significant amount of historic incision as well substantial downcutting in response to the 2011 impacts of Irene. Even upstream of the direct influences of glacial Lake Hitchcock, all the tributaries assessed in Bethel evidenced unconsolidated tills along the valley walls, and impacts in Irene included a high number of mass failures along valley walls.

Along the Third Branch and lower portions of Gilead Brook numerous mass failures ranged 60 to 90 ft. in height and hundreds of ft. in length, contributing heavy dumps of fine-grained wash-load sediments to the stream network (wash load and bed load sediments are discussed further in Sec. 5.1.2, Sediment regime stressors). Ongoing slope instability has and can still trigger further dumps that are frequently noticeable in the turbidity of the Third Branch as it empties into the White mainstem in Bethel village following heavy downpours.

Although the valleys themselves along the White mainstem and upstream portions of tributaries in both basins contain substantial amounts of fine-grained alluvial sediments, the valley walls in these areas tend to have a higher proportion of coarser sediments (cobbles to boulders). Mass failures and general sediment transport in these areas indicated a higher proportion of cobble-dominated sediment "slugs" following flash floods in 2007 and 2008 and again following Irene in 2011. Transport of fines following heavy rains was noticeably higher in areas where these cobbles ("bed armor") had been disturbed or removed from the bed during post-Irene instream work (Fig. 11). Sediment dumps on the Third Branch mainstem had few cobbles and were more heavily dominated by fine gravels and sands, with steep faces frequently followed by deep scour pools immediately downstream. These deposits were clearly very unstable and "washing out" quickly in high flows.

Figure 11. Although coarse sediments are common along the White mainstem and most tributaries in Bethel, fine sediments are easily transported in areas where the "bed armoring" of these cobbles and boulders has been removed from the channel as in this portion of Gilead Brook; note color of water that clouded rapidly after initiation of bridge repairs upstream.

While the bedrock underlying the Bethel area is variable (Doll et al 1961), portions that are calcareous, carbonate-rich and relatively easily weathered to fertile soils are more predominant in the Third Branch basin, especially along the Third Branch mainstem and Gilead Brook (tributary T1; Thompson and Sorenson 2000); the White mainstem basin upstream of Bethel is primarily located on bedrock with lower levels of the carbonate and calcareous components of sweet soils (Fig. 12). The distribution of this bedrock has much to do with a stronger agricultural presence in the Third Branch basin as well as the presence of a Significant Natural Community of statewide importance (sugar maple-ostrich fern riverine floodplain forest; VT-ANR 2013, Thompson and Sorenson 2000) along reach M03 of the Third Branch and extending northward into the protected Randolph Village Forest - further discussed in section 3.5, Ecological setting.

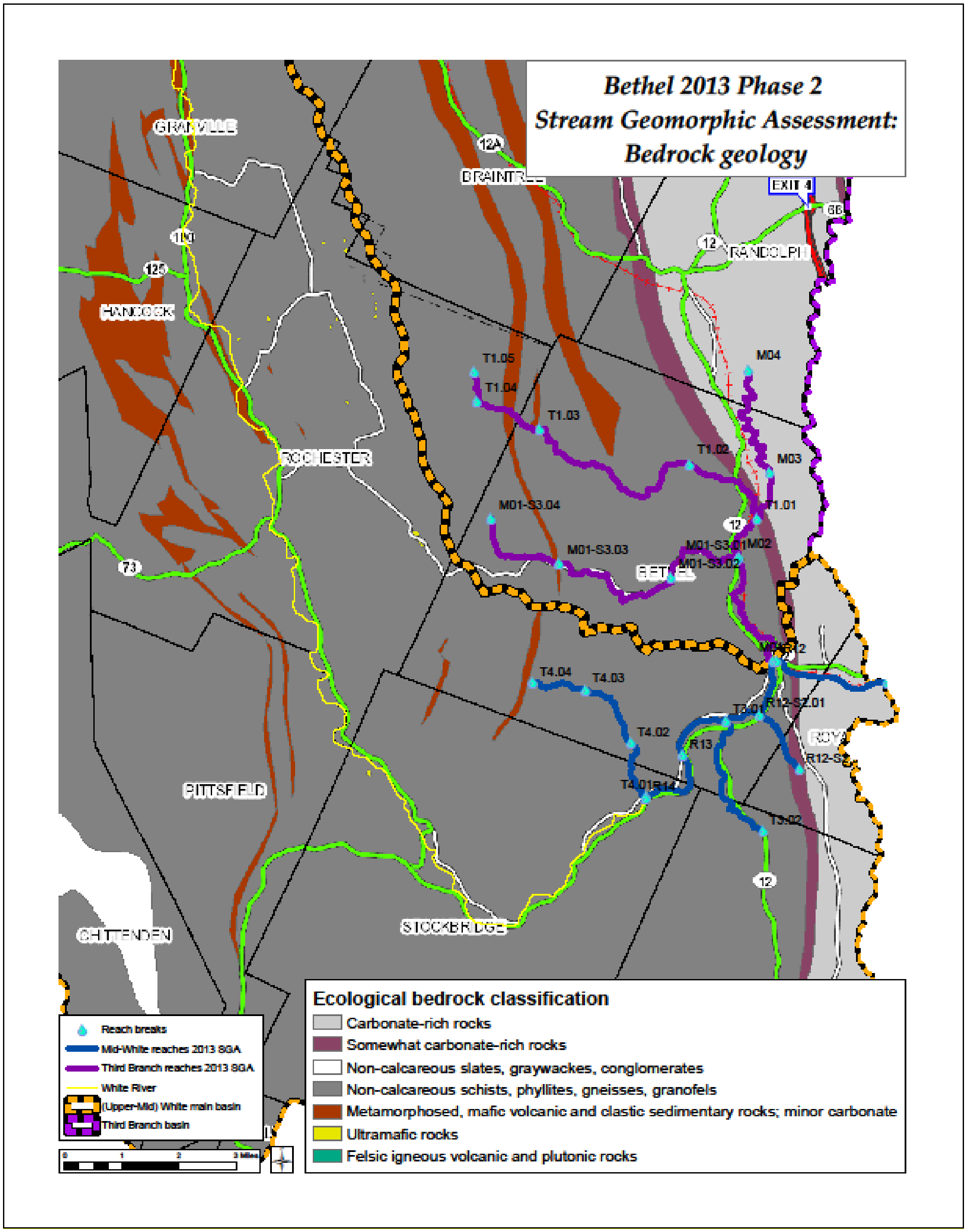


Figure 12. Ecological bedrock geology of Bethel Phase 2 assessment area.

3.3 GEOMORPHIC SETTING

3.3.1 Location of assessed reaches

For the purposes of geomorphic assessment and corridor planning, streams in the study area were divided into eighteen “reaches”. Reaches selected for Phase 2 assessment in 2013 included portions of: the Third Branch mainstem (M01-M03, ~7.5 mi.); Third Branch tributaries Camp Brook (M01-S3.01 - M01-S3.03, ~6.4 mi.) and Gilead Brook (T1.01 – T1.04, ~7.7 mi.); the Middle White main stem (R11 – R13, ~6.5 mi.); and Middle White tributaries Cleveland Brook (R12S2.01, ~1.3 mi.), Locust Creek (T3.01, ~2.7 mi.) and Lilliesville Brook (T4.01 – T4.03, ~3.7 mi.). The ‘Bethel basins’ (Fig.3) and overview (Fig. 1) maps show the location of Phase 2 reaches of the Third Branch basin in purple; the White mainstem basin reaches are in dark blue.

3.3.2 Longitudinal profile, alluvial fans, and natural grade controls

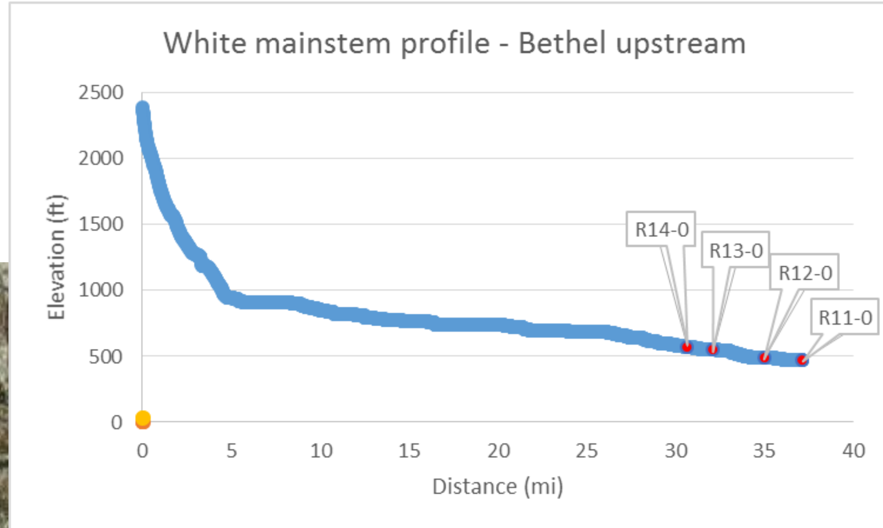
A longitudinal profile of the White mainstem from Bethel upstream indicates relatively low gradients along the reaches included in the Bethel phase 2 assessment in 2013 (U.S. Geological Survey 2012; Fig. 13). Note, however, that the gradients along the Bethel reaches (labeled) are steeper than in the Upper White mainstem reaches along Rte.100 (mid-section of elevation profile graph in Fig. 13). This is due in part to the straightening/lack of meanders along Rte. 107 leading into Bethel, which decreases the length of the stream over which the stream drops in elevation and thus increases slope.

A similar situation exists on the Third Branch as well (Fig. 14), where the slope gradient of reaches M01 and M02 coming into Bethel village is steeper than reach M03 (northern portion of Bethel township) due to the lack of meander development enforced by the railroad embankments that cut through significant portions of the natural floodplain of the Third Branch, decreasing the length of the stream over which elevation drops and thereby increasing slope.

Only the downstream portions of Gilead Brook (T1.101) and Locust Creek (T3.01) have slopes of less than 2 percent (Figs. 15-16), making overall gradients for the assessed tributaries significantly steeper than the mainstem White and Third Branch reaches in Bethel (Figs. 13-14), which are all less than 1 percent even with the aforementioned degree of straightening. With steeper gradients along the tributaries and valley walls combining with the geologic legacy of highly erodible glacial Lake Hitchcock and “ice-contact” sediments (from glacial melting), deltaic formations and high deposition zones are common at tributary mouths even though classic alluvial fans were not commonly noted in the Bethel Phase 2 assessment area.

Alluvial fans, located at the base of a steep slope when the gradient suddenly flattens, are naturally high deposition zones and tend to be areas where streams move frequently across the horizontal plane, sometimes suddenly shifting channel locations or becoming braided before re-establishing a new channel location and planform.

Figure 13. Longitudinal profile for the White mainstem from Bethel upstream.



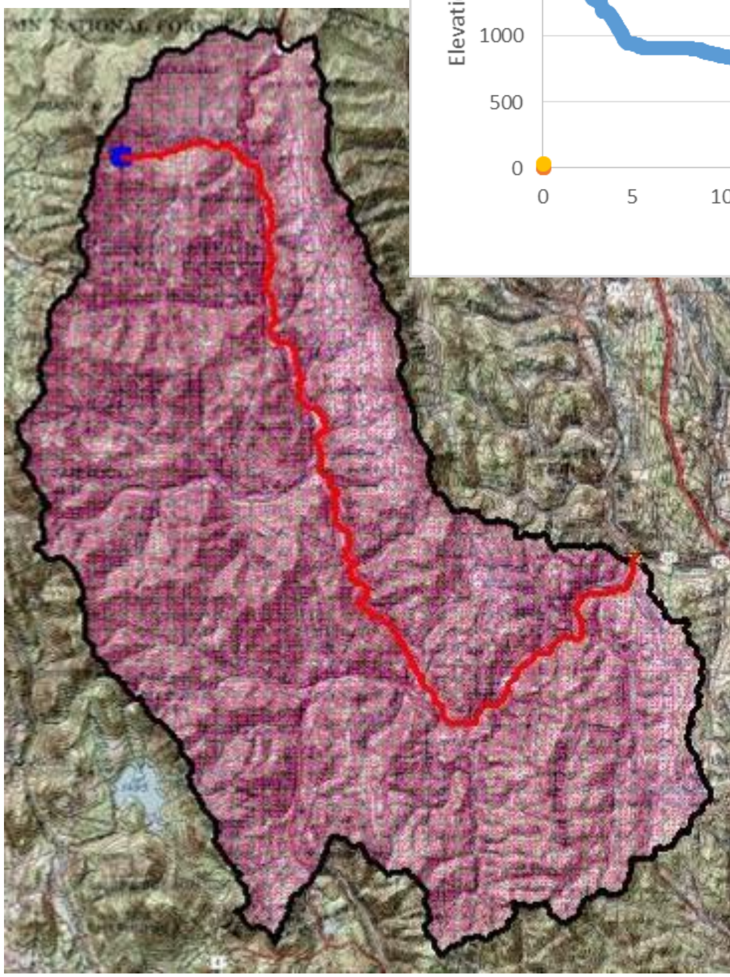
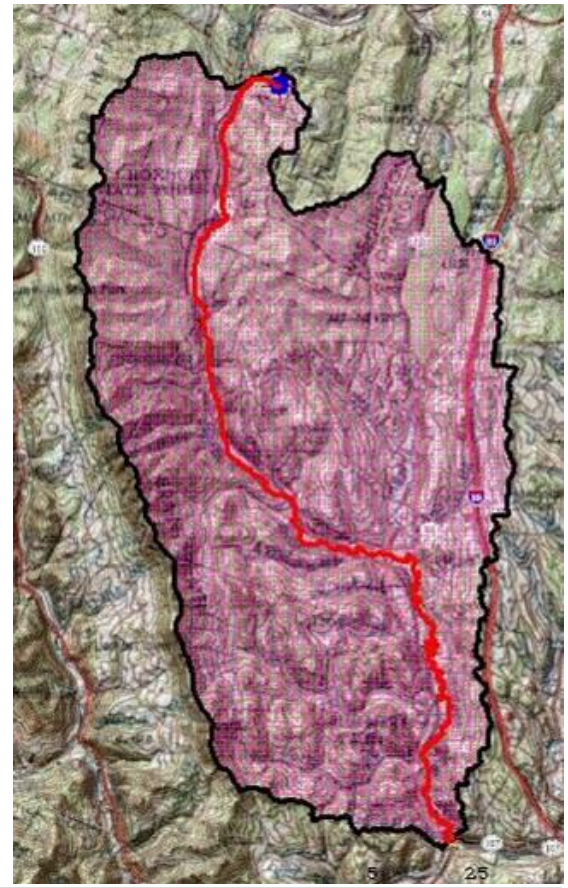
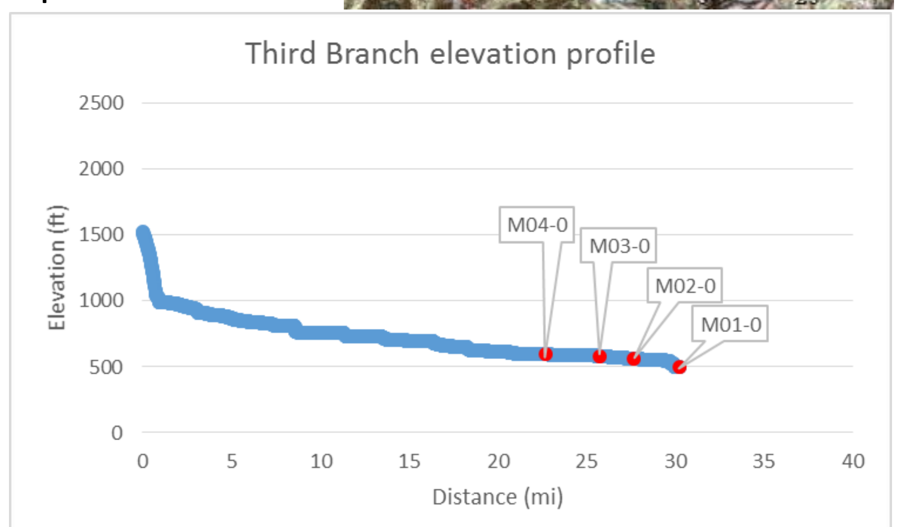
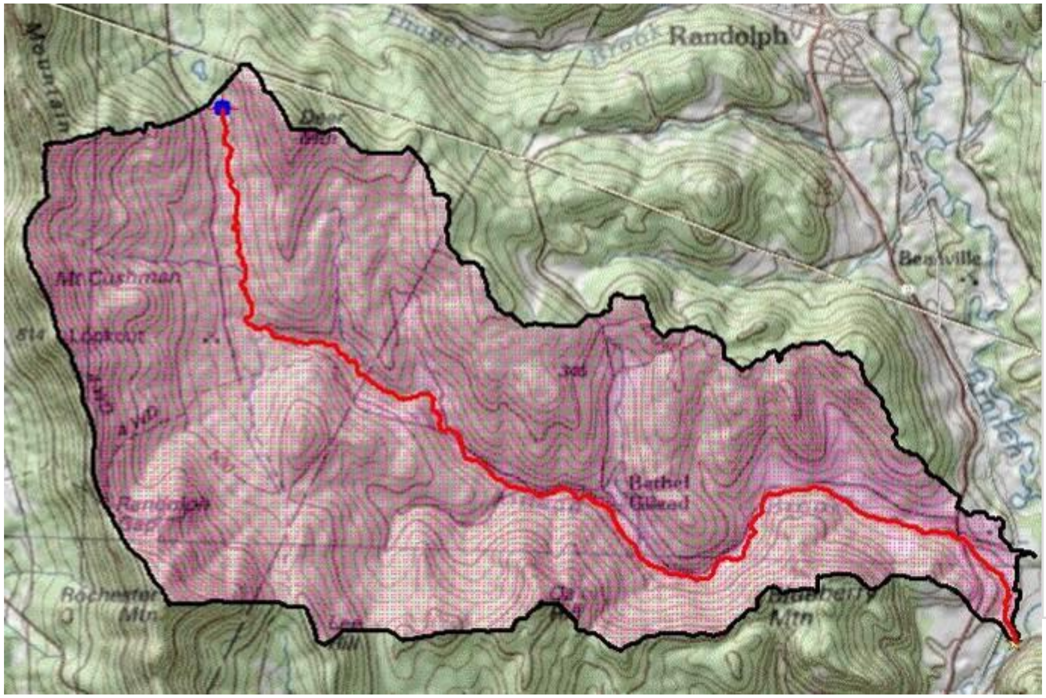


Figure 14. Longitudinal profile for the Third Branch.







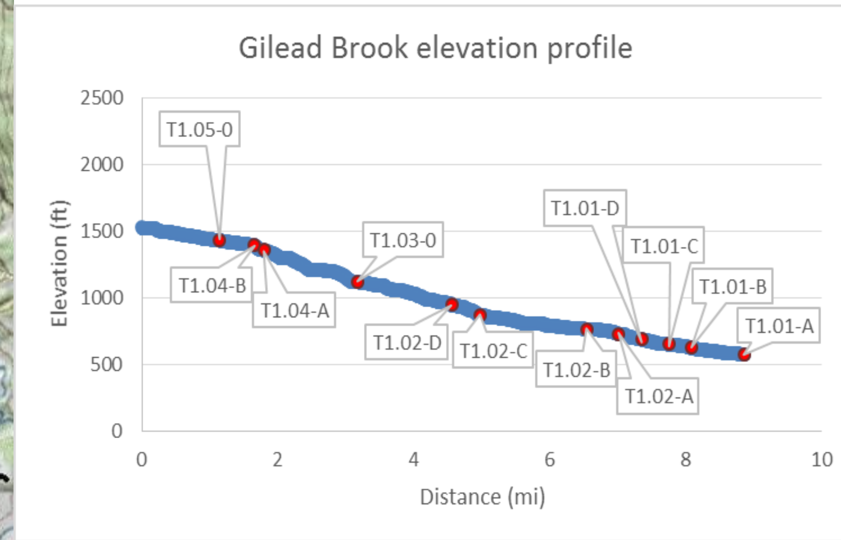


Figure 15. Elevation profile for Gilead Brook.

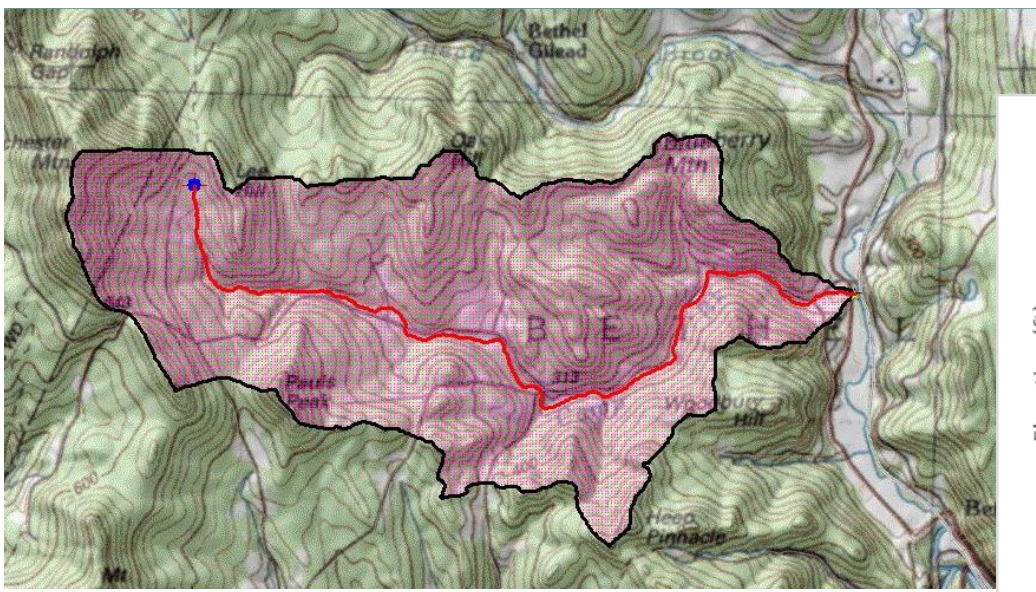
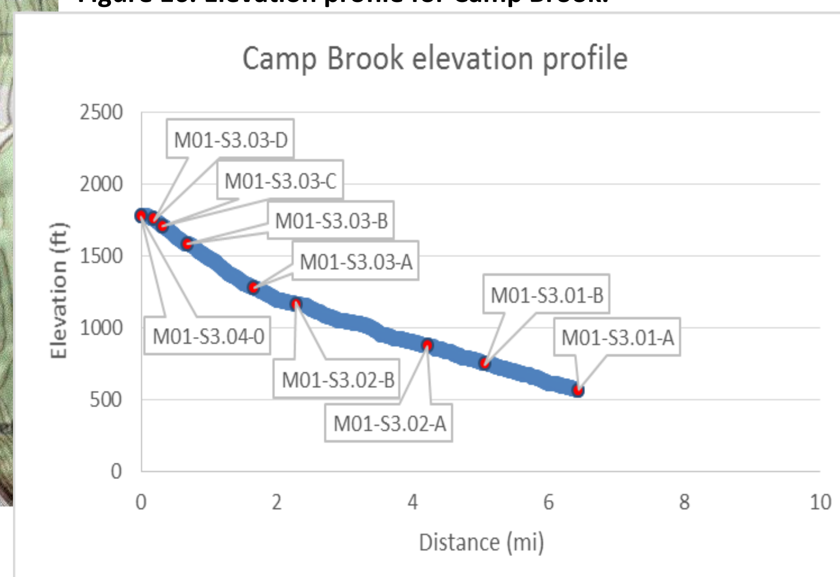


Figure 16. Elevation profile for Camp Brook.



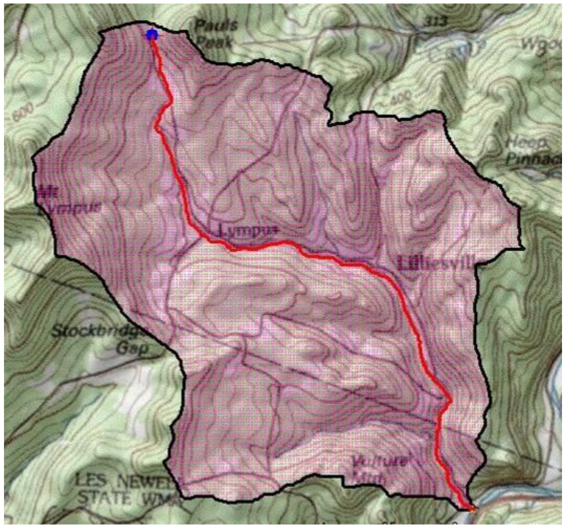


Figure 17. Elevation profile for Lilliesville Brook.

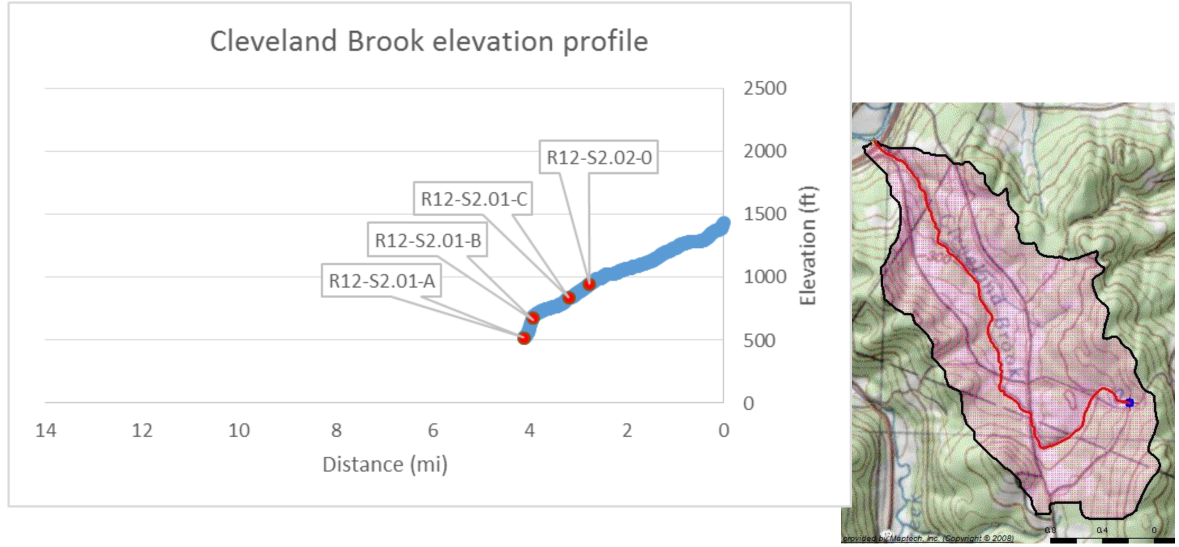
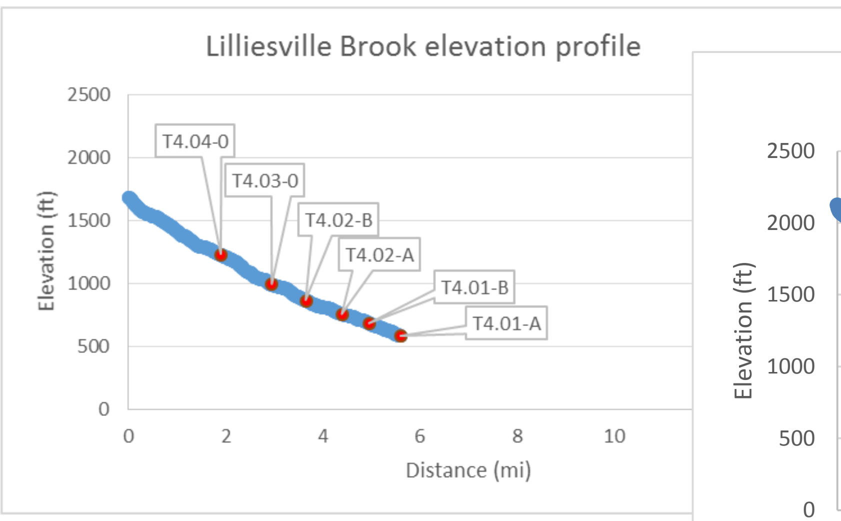
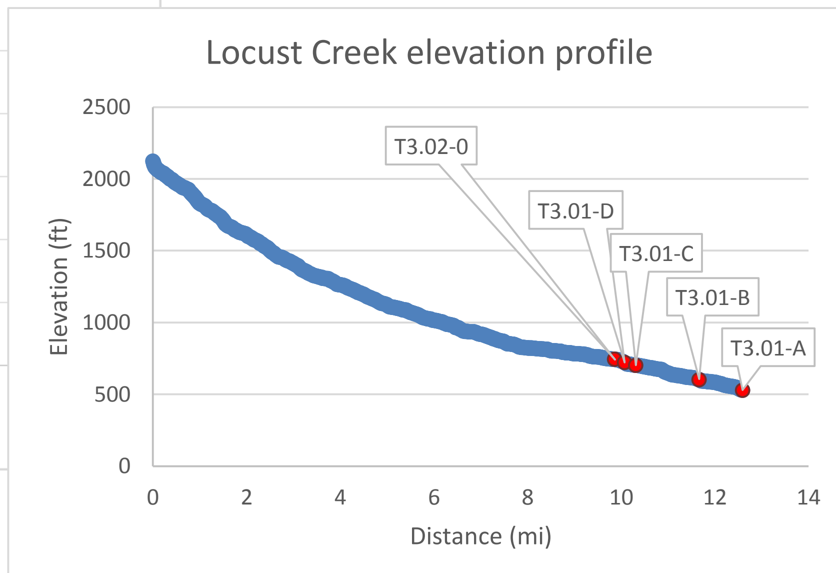


Figure 18. Elevation profile for Cleveland Brook.





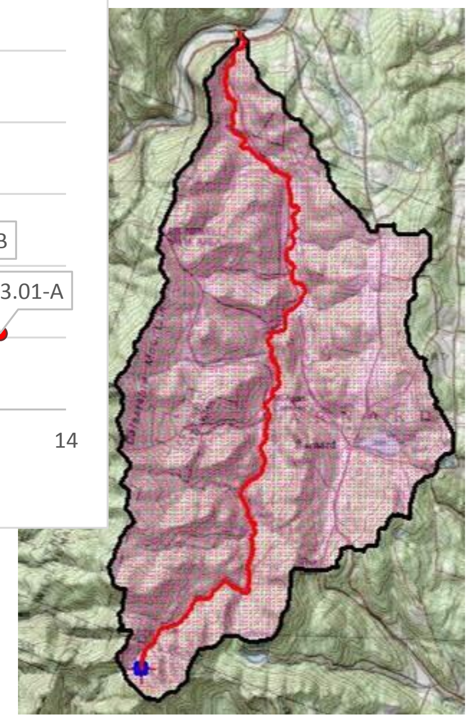


Figure 19. Elevation profile for Locust Creek.

A classic alluvial fan exists at the base of Cleveland Brook where it crosses Rte. 107, and heavy deposits observed in 2013 still bore evidence of the fan that had spilled out across the road during Irene. Although there did not appear to have been major damage, the undersized culvert at this location did appear to have plugged and contributed to the spread of the fan (Fig. 20). Other alluvial fans were noted on Camp Brook (M01-S3.01), Gilead Brook (T1.01), and Lilliesville Brook (T4.01, T4.02; Table 5) but all lacked the steep gradient contributing to the classic fan on Cleveland Brook and appeared largely related to the soil legacies of glacial Lake Hitchcock. Infrastructure or development is in close proximity to the stream near all of these fans, and all appear to have incurred significant investments for management of conflicts with stream processes over multiple flood events.

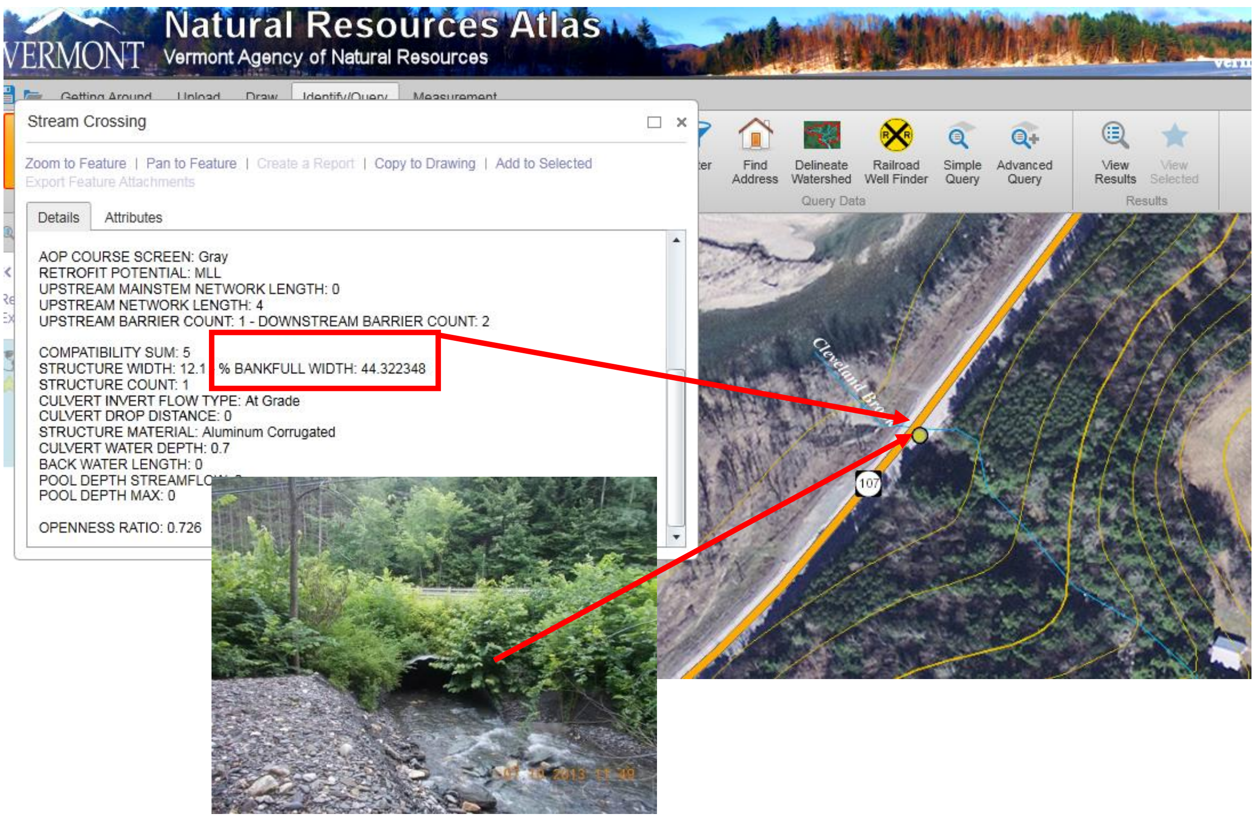


Figure 20. Undersized culvert under Route 107 sits at slope break contributing to alluvial fan sedimentation in the culvert as well as sediments that washed over the road during Hurricane Irene; the structure did not appear to have been damaged in Irene.

Natural grade controls are channel-spanning features that can be present in the form of bedrock or ledge exposures, or as steeper cascades or waterfalls. Dams and weirs represent human-constructed grade controls. Grade controls are important in providing vertical stability for a stream, ensuring that streams do not lose access to floodplains due to incision (downcutting) - frequently one of the effects of straightening and artificial confinement. If major floods or straightening and encroachment amplify the effects of erosion in upstream portions of the watershed, grade controls may mean that streams will aggrade (build up their beds) due to sediment inputs.

Table 5. Geology and soil parent materials for reaches assessed in Bethel 2013 Phase 2 assessments, including alluvial fans and grade controls.

RCHPTID	ALLUVIAL FAN	GRADE CONTROL	DOMINANT MATERIAL	PCT DOMINANT MATERIAL	SUBDOMINANT MATERIAL	PCT SUBDOMINANT MATERIAL
Third Branch and tributaries						
M01	None	Dam	Ice-Contact	39	Alluvial	36
M02	None	None	Ice-Contact	52	Alluvial	37
M03	None	None	Alluvial	73	Ice-Contact	20
M01-S3.01	Yes	Ledge	Other	77	Alluvial	12
M01-S3.02	None	Ledge	Other	40	Ice-Contact	32
M01-S3.03	None	Ledge	Till	100	Ice-Contact	0
T1.01	Yes	Ledge	Alluvial	74	Ice-Contact	20
T1.02	None	Multiple	Other	46	Ice-Contact	26
T1.03	None	None	Other	66	Till	34
T1.04	None	None	Ice-Contact	57	Till	22
White mainstem and tributaries						
R11	None	None	Ice-Contact	43	Till	26
R12	None	Weir	Ice-Contact	41	Alluvial	31
R13	None	None	Ice-Contact	48	Till	30
R12-S2.01	Yes	Multiple	Till	97	Ice-Contact	1
T3.01	None	Ledge	Ice-Contact	65	Till	22
T4.01	Yes	Ledge	Glacial Lake	53	Till	37
T4.02	Yes	Ledge	Ice-Contact	41	Alluvial	40
T4.03	None	None	Till	87	Ice-Contact	12

Although grade controls exist on most of the tributaries assessed in Bethel in 2013 (Table 5), the mainstem reaches of both the White and Third Branch were remarkable for only having human constructed grade controls (although the Bethel Mills dam in M01 on the Third Branch is situated atop ledge grade controls of a significantly lower height). Grade controls on the tributaries were widely dispersed and relatively uncommon as well (Fig 21), and streams throughout the assessed basins indicated a significant amount of incision both historically and more recently. Due to the relative scarcity of natural grade controls, portions of Camp Brook and Gilead Brook required installation of weirs (following extensive post-Irene bulldozing, dredging and channel straightening) in order to limit headcuts and other downcutting processes that could further restrict access to floodplains and lead to further increases in the erosive power of stream flows contained within the channel (Fig. 22).

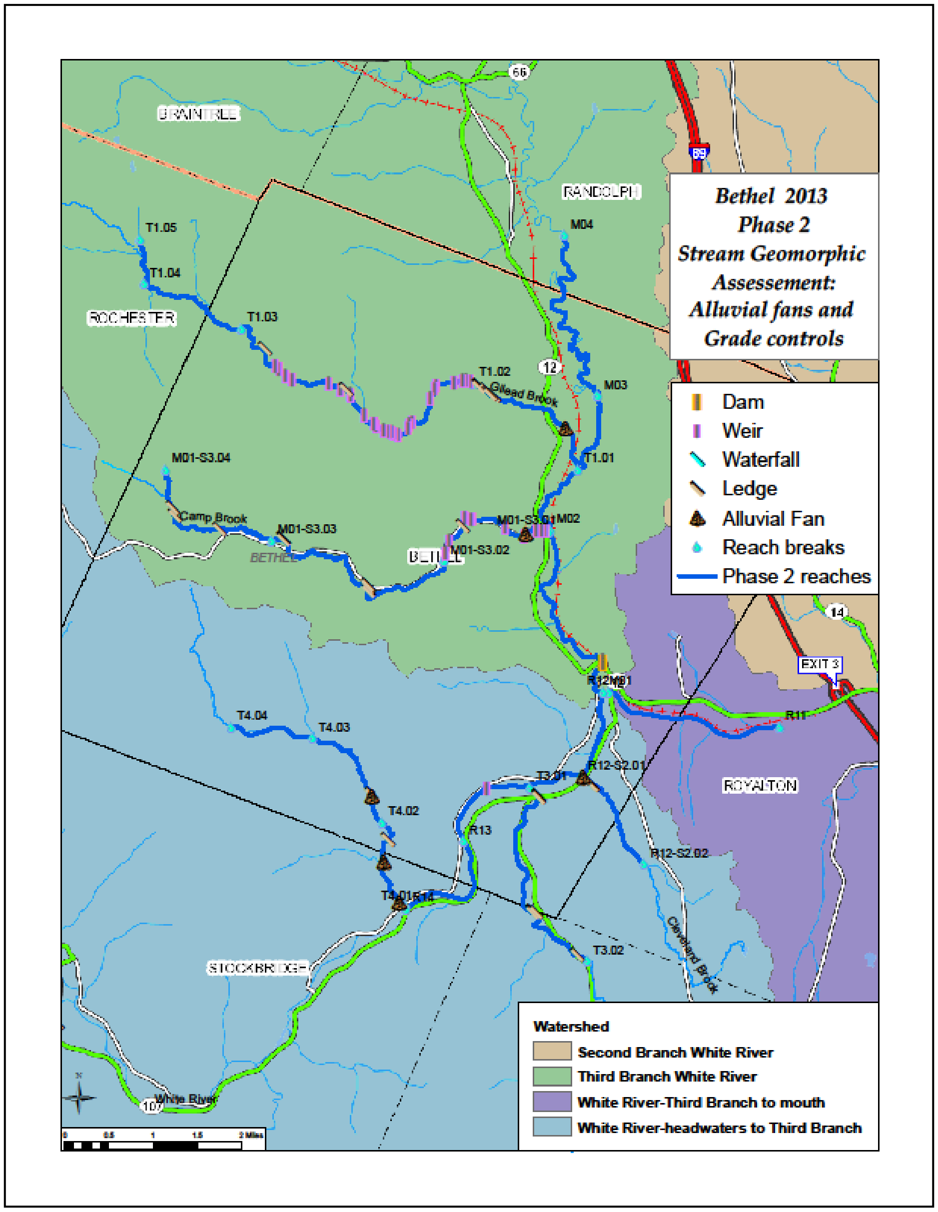


Figure 21. Natural grade controls are relatively uncommon and widely dispersed in Bethel, lending to a high degree of incision noted in most of the streams assessed in 2013 fieldwork.

Figure 22. With few natural grade controls, portions of Camp Brook and Gilead Brook required installation of weirs to limit headcuts and downcutting in highly channelized areas post-Irene. The only weir on the White mainstem is a long-standing one at the National Fish Hatchery.

3.3.3 Valley and reference stream types

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

Table 6. Reference stream type summary indicating classification parameters pertinent to Bethel reaches included for 2013 fluvial geomorphic assessments (VT-RMP 2009, Phase 1 Protocols, p. 28).

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

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

Streams may diverge somewhat from these broad classifications, particularly in the area of slope. A reference "subslope class" is assigned to a reach that has a higher or lower slope than that typically associated with a reach of that type, and the class designation reflects the stream type normally associated with that slope (but in a lower case letter rather than upper case):

Subslope class	Slope
a	Very Steep: 4.0–6.5%
b	Moderate–Steep: 2.0–4.0%
c	Moderate–Gentle: <2.0%

A and B type streams (steeper slopes) are primarily expected to be sediment Transport reaches, as will be further discussed in Section 5.1.3 of this report.

- A and B type streams included 373 of 439 reaches accounting for 76.9% of total stream length included in Phase 1 assessment of the combined White and Third Branch basins (Table 7 Grand Totals, right hand column)
- B type streams included 4 of 18 reaches accounting for 18.9% of total stream length included in Phase 2 assessment; no A type streams were included.

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

- C and E type streams included 66 of 439 reaches accounting for 23.3% of total stream length included in Phase 1 assessment of the Bethel portions of the White mainstem and Third Branch basins (Table 7)
- C and E type streams included 14 of 18 reaches accounting for 81.1% of total stream length included in Phase 2 assessment of the Bethel portions of the White mainstem and Third Branch basins

Table 7. Reference Rosgen stream types included in Phase 1 (overall White and Third Branch basins) and Phase 2 (Bethel) geomorphic stream assessments in the 2013 study area.

PHASE 1 – White mainstem and Third Branch basins

	White River - Mainstem		Third Branch		Grand Total	
Stream Type	Reach Count	Stream Length	Reach Count	Stream Length	Reach Count	Stream Length
A	185	51.5%	90	53.0%	275	52.0%
B	66	26.9%	32	20.1%	98	24.7%
C	41	21.4%	19	20.2%	60	21.0%
E	1	0.2%	5	6.7%	6	2.3%
Grand Total	**293**	**100.0%**	**146**	**100.0%**	**439**	**100.0%**

PHASE 2 – Bethel - White and Third Branch basins

	White River - Mainstem		Third Branch		Grand Total	
Stream Type	Reach Count	Stream Length	Reach Count	Stream Length	Reach Count	Stream Length
B	2	22.2%	2	16.8%	4	18.9%
C	6	77.8%	7	69.3%	13	72.7%
E		0.0%	1	13.9%	1	8.4%
Grand Total	**8**	**100.0%**	**10**	**100.0%**	**18**	**100.0%**

Visual assessment of the distribution of these stream types in the Bethel area indicates a strong preponderance of the lower gradient stream types (C and E) along the White and Third Branch mainstems as well as Gilead Brook and mid-section portions of Camp Brook, with more limited opportunity for "attenuation" (storage of sediment, high flows and nutrients) on other tributary reaches of this watershed (Fig. 23). Cleveland Brook reach R12-S2.01 is an unusual stream in terms of the degree of attenuation capacity it affords despite its location in a high gradient setting and a relatively narrow valley. Locust Creek reach T3.01 is less steep but similarly offers moderate attenuation capacity in a relatively high gradient, narrow valley setting.

It should be noted that these are the "Reference" (i.e., Phase 1) conditions; Phase 2 assessments indicated that a number of these streams have departed from reference conditions and no longer fulfill the same functions in the landscape (discussed in detail in Section 5 "Results").

Reaches selected for Phase 2 assessment conducted in 2013 (Table 7 above) included a clear preponderance of lower gradient C and E type streams, an efficient approach to gathering

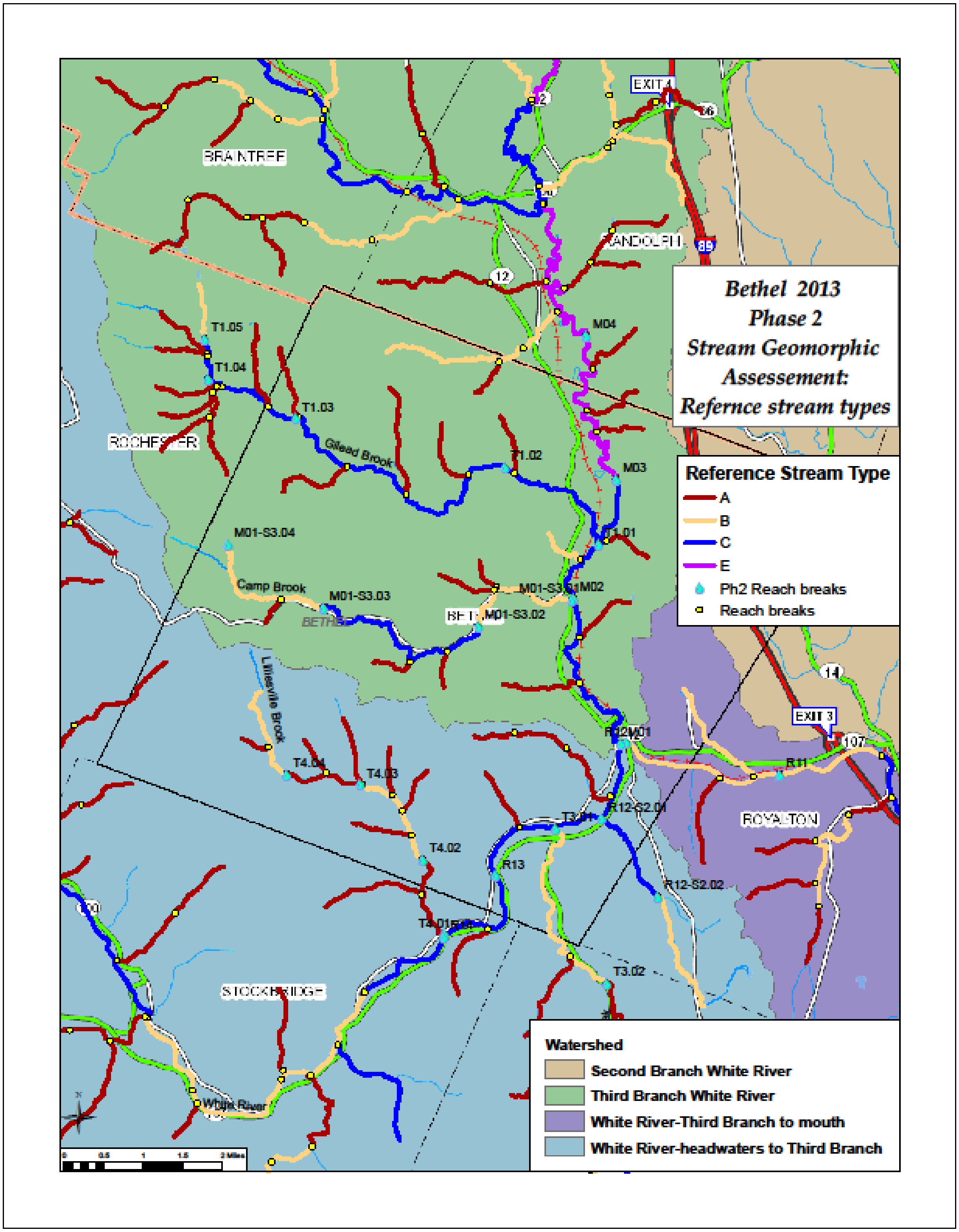


Figure 23. Spatial distribution of reference stream types in the vicinity of the Bethel Phase 2 study area indicates primary opportunities for storage of sediment, high flows and nutrients are concentrated along the White and Third Branch mainstems as well as Gilead Brook (blue and purple reaches).

information for identifying key areas for protecting or restoring the critical functions of floodplains in the Bethel area. It is important to note, however, that nearly all of the tributary reaches assessed in Phase 2 were ‘segmented’ following field assessment - an indication that other stream types were present within what was originally aggregated as a single stream type. This is primarily a matter of scale, as the smaller streams have accordingly smaller lengths of lower gradient stream (with wider pockets of floodplain) interspersed over their length.

While the 2013 geomorphic assessment work did much to identify the greatest attenuation assets and opportunities for creating more stable conditions in the watershed (concentrated along the Third Branch (especially) and White mainstems, Gilead Brook, mid-section of Camp Brook and limited portions of Locust Creek and Cleveland Brook), these scale issues can cloud identification of smaller areas of critical floodplains dispersed along Lilliesville Brook and in areas not able to be included for field assessment (Figs. 24, 25). These areas include important opportunities for floodplain protection or restoration (critical to hazard mitigation as well as a range of stream health and habitat enhancement) on steeper gradient streams that are prone to flash flooding and frequent, recurrent conflict between development, encroachment, and inevitable stream processes (particularly road damage).

Further basic geomorphic information for the reaches that were included in the 2013 Phase 2 fieldwork is included in Table 8.

Figure 24. Cross-section location on Cleveland Brook is representative of small pockets of floodplain (important “attenuation assets”) available along some of the steeper gradient small tributaries in the Phase 2 assessment area.

Figure 25. Similar pockets of floodplain on Lilliesville Brook occupied by development and infrastructure.

Table 8. Reference (i.e., Phase 1) geomorphic characteristics for reaches included in 2013 Phase 2 assessments in the Bethel, VT area (shading is just for visual separation of different tributaries).

Stream	*ReachID*	*Drainage (sq mi)*	*Valley Type*	*Channel width (ft)*	*Channel length (mi)*	*Sinuosity ratio*	*Reference Stream Type*	*Channel Sub-Slope*	*Bedform*	*Bed Material*
Third Branch and tributaries										
Third Branch mainstem	M01	136.93	VB	114.1	2.55	1.93	C	None	Riffle-Pool	Gravel
	M02	125.94	BD	110.0	2.00	1.16	C	None	Riffle-Pool	Gravel
	M03	110.09	VB	103.7	3.02	1.47	E	None	Riffle-Pool	Gravel
Camp Brook	M01-S3.01	7.64	NW	32.0	1.67	1.05	B	None	Plane Bed	Cobble
	M01-S3.02	5.78	BD	28.4	2.77	1.11	C	b	Riffle-Pool	Cobble
	M01-S3.03	2.12	SC	18.2	1.97	1.11	B	a	Step-Pool	Cobble
Gilead Brook	T1.01	13.39	BD	41.0	1.84	1.23	C	None	Riffle-Pool	Gravel
	T1.02	11.99	BD	39.1	3.85	1.10	C	None	Riffle-Pool	Cobble
	T1.03	5.43	NW	27.6	1.37	1.06	C	b	Step-Pool	Cobble
	T1.04	2.06	BD	18.0	0.66	1.77	C	b	Riffle-Pool	Gravel
White mainstem and tributaries										
White River mainstem	R11	411.74	SC	185.2	2.14	1.04	B	c	Riffle-Pool	Cobble
	R12	270.58	BD	154.0	2.90	1.00	C	None	Riffle-Pool	Gravel
	R13	238.08	BD	145.6	1.46	1.18	C	None	Riffle-Pool	Cobble
Cleveland Brook	R12-S2.01	3.50	NC	22.7	1.34	1.01	C	a	Step-Pool	Cobble
Locust Creek	T3.01	24.90	BD	53.9	2.73	1.13	C	None	Riffle-Pool	Gravel
Lilliesville Brook	T4.01	9.00	VB	34.4	1.21	1.12	C	b	Riffle-Pool	Cobble
	T4.02	6.89	BD	30.6	1.46	1.08	C	b	Riffle-Pool	Gravel
	T4.03	3.36	NW	22.3	1.04	1.01	B	a	Step-Pool	Cobble

3.4 HYDROLOGY

3.4.1 Bethel area StreamStats

Hydrology describes the movement and storage of water in and around the earth, which is subject to both natural fluctuations and human modification (Dunne and Leopold 1978). The information presented in this section deals briefly with the basis and interplay of natural fluctuations, while human modifications are discussed further in section 5.1.1, *Watershed-scale hydrologic regime stressors.*

The Bethel area is fortunate to have both long-term and short-term USGS stream gages in the vicinity. The nearest gages helpful for deriving hydrologic information in the vicinity of the Bethel 2013 Phase 2 assessment area are on the White River mainstem at West Hartford to the southeast, and in Third Branch tributary basins for Ayers Brook (Randolph) and a small unnamed tributary (draining from Braintree Hill to the Third Branch) to the north (Fig. 26). None of these gages is affected by flow regulation (dams or other). Table 9 presents a comparison of basin characteristics for these gages versus the primary basins studied in the Bethel area 2013 Phase 2 work.

Figure 26. Location of USGS stream gages in the Bethel area (http://maps.waterdata.usgs.gov/mapper/index.html)

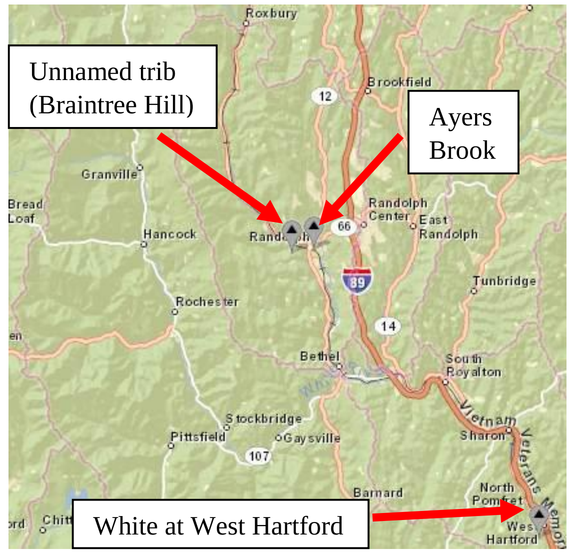


Table 9. Comparison of select basin characteristics for Bethel 2013 study basins and nearest gaged stream basins. Shaded columns are the study basins for this report.

	Third Branch	*Upper-Mid White to Bethel*	*Ayers Brook*	*Unnamed 3rd Branch trib (Braintree Hill)*	*White River at West Hartford*	units
Drainage Area	137	271	30.5	0.77	690	square miles
Main Channel Length	28.6	34.0	10.2	1.8	49.7	miles
Mean annual precipitation	40.6	51.4	40.6	39.6	43.2	inches
Mean Basin Elevation	1422	1737	1320	1200	1300	feet
Area >1200 ft. elevation	67.1	84.6	65.0	55.0	68.9	percent
Percent Forest	85	90	30	23	53	percent
Percent Lakes and Ponds	0.15	0.12	0.20	0.00	0.19	percent

An important factor of note in the comparison of these basins is the significantly higher elevation and annual precipitation levels for the Upper-Mid White basin upstream of Bethel. In addition, basin characteristics for all of these basins show relatively low levels of lakes and ponds, and other wetlands are relatively scarce in these areas as well (~0.36% of overall landcover in the White basin upstream of Bethel and ~1.01% in the Third Branch basin; note both forested and non-forested wetlands in Table 2 (land cover/land use) of this report). Lakes, ponds and wetlands can help store flow and sediment discharges in extreme weather events, and these levels indicate that such buffering capacity in the Bethel area is relatively minimal. This factor combines with the steep/dissected character of the topography (especially on the western side of the study area toward the Green Mountains), localized nature of intermittent storms, and cultural relationship to streams to predispose the area to flash flooding.

In the Burlington Weather Service coverage area (an area covering most of Vermont and portions of New Hampshire and upstate New York) 34 years of flood data (1975-2009) indicates that Windsor County (which includes Bethel) has relatively high frequency of flash flooding while Orange County, VT (which includes much of the upstream portions of the Third Branch basin) is toward the low end of total events but has the highest damage per flood event (Breitbach 2010). These data further indicate that flash floods are evenly distributed throughout the Green Mountains and Champlain Valley, while there are relatively few of these events in the Connecticut River Valley. A pattern of very localized flooding thus appears characteristic of the Bethel area, indicating the variable nature of precipitation events due in large part to orographic effects as well as a level of "flashiness" related to a variety of factors including steepness of slope, the relatively minimal buffering capacity of wetlands and other waterbodies, narrow valley widths and limited floodplain accessibility, and the effects of a variety of human influences.

The localized nature of these events is highlighted by data from nearby stream gages (further discussed below in section 3.4.2, *Bethel area flood history*), but it should also be noted that climatology data from the last 50 years (Kunkel et al 2013) indicates that the amount of precipitation falling in heavy precipitation events has dramatically increased in the northeast United States (Fig. 27).

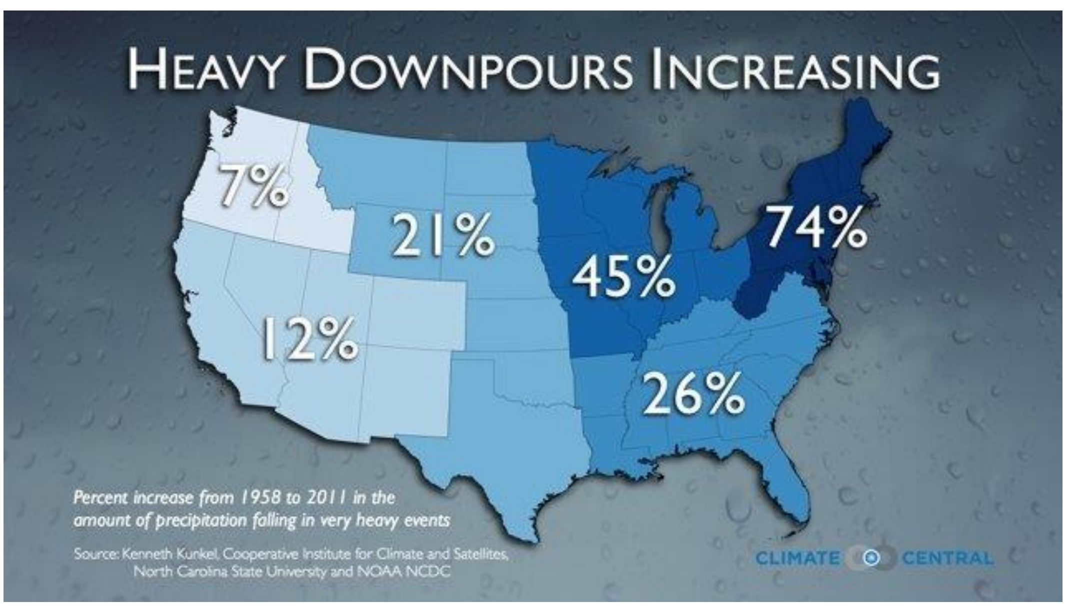


Figure 27. Climatology data from the last 50 years (Kunkel et al 2013) indicates a dramatic increase in heavy precipitation events in the northeast United States

3.4.2 Bethel area flood history

Peak flow data from the nearby USGS stream gages (Figs. 28-29) highlights important information about flood history in the Bethel area.

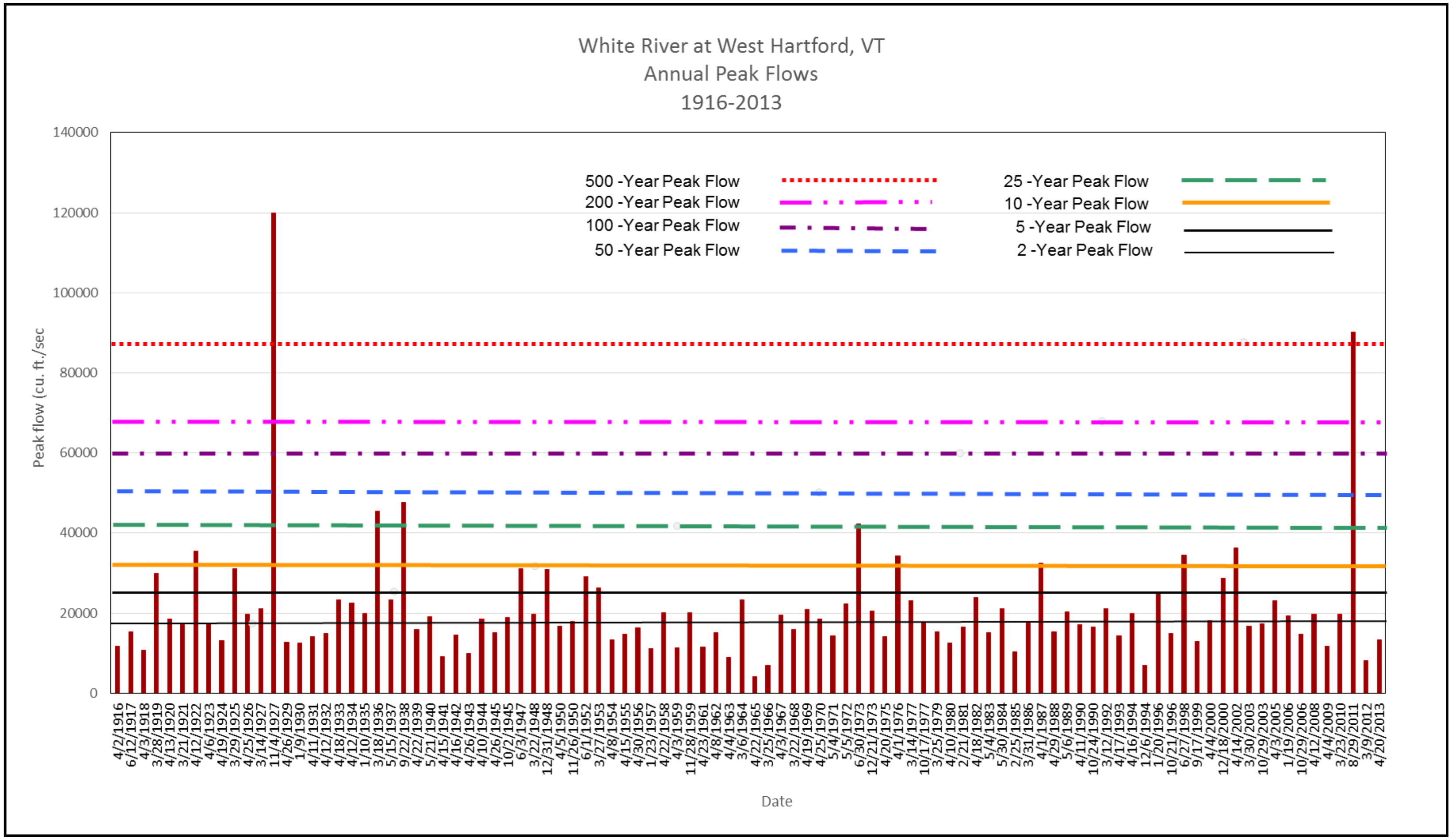
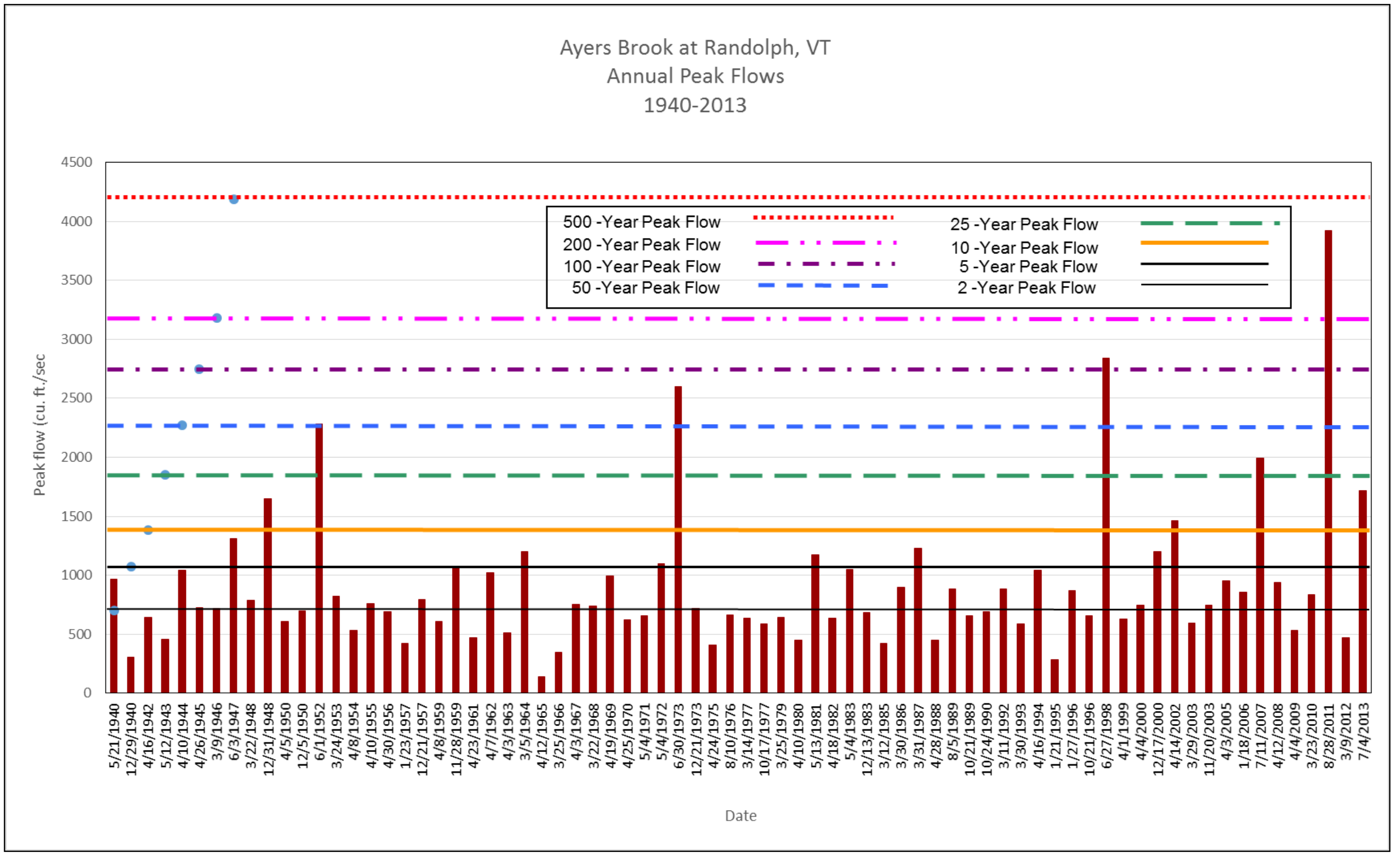


Figure 28. Annual peak flow chart for the USGS gage on the White River mainstem at West Hartford.

The gage on the White mainstem has continuous records as far back as the region-wide 1927 flood of record for the state of Vermont, and 2011 flooding accompanying Tropical Storm Irene joined that flood in exceeding the 500-year peak flow at this gage (Fig. 28; technically the flow with a .02% chance of occurring in any given year, not one that is expected to occur every 500 years). That gage also recorded major floods in 1936 and 1938 that pre-date the period of record for the Ayers Brook gage; flooding associated with the 1938 Hurricane was a widespread regional event.

The Ayers Brook and Braintree Hill gage data (Fig. 29) indicate that the primary (post-1938) region-wide major flood was in 1998; other major flood events are particular to each basin or commonly indicated at two of the gages, but not all three.



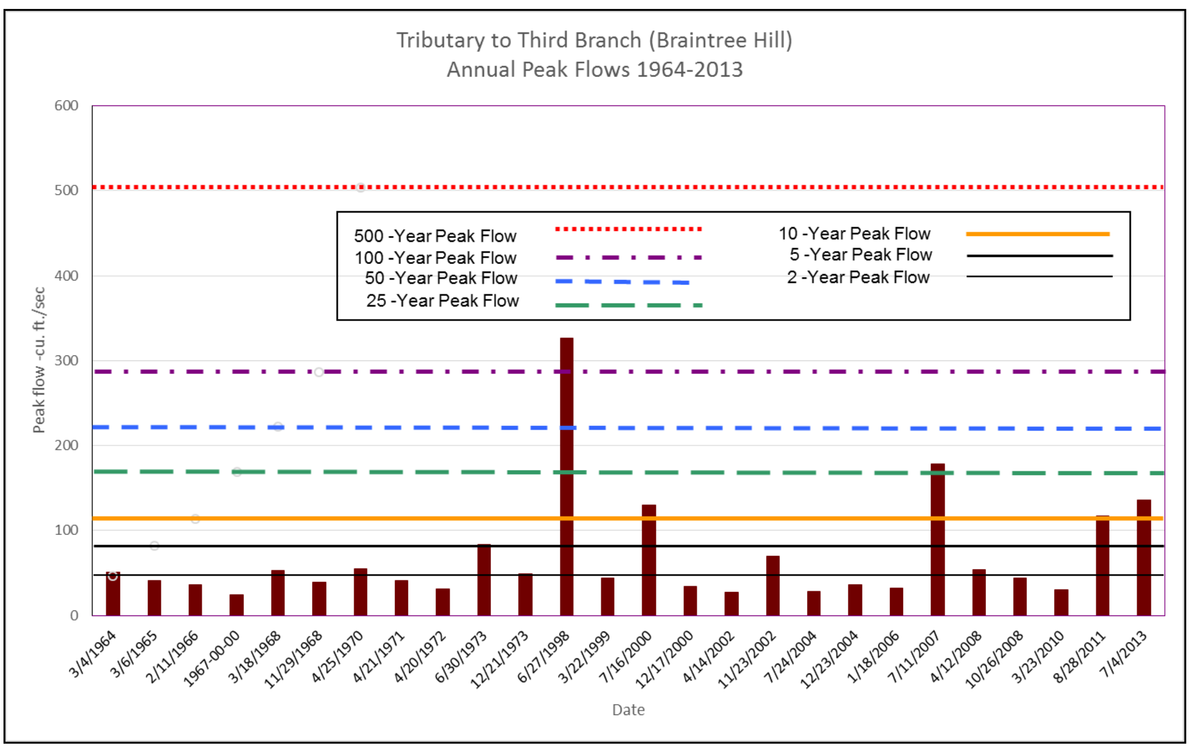
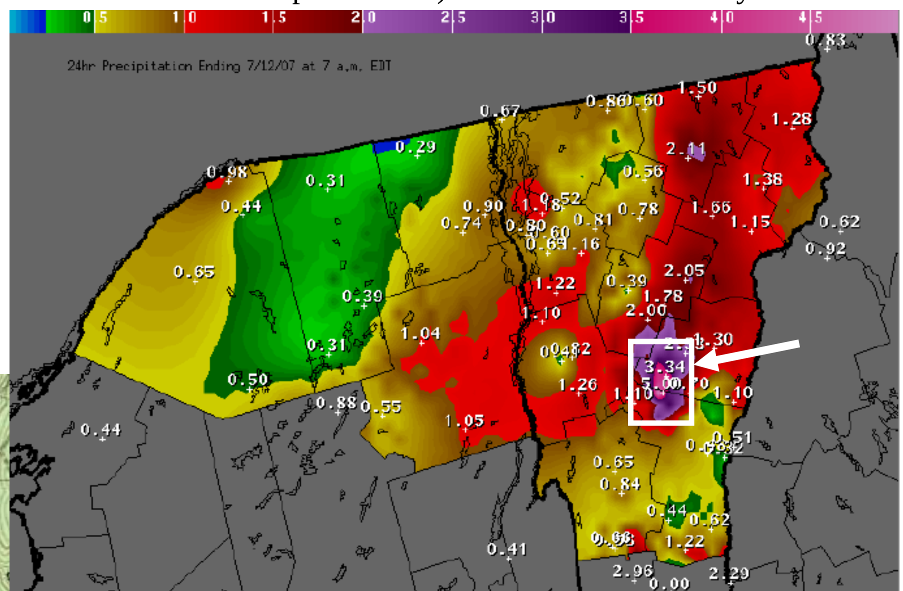


Figure 29. Annual peak flow charts for Ayers Brook and Third Branch unnamed tributary (Braintree Hill) basins.

Of particular note in terms of recent flood history in the Bethel area is that Tropical Storm Irene (August 28, 2011) barely surpassed the level of a 10-year peak flow event at the Braintree Hill gage but exceeded or approached 500-year levels at the West Hartford and Ayers Brook gages, respectively (Figs. 28-29).

Flash flooding in July 2007 hit the Third Branch basin and Lilliesville Brook hard (Figs. 30-32), exceeding 25-year peak flow levels at the Ayers Brook and Braintree Hill gages, but did not even register as the high flow of water year 2007 at the West Hartford gage - which instead came on October 29, 2006 (water years run from October 1-September 30) and was less than a 2-year peak flow at that gage.



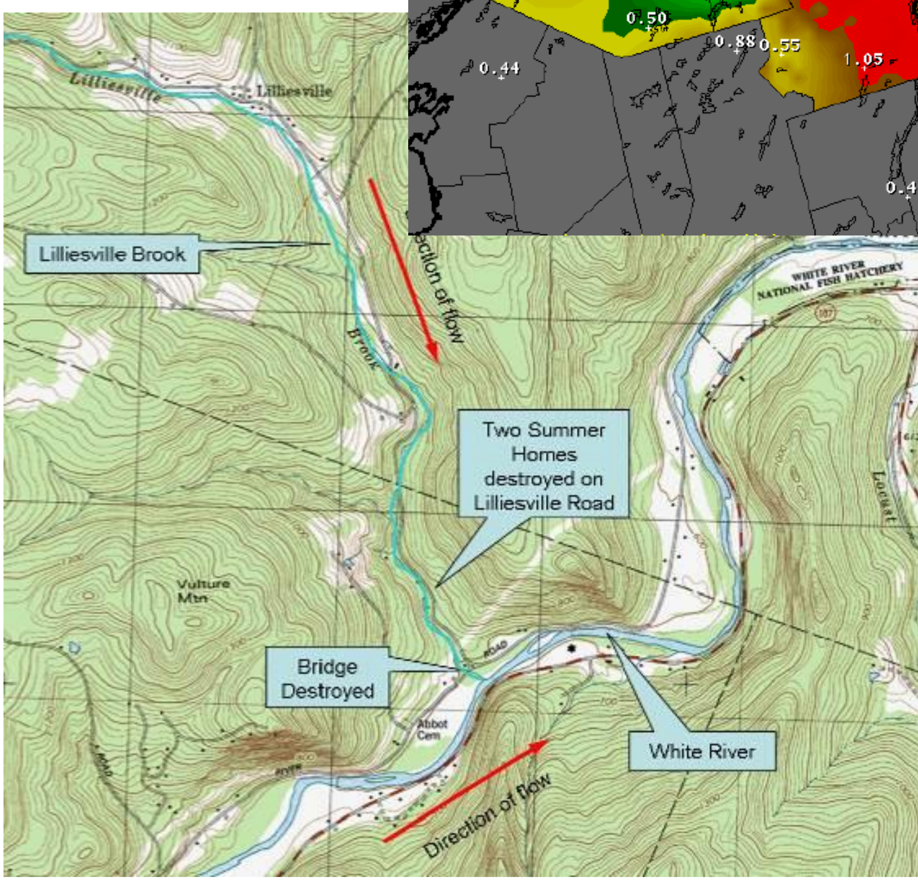
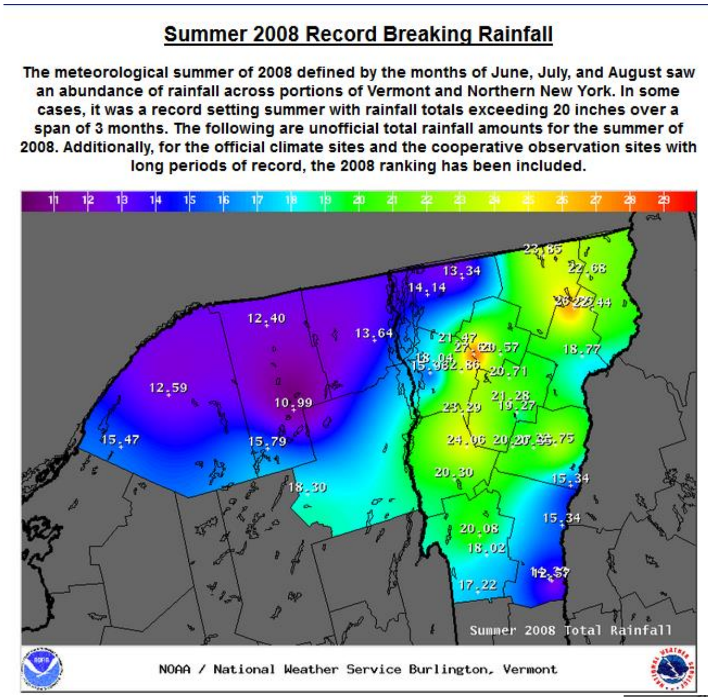
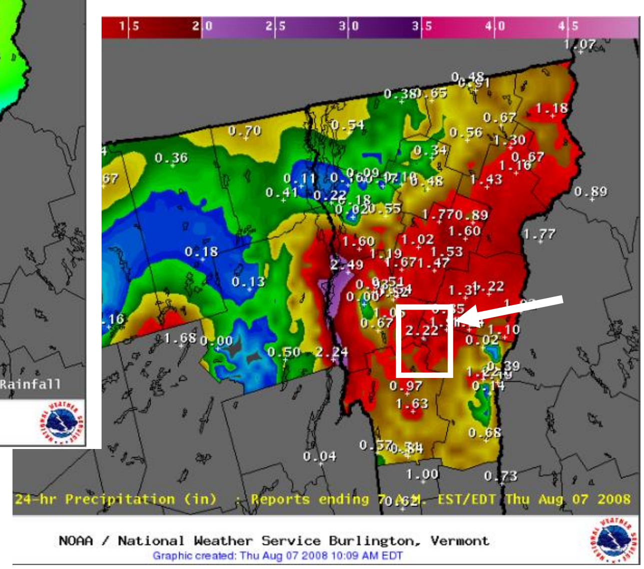


Figure 30. Graphics from the National Weather Service Burlington office Monthly Report of Hydrologic Conditions indicating the 3-5 in. downpours contributing to flash flood damage on Lilliesville Brook and much of the Third Branch basin on July 11, 2007.

Figure 31. Flash flood damage on an unnamed tributary to Ayers Brook from July 11, 2007 storms; the woman at the center of the photo is indicating the post-storm (i.e., typical) width of the stream with her arms.

Figure 32. Damage from the July 11, 2007 flash flood on Lilliesville Brook, pictured here, was followed by similar damage in this area on August 7, 2008 when an even more localized downpour of 2+ inches of rain came along with record-setting summer rainfall in much of central Vermont.





It should be noted that the flash floods that hit hard in portions of Stockbridge and Bethel (especially Lilliesville) in 2008 did not register as the peak flow for 2008, which was not even a

5-year peak flow for any of the three nearby gages (Figs. 28-29). During fieldwork for the 2013 Phase 2 SGA in Bethel one resident at the upstream end of reach T4.02 on Lilliesville Brook recounted that her area had flooded over Lilliesville Brook Rd. five times since 1973.

Despite the relatively widespread damage of Tropical Storm Irene at the end of August, 2011, this pattern of very localized flash flooding held true even in that storm, as indicated at the gage near Braintree Hill (Fig. 29 above) and in nearby basins such as the First Branch further east. This pattern of localized flooding indicates the variable nature of precipitation events due in large part to orographic effects as well as a level of “flashiness” related to a variety of factors including steepness of slope, the relatively minimal buffering capacity of wetlands and other waterbodies, narrow valley widths and limited floodplain accessibility (especially outside of the Third Branch mainstem), and the effects of a variety of human influences.

Overall, however, flood impacts from Irene in Bethel were town-wide and extensive, and the high degrees of current fluvial geomorphic instability on the streams observed during 2013 are strongly correlated to that event and will contribute to stream adjustments for a number of years to come.

Federal information concerning flooding and other natural hazards is typically aggregated at a county level and hence not specific to Bethel. With the caveat that the Connecticut River Valley region does not experience as much flash flooding (Breitbach 2010), data from Windsor County can help identify the general types of impacts experienced in the Bethel area and has been compiled for the town of Hartford Hazard Mitigation Plan (Hartford is in the Connecticut River Valley portion of Windsor County; Hartford HazMit 2013). Pertinent data reported there indicates:

FEMA (National Emergency Management Information System (NEMIS); Federal Emergency Management Agency):

Fifteen federally declared disasters occurred in Windsor County between 1969-2013 (averaging ~one event every three years), ***all of which involved flooding to some degree*** (emphasis added) . Total damage reported for Windsor County from Tropical Storm Irene in 2011 was $130.1 million, representing 65% of all reported damages over the 50+-year reporting period.

SHELDUS (Spatial Hazard Events and Losses Database for the US; Hazards and Vulnerability Research Institute 2013):

A range of natural hazards reported between 1960-April 2012 indicate winter weather as the most common event, but flooding by far and away accounts for the most reported damage. Total reported events (708): ***7.6% flooding related***; reported total damages ($199,434,797, adjusted to reflect 2012$ equivalent): ***88% due to flooding*** ($175,493,766; 2012$) (emphases added).

Two Rivers-Ottauquechee Regional Commission (which serves Bethel among its 30 member towns) has recently completed a document to help towns meet new Vermont statutory requirements for inclusion of a “Flood Resiliency” chapter in Town Plan updates going forward from 2014 (TRORC 2014) that includes more specific documentation of a number of flood events in Bethel, Stockbridge, Randolph and the surrounding area as well.

3.5 ECOLOGY

3.5.1 Distribution of instream, riparian and wetland habitats

The White River's ecology and status as the longest free-flowing, undammed tributary to the Connecticut River have long contributed to its eminence and popularity as a recreational fishing resource, contributing to a number of other key attributes that have led to proposal of the White River mainstem as an Outstanding Resource Water for recreational attributes in particular (Ryan 2013). Vermont Fish & Wildlife surveys have indicated Gilead Brook as supporting Very High Quality significant wild trout populations, and Lilliesville Brook and Locust Creek have been documented as Very High Quality Wild Trout Spawning and Nursery Tributaries to the White River main stem (Kirn 2012; Ryan 2013).

In addition, the calcareous bedrock and surficial geology in much of the study area for this report combines with ice and flow scour regimes on streams with unregulated flows to provide habitat for numerous Uncommon to Rare, Threatened and Endangered (RTE) species (Thompson and Sorenson 2000; VT-ANR Atlas 2014; Ryan 2013, esp. p. 58). Generally speaking, the White River basin has relatively limited wetland habitats, particularly of large spatial extents, but small calcareous seeps, rich fens and unusual softwood swamps along riparian areas represent some of the important biological assets of the basin (Thompson and Sorenson 2000; Ryan 2013).

3.5.2 Aquatic life

Rapid Habitat Assessment (RHA) data collected during the 2013 Phase 2 assessments indicate a heavy preponderance of scores in the 'Fair' range in the Bethel area, with 2 out of 36 stream segments assessed with an overall habitat Condition of Poor, 30 segments Fair, and 2 segments Good; none of the overall Condition assessments scored in the Reference range (Appendix 1). Factors contributing to these Condition ratings (Table 10) indicates that the primary factor contributing to low habitat condition assessments was channel morphology, in large part due to the deep incision (downcutting), both historic and more recent, which has left the large majority of the assessed streams functioning in significantly smaller floodplains and/or valleys. This condition contributes to current widening with heightened erosion, mass failures and sediment transport leading to consequent filling of pools, unstable bed features and high volumes and transport of fines in heavy precipitation events – particularly detrimental to macroinvertebrates that are an important part of the food chain in these streams.

While in many areas these scores indicate natural recovery to storm impacts from Irene, extended portions of Gilead Brook (T1) and Camp Brook (M01S3) as well as shorter sections of Locust Creek (T3) and Lilliesville Brook (T4) were heavily channelized and/or "cleaned out" of large wood in and along the stream channel. Although the heaviest channelization along the White mainstem occurred upstream of the study area for this report, instream heavy equipment work and channelization was conducted in reach R13, and a ford for heavy traffic from large trucks and other equipment was constructed at the confluence of the White and Third Branch to support reconstruction of Route 107 (further discussed in the reach descriptions for R12 and R13 in section 6.1 of this report). Phase 2 assessments on Gilead Brook during 2013 included fieldwork downstream of work for two bridge replacements, where the stream rapidly became opaque and difficult to read in bulldozed areas following workday start-ups. There was a notable contrast where the stream bed had not been disturbed (wood and larger size substrates were still present) and the stream got cloudy but not opaque. As of 2014 similar dynamics were still evident following rainstorms in the vicinity of highly channelized portions of the White mainstem, highlighting the importance of floodplain access, large wood and a variety of substrates for helping trap and stabilize sediments being transported through the stream network.

Table 10. Number of reaches/segments by Condition for parameters included in Rapid Habitat Assessment during 2013 Phase 2 assessments in the Bethel area.

	Condition (Departure from Reference)			
Assessment step and parameter	Poor (Extreme)	Fair (Major)	Good (Minor)	Reference (No departure)
6.1 Woody Debris Cover	1	15	15	5
6.2 Bed Substrate Cover		26	10	
6.3 Scour and Deposition Features	5	26	5	
6.4 Channel Morphology	18	17	1	
6.5 Hydrologic Characteristics	2	22	11	1
6.6 Connectivity	1	9	22	4
6.7 River Banks (Left)	2	21	11	2
6.7 River Banks (Right)	3	19	12	2
6.8 Riparian Area (Left)	9	11	9	7
6.8 Riparian Area (Right)	6	10	15	5

As noted in the 2012 Vermont Fish and Wildlife Annual Report (Kirn 2012),

> "…. long-term monitoring studies in Vermont indicate that, in the absence of post-flood channel alterations, wild trout populations generally recover within 2-4 years. Where aquatic habitat has been severely altered through streambed and natural wood mining, channel widening and straightening…recovery of longer reaches may take decades and will depend upon the availability and mobility of upstream sources of coarse streambed material and natural wood, as well as the magnitude and frequency of future flood events."

Large wood in the channel and adjacent riparian areas plays a crucial role throughout the basins feeding into Bethel, particularly due to the high degree of downcutting noted above as well as the naturally narrow valleys along the White mainstem and most of the tributaries, and the heavy preponderance of very fine, highly erodible sediments along the Third Branch. In these settings the large woody debris and coarse sediments retained behind down wood represent primary raw materials and mechanisms for establishing a variety of deposition and scour features as well as rebuilding access to abandoned floodplains, a dynamic that was observed post-Irene in upstream portions of Camp, Gilead and Lilliesville Brooks as well as more limited portions of downstream sections of Gilead and Cleveland Brooks.

In areas where large wood was present, and even more so in areas where ledge grade controls limited heavy equipment entry into the stream channel, there was some pool formation, relatively stable undercut banks with accompanying overhanging vegetation, and a variety of substrates. Toppling trees were observed helping stabilize mass failures along steep valley walls and contributing to step formation and fine sediment retention. These dynamics were encouragingly present in at least intermittent portions of most the assessed streams, but the heavily channelized sections of stream noted above are currently lacking these materials in any accessible distance to the stream where they might become available for these dynamics in future high water events. The most striking example of these issues during 2013 assessments was in segment T1.02C of Gilead Brook where a dead 5-inch brook trout was found lying in an extremely over widened, shallow portion of the stream with no pools; although there was no way to confirm the cause it appeared likely this was due to shallow water, lack of refuge and overheating - there were no signs of visible trauma.

In bulldozed portions of Camp, Gilead and Lilliesville Brooks (as well as smaller portions of Locust Creek) neither substrate nor wood is easily available to the stream, enormously prolonging the timeline of potential channel evolution and stabilization. These areas would greatly benefit from active restoration efforts to make these materials available to the stream again and ensure that bridges and culverts are adequately sized to pass sediment, wood and water and limit the "hourglass effect" of undersized structures. These issues are accentuated by the documented significance of these same streams as Very High Quality streams for wild trout populations and/or wild trout spawning and nursery areas.

The importance of large wood for stream stability and dynamics in the Bethel area, particularly due to extensive downcutting through highly erodible sediments (and consequent loss of floodplain access) should be emphasized. Even in areas that were not bulldozed, much of the large wood entering the stream channels in the narrow valleys of the study area has been "snagged" (removed) due to conflicts (both real and perceived) with undersized stream crossing structures. Following Irene personnel from the Green Mountain Forest District of the USDA Forest Service documented a number of recently installed culverts, sized at 100 percent stream bankfull width or larger, that sustained no damage during Irene despite having had to pass significant amounts of large woody debris and coarse sediments (Kirn 2014). Because these culverts were sized this large, they limited the "hourglass effect" associated with undersized structures (Fig. 33) that tends to funnel and accumulate sediment and woody debris just upstream of a structure, while downstream of the structure the heightened stream power of "tailwater" being accelerated after being forced through an undersized opening tends to cause amplified erosion that typically is controlled with bank armoring.

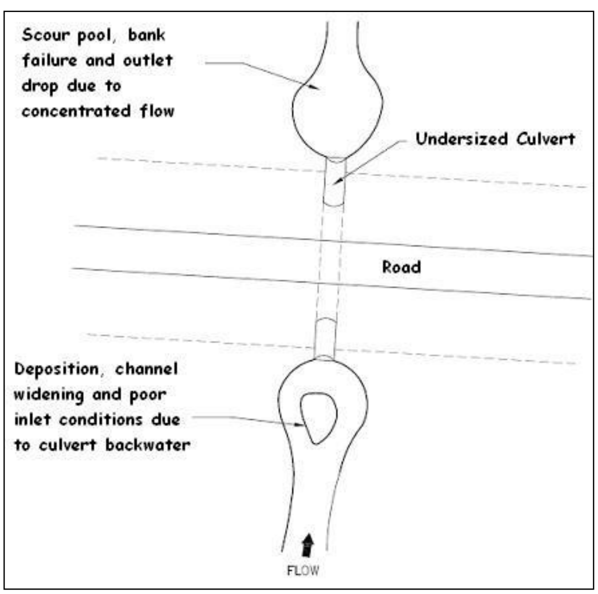


Figure 33. "Hourglass effect" at undersized stream crossing structures tends to accumulate sediment and woody debris in an over widened channel just upstream of the undersized opening, while scour due to heightened erosive power of "tailwater" forced through the structure overwidens the channel just downstream (Kirn 2014; Bates and Kirn 2009).

3.5.3 Unique plant and animal communities

The undammed status of the White mainstem combines with the distinctive geology of both the White and Third Branch basins to provide the backdrop for an area with strong contributions to biodiversity (BioFinder 2014), with the streams of the 2013 study area for this Corridor Plan all identified with Very High to Greatest Contributions to biodiversity.

Two Rare (one insect, one plant), two Threatened or Endangered (both plants), and 3 Uncommon species (one insect, two plants) as well as two Significant Natural Communities (Sugar Maple-Ostrich Fern Riverine Floodplain Forest and Spruce-Fir-Tamarack Swamp) have been documented in the 2013 study area for this report. The Sugar Maple-Ostrich Fern Riverine Floodplain Forest extends in patches along much of reach M03 on the Third Branch, included in this study and characterized by an unusually high diversity of both trees and herbaceous species, as well as more of the Third Branch extending north to the Village Floodplain Forest in Randolph to encompass nearly 6.5 miles accompanied by this Significant Natural Community.

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

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

Phase 2 involves rapid assessment fieldwork to inform a more detailed analysis of adjustment processes that may be taking place, whether the stream has departed from its reference conditions, and how the river might continue to evolve in the future. This sometimes requires further division of ‘reaches’ into ‘segments’ of stream, based on such field-identified parameters as presence of grade controls, change in channel dimensions or substrate size, bank and buffer conditions, or significant corridor encroachments. The data collected in Phase 2 also help identify the inherent sensitivity to changes in watershed inputs of a given stream segment, and these data can be used to map and classify Fluvial Erosion Hazard zones (VT-RMP FEH 2010; VT-RMP RCProtect 2008). River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology. Phase 3 involves detailed fieldwork for projects requiring survey and engineering-level data for identification and implementation of management and restoration alternatives.

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

4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS

VT-RMP is committed to providing watershed groups, towns, regional planning commissions, consultants and other interested parties with technical assistance and shares responsibility for a thorough quality assurance/quality control (QA/QC) procedure for data collected in geomorphic assessments. Checks were initially conducted by Redstart personnel utilizing the QA/QC tools developed by VTANR and implemented through the online Data Management System. Documentation of these quality control checks is maintained within the DMS as well. Further review by both RMP and Redstart personnel were cross-checked to verify integrity of the data, and this iterative process was completed in April 2014; further documentation of that process can be found in Appendix 5. General questions about data collection methods can be answered by referencing the SGA Protocols (VT-RMP 2009).

Phase 1 data analysis was originally done for the overall White River watershed from 2001-2005 and lumped the entire Third Branch basin as a single subwatershed. In 2013 the Third Branch was broken out for further analysis and broken into smaller subwatersheds. Primary ramifications for this report:

Phase 1 valley confinement types (Table 8 in Sec. 3.3.3) for Camp Brook (M01-S3) and Gilead Brook (T1) are based on field-measured valley widths (laser range finder), which are done on a per-segment basis, and estimated to best represent the overall reach confinement (over all segments) – in all of these cases these were based on the Confinement Type for the longest segment.

The subwatershed for White mainstem reach R11 originally included the entire drainage of the Third Branch. Data represented in the mapped polygon for a much smaller, stand-alone subwatershed for R11 likely overestimates agricultural land and underestimates ‘urban’ landuses.

Additional data qualifications for the Bethel 2013 SGA concern representational cross-section data collected for stream segments in the assessment area, specifically regarding the “bankfull” and “recently abandoned floodplain” indicators used to calculate incision ratios.

Tropical Storm Irene moved through the basin (and the rest of Vermont) in August 2011, not quite two years before the Bethel area Phase 2 Stream Geomorphic Assessment (SGA) was initiated. The impacts of Irene were dramatic, and high water levels clearly exceeded the levels of typical “bankfull flows” (the statistical “2-year peak flow” or “channel-forming flow”), and in some areas significantly obscured typical ground-based evidence of these flow levels (VT-RMP_ApxI 2009). Summer 2012 was very dry, and typical bankfull flows (which would re-establish these indicators in areas where they had been obscured) did not occur again until mid-summer 2013; channel adjustments were still unfolding at a relatively rapid pace but indicators of more typical bankfull flows were beginning to re-establish. What was clear, however, was that the impacts of Irene had included significant stream incision (downcutting) in most of the assessment area, due in large part to the highly erodible geologic materials and relative lack of ledge grade controls.

These impacts were strongly felt in narrow, extremely steep-walled valleys; areas lacking woody buffers along streambank areas where x-sectional measurements were taken (especially lower mainstem reaches with highly erodible banks); in highly channelized reaches on Gilead, Camp and Lilliesville Brooks; and in stream segments downstream of areas impounded by beavers (upstream portions of Camp and Gilead Brooks). All cross-sectional areas were thus checked against predicted bankfull widths derived from hydrologic curves (based primarily on watershed area draining to the point the cross-section was located, VT-RMP_ApxJ 2009; Olson 2002) and interpolated with the field-recorded measurements to help interpret bankfull widths and incision ratios where clear indicators were lacking.

The timing of floodplain abandonment (as represented by incision ratios and frequently noted in the field as a series of terraces along the sides of the stream) in the Bethel area is a related facet of this data qualification. High terraces along the sides of relatively narrow valleys are widespread in these basins and in many cases are related to geologic features formed during glacial retreat in “ice-contact” areas. Streams clearly have cut further through these highly erodible materials during the last 200 years, contributing to “historic incision”, but the degree to which the abandonment of former floodplains on these high terraces is “historic” or “post-glacial” can be hard to determine with any surety. The highest incision ratios may be measured in relation to some of the post-glacial features.

In regards to these data qualifications, the primary values of the incision ratios reported here are as indicators of the degree to which the streams of the basin have lost access to former floodplains regardless of when the timing was.

Significant sediment loading following Irene was particularly evident at the bases of numerous tributaries and gullies on valley sidewalls along Camp Brook (M01-S3), Gilead Brook (T1), and Lilliesville Brook (T4) in particular. This study was limited in available time for surveying the sources of these sediments, but in areas where gully formation has been initiated due to stormwater outlets related to road ditches and/or agricultural ditching it may be possible to address future excess sediment loading (and loss of valuable soils) at concentrated discharge points. Surveying such areas off Little Hollow Rd. and the fourth class section of Gilead Brook Rd. (right valley wall above Gilead Brook reaches T1.03 and T1.04), Whittier Rd. (upstream end of Lilliesville Brook reach T4.01), Pond Rd (upstream end of Camp Brook reach M01-S3.02) and the upstream end of Gilead Brook reach T1.01 and downstream end of reach T1.02 (Messier Rd., Winterberry Ln.) may be priority areas based on observations of sediment loading along the main channels. The White River Partnership has conducted 4th class road inventories in other portions of the White River basin that may serve as a good model.

5.0 RESULTS

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

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

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

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

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

5.1 DEPARTURE ANALYSIS

5.1.1 Hydrologic regime stressors

The net effect of precipitation patterns and hydrologic regime stressors in much of Bethel contributes to high volumes, rates and intensity of water discharges in heavy precipitation events. Limited access to floodplains amplifies these effects in most tributaries, and cumulative impacts of basin-wide discharges concentrate in Bethel as it sits at the downstream end of the Third Branch and Upper White mainstems. The primary drivers of these impacts appear to be a high degree of straightening and encroachment that has contributed to floodplain loss (particularly in areas where road and railroad encroachments significantly reduce available floodplain widths) in combination with naturally narrow valleys on most of the tributaries and the White mainstem; relatively steep gradients on many tributaries; and orographic effects contributing to very heavy localized downpours.

The hydrologic regime involves the timing, volume, and duration of flow events throughout the year and over time; as addressed in this section, the regime is characterized by the input and manipulation of water at the watershed scale. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, an impacted stream will adjust morphologically (e.g., enlarging through either downcutting or widening when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches (Kline 2010). The primary morphologic change noted in Bethel is a high degree of channel incision (downcutting), with multiple terraces evident alongside the stream (indicating a history of successive floodplain abandonment) in most of the assessment area. Although much of this channel incision appeared to be historic, impacts from Tropical Storm Irene close ahead of the Bethel 2013 fieldwork significantly amplified these channel adjustments.

Historic deforestation that occurred throughout much of Vermont starting in the late 18th century provides a “backdrop stressor” on the hydrologic regime. Eastern portions of Bethel appear to have experienced similar historical dynamics as much of Vermont, with heavy deforestation during the 19th century peaking roughly in the 1840s-70. Steeper portions of the hilly terrain in this area, in combination with the much steeper terrain approaching the foothills of the Green Mountains on the western side of town, were less amenable to agricultural endeavors and this factor likely kept the level of town-wide deforestation lower than overall estimations of 70%

deforestation statewide (Thompson and Sorenson 2000; Cronon 1983; UVM Landscape Change 2011); much of the town was regenerating second-growth forest in the early 20th century (Town of Bethel 2012). As noted in section 3.1.3 of this report, Land use and general characteristics, the early 21st century finds the Upper-Mid White basin more than 90% forested, and the Third Branch basin nearly 85% forested. Despite this relatively high degree of forest cover, however, there are other factors in that contribute to a high degree of "flashiness" in these basins.

Historical clearing initially contributed to higher runoff of both water and sediment (Marsh 1848, p. 253). While this situation tended to diminish with reforestation, it is likely that the initial downcutting and transport of sediment out of uplands extended the stream network, initiating or furthering channel formation in areas that formerly had a broader absorptive base, and deposited thick layers of sediment in the valleys. Streams have cut back down through these sediments over time, restricting access to historic floodplains and requiring widening and planform adjustments to establish new floodplains at a lower elevation.

Due in large part to the geologic legacy of glacial Lake Hitchcock (see Sec. 3.2, *Geologic setting*, of this report) and patterns of glaciation and glacial retreat, many portions of the 2013 study area exhibit extremely deep soils with few grade controls to limit downcutting. Recent impacts from Tropical Storm Irene essentially initiated another round of the cycle of downcutting and transport of sediment out of uplands, with deep incision and gully formation observed in narrow valleys of upland tributaries as well as more localized scour in narrow portions of the lower elevation mainstem reaches. While this effect was at first glance more noticeable in the bed scour along the mainstem White reaches due to the narrower valleys there than along the Third Branch, deep bed incision was noted on the Third Branch as well – evidenced there by deep scour pools immediately downstream of sediment "slugs" with steep faces. Due to the very fine sediments on the Third Branch, both the bed and sediment deposits are highly mobile and were "washing out" quickly in high flows - typically transporting large amounts of fines and dramatically increasing turbidity levels following heavy rains. A number of historically disconnected oxbows along the Third Branch mainstem reaches on the "back side" of the railroad tracks from the current channel location (visible in aerial photography and on topographic maps) as well as very high banks along most of the mainstem indicate that high flows are currently contained within significantly reduced floodplains there as well as along the more naturally confined mainstem of the White in the Bethel area. The net effect at the current time is an overall pattern of deeply entrenched streams, with stream flows tending to cut down into erodible beds while contained within vastly reduced floodplains and typically only accessing historic floodplains at very high level flood flows.

A large part of the high degree of current entrenchment of streams is due to historic incision through the highly erodible geologic materials in these basins, a factor also influenced by mill history in the area. Flow regulations are not a significant contemporary contributor to changes in water inputs in the Bethel region, but historic mill sites are indicated on 1856 (Doton), 1860 (Walling) and 1869 (Beers) maps on Gilead, Camp and Lilliesville Brooks as well as at the base of Locust Creek and on the White mainstem just downstream of Bethel in Royalton. Only one dam (Bethel Mills) currently exists in the study area and has a fairly small impoundment above it

(VT-DEC 2009). Flow regulation at mills usually included water storage and release for mill use that contributed to “pulse” flows. The combination of an intermittent increase in stream power and “sediment starving” at dams contributes to “hungry water”, a phenomenon that may help explain some of the historic channel incision (also referred to as downcutting or degradation of the channel) and/or channel widening in these areas.

In addition to straightening and loss of access to historic floodplains in the Bethel area, the Hydrologic Alterations map (Fig. 34) indicates primary stressors commonly associated with stream channel adjustments (Kline 2010, pp. 26-27). Stormwater inputs exceed “high” levels of >5 inputs/stream mile on a third of the stream segments walked in 2013, all located on and including at least some portion of each of the tributary reaches (highest impacts on Camp, Gilead and Lilliesville Brooks, lower but significant on Locust Creek and Cleveland Brook). These inputs were primarily road inputs, although there were also indications of historic ditching along agricultural fields on both the White and Third Branch mainstems as well as Gilead Brook. “Urban” and “crop” land use does not exceed “low” levels of impacts at a subwatershed level in any of the study area, although both “urban” and “crop” land uses are rated “high” impact in reach M01 (Bethel village) on the Third Branch and segment T1.01B (near Rte. 12) on Gilead Brook. “Urban” land use is rated “high” in portions of the stream corridors along each of the tributaries included in 2013 fieldwork as well, often in the vicinity of historic village settlements (Bethel-Gilead, Camp Brook, Lilliesville, Lympus).

“Urban” land uses tend to increase the amount of impervious surface in a drainage basin, and crop land lacks the buffering capacity of trees that both physically intercept precipitation and transpire some degree of moisture (the latter factor is easily observable in the difference between streams that drop within hours after a summer rainfall vs. streams that can stay at high levels for a day or two following a rainfall after deciduous trees’ leaves have fallen). Both factors can contribute to more rapid delivery of water to the stream network, as further discussed below in relation to additional land use/land cover stressors.

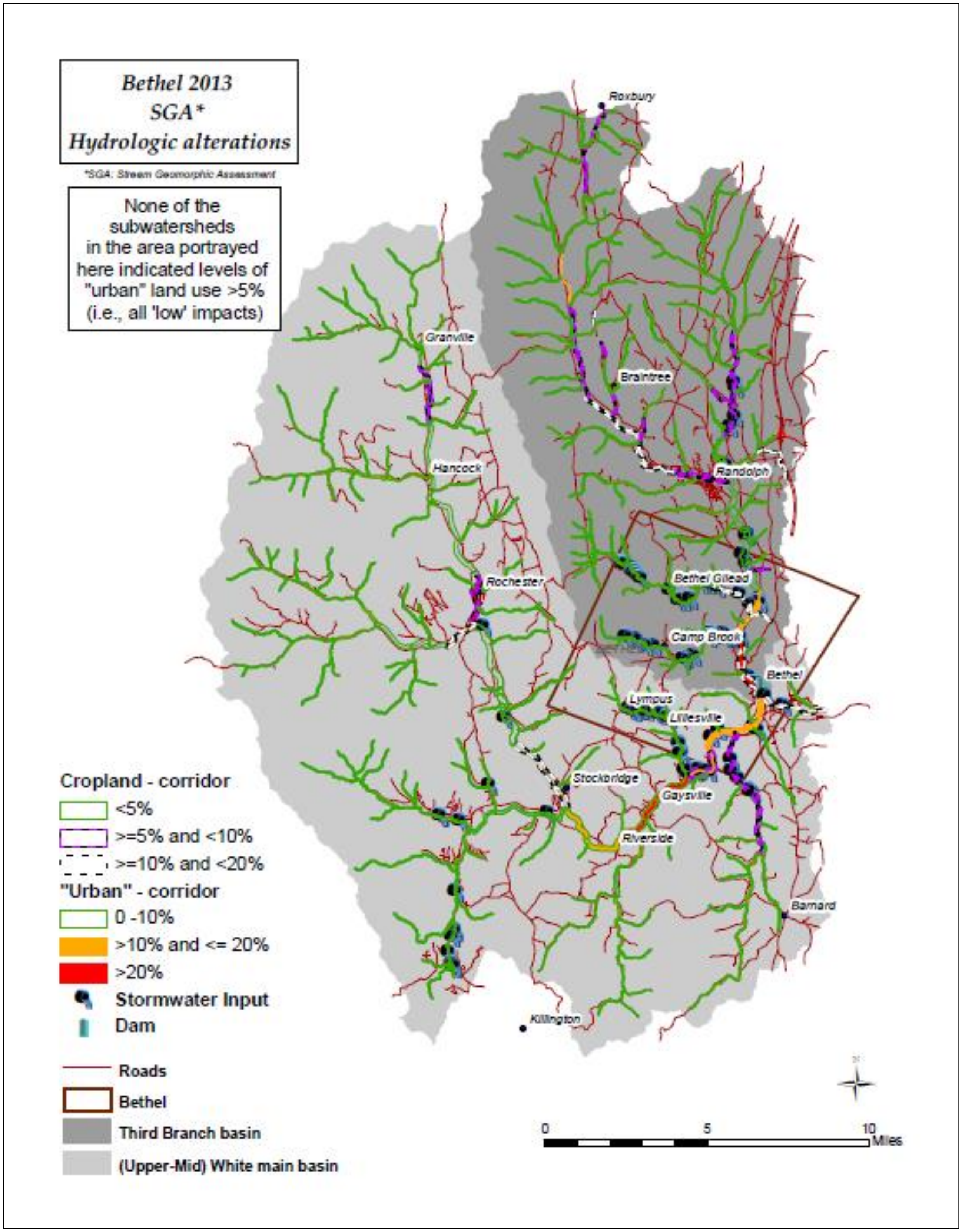


Figure 34. Hydrologic Alterations map for the basins feeding into the Bethel 2013 study area.

Many of the fields, roads and "urban" land uses in the stream corridors of the Bethel area are accompanied by ditches. In the Bethel area road density exceeds "high" (5-6 mi. rds./sq. mi. basin area) or "very high" (>7 mi. rds./sq. mi. basin area) levels in subwatersheds for White mainstem reaches R11 and R12 and Third Branch mainstem reach M01 (Bethel village), Locust Creek reach T3.01, Camp Brook reach M01-S3.02 (Camp Brook village) and Gilead Brook reach T1.02 (Bethel-Gilead) (Fig. 35). With the increasing ubiquity of heavy equipment, it has become more cost-effective to expand road ditching rather than continually repair roads from the damages of heavy frost heaving and washouts. Expanded ditching exacerbates the "flashy" nature of these basins by increasing the rate and intensity of water delivery to the streams. Careful attention to directing these surface water inputs to well vegetated surfaces can help mitigate the effects of direct surface water inputs to streams, and increasing retention and opportunities for water to percolate through uncompacted soils before entering the streams addresses observations penned by George Perkins Marsh in 1864:

> "…the accumulation of water in the channel of a river depends far less upon the quantity of precipitation in its valley, than upon the rapidity with which it is conducted, on or under the surface of the ground, to the central artery that drains the basin." (Marsh 1864, p. 182)

Drainage societies ditched many agricultural areas in Vermont during the 19th century, and these ditch systems were maintained and/or expanded well into the 20th century (Kline 2010, p. 28). Some of these ditch networks are still maintained and/or expanded on a more limited basis, as was evident during 2013 fieldwork on the Third Branch, Gilead Brook and White mainstem in particular; ditch networks are easily observable on aerial imagery of these areas and frequently coincide with straight hedgerows running through fields and draining into these streams.

Possible wetland loss (and accompanying loss of the buffering capacity of these wetlands, which further contributes to the "flashy" nature of the stream network in heavy downpours) is indicated where "urban" land uses (including road networks) and agricultural lands intersect existing wetlands or hydric soils (Fig. 35). Due to the generally limited extent of wetlands and hydric soils in the Bethel area these impacts do not appear highly significant in the 2013 study area, but moderate levels of contributory impacts may be indicated in Lilliesville (reach T4.02 of Lilliesville Brook), as well as lower level impacts in Bethel village (reach R12 on the White mainstem and M01 on the Third Branch) as well as further upstream on the Third Branch (reach M03; Table 11).

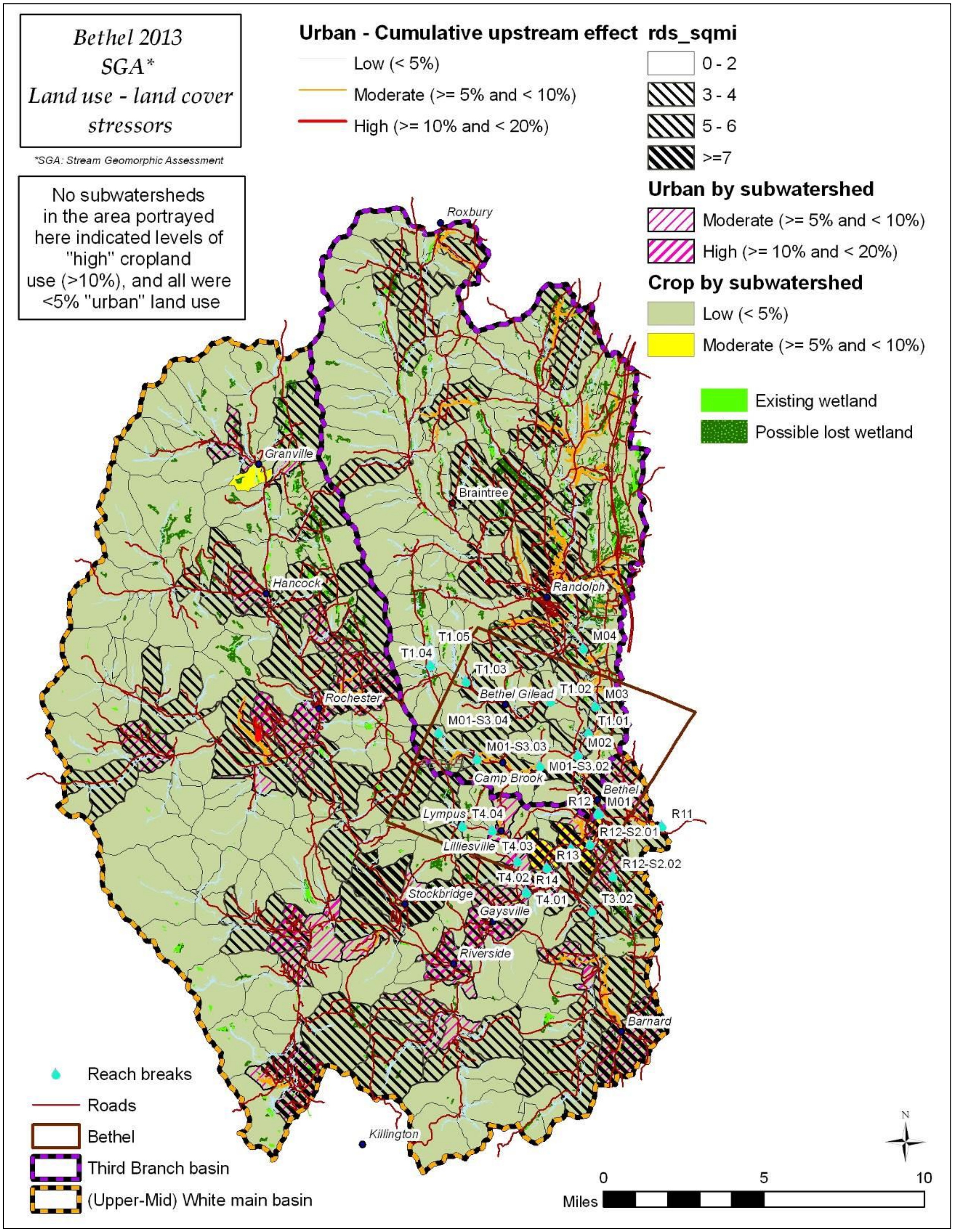


Figure 35. Land use-land cover stressors map for the basins contributing to the 2013 Bethel SGA study area.

Table 11. Hydric soils as a percentage of overall land cover in subwatersheds and stream corridors of the Bethel area, with "urban" and agricultural land use intersections with hydric soils that indicate potential loss of wetlands and their accompanying buffering capacity. Tan highlights indicate low-moderate levels of concern for "flashiness" in heavy downpours, orange indicates moderate concern (though concern levels currently have no scientifically validated thresholds).

	Subshed				corridor			
ReachID	Hydric pct	Urban pct of hydric	Ag pct of hydric	Urban-Ag-hydric pct of total	Hydric pct	Urban pct of hydric	Ag pct of hydric	Urban-Ag-hydric pct of total
M01	3.49%	13.35%	13.34%	0.93%	15.70%	9.00%	11.73%	3.25%
M01-S3.01	0.45%	0.00%	0.00%	0.00%	0.00%	NA	NA	NA
M01-S3.02	1.98%	35.30%	0.29%	0.70%	0.00%	NA	NA	NA
M01-S3.03	4.67%	1.25%	0.66%	0.09%	6.99%	0.00%	0.00%	0.00%
M02	1.46%	4.69%	17.58%	0.32%	0.00%	NA	NA	NA
M03	7.13%	6.30%	18.48%	1.77%	7.02%	0.00%	35.80%	2.51%
R11	0.03%	19.90%	28.78%	0.01%	0.00%	NA	NA	NA
R12	1.59%	10.93%	35.70%	0.74%	3.79%	24.90%	63.99%	3.37%
R12-S2.01	6.18%	0.00%	9.89%	0.61%	0.67%	0.00%	0.00%	0.00%
R13	0.64%	32.22%	3.38%	0.23%	2.58%	32.22%	3.38%	0.92%
T1.01	0.68%	0.14%	16.41%	0.11%	0.48%	0.00%	44.70%	0.21%
T1.02	0.31%	0.00%	0.00%	0.00%	0.00%	NA	NA	NA
T1.03	3.31%	7.02%	24.83%	1.05%	0.00%	NA	NA	NA
T1.04	2.22%	1.71%	0.25%	0.04%	21.58%	0.00%	0.00%	0.00%
T3.01	1.82%	3.61%	0.30%	0.07%	0.00%	NA	NA	NA
T4.01	1.05%	50.28%	2.39%	0.56%	9.63%	47.72%	2.81%	4.87%
T4.02	10.47%	73.24%	0.00%	7.67%	1.43%	24.92%	0.00%	0.36%
T4.03	3.90%	0.00%	0.00%	0.00%	0.00%	NA	NA	NA

5.1.2 Sediment regime stressors

With the impacts of Irene shortly ahead of the 2013 assessment work in Bethel, the combination of hydrologic regime stressors noted in the previous section combined with watershed-scale sediment regime stressors to leave the streams of both the White and Third Branch basins in a state of current instability and ongoing channel adjustments typically characterized by redistribution of "sediment slugs", including dynamics succinctly summarized in a presentation by geologist George Springston and colleagues:

"Summary of Geomorphic Impacts

- Tremendous volume of sediments stripped from steep, eroding tributaries.
- Along mainstem scour was generally greatest where valley most constricted.
- In less-constricted reaches floodplains and low terraces overtopped, leaving behind extensive gravel and sand deposits and masses of woody debris.
- Impacts intensified at bridges, culverts.
- Adjustment processes triggered by Irene will take many years to play out."

(Springston et al 2013)

At a watershed scale, overall sediment load in Bethel includes widespread distribution of relatively high levels of depositional features such as mid-channel bars, steep riffles, and areas of "braiding". Following Irene, the only areas where these types of depositional features were not found at "high" levels (>5 depositional features/mi.) were on mainstem reaches M02 and M03 (Third Branch) and R11 and R12 (White mainstem). These reaches had 'moderate' rather than 'high' levels of sediment loading in the channel, but all had heavy deposition on the floodplains outside of the main channel (Fig.36).

Figure 36. Although mainstem reaches of the White and Third Branch had only "moderate" levels of sediment loading in the channel following Irene, these areas had heavy deposition on the floodplains-as evident in this September 2011 view up the White mainstem west-southwest of Bethel. National Fish Hatchery outlined in green at top of photo was covered with heavy sediment as well.

Widespread distribution of sediment load indicates the effects of channel widening and planform adjustments in upstream portions of these watersheds as well as extensive erosion along the mainstem reaches of the Third Branch, with extensive mass failures particularly evident in upstream portions of the tributaries and along the valley walls of narrow reaches (Fig. 37). Tributary rejuvenation, a large-scale process elevating sediment loads that occurs when stream beds incise and the base elevation of tributary streams down-cut to match the receiving stream, was also evident in most of the study area.

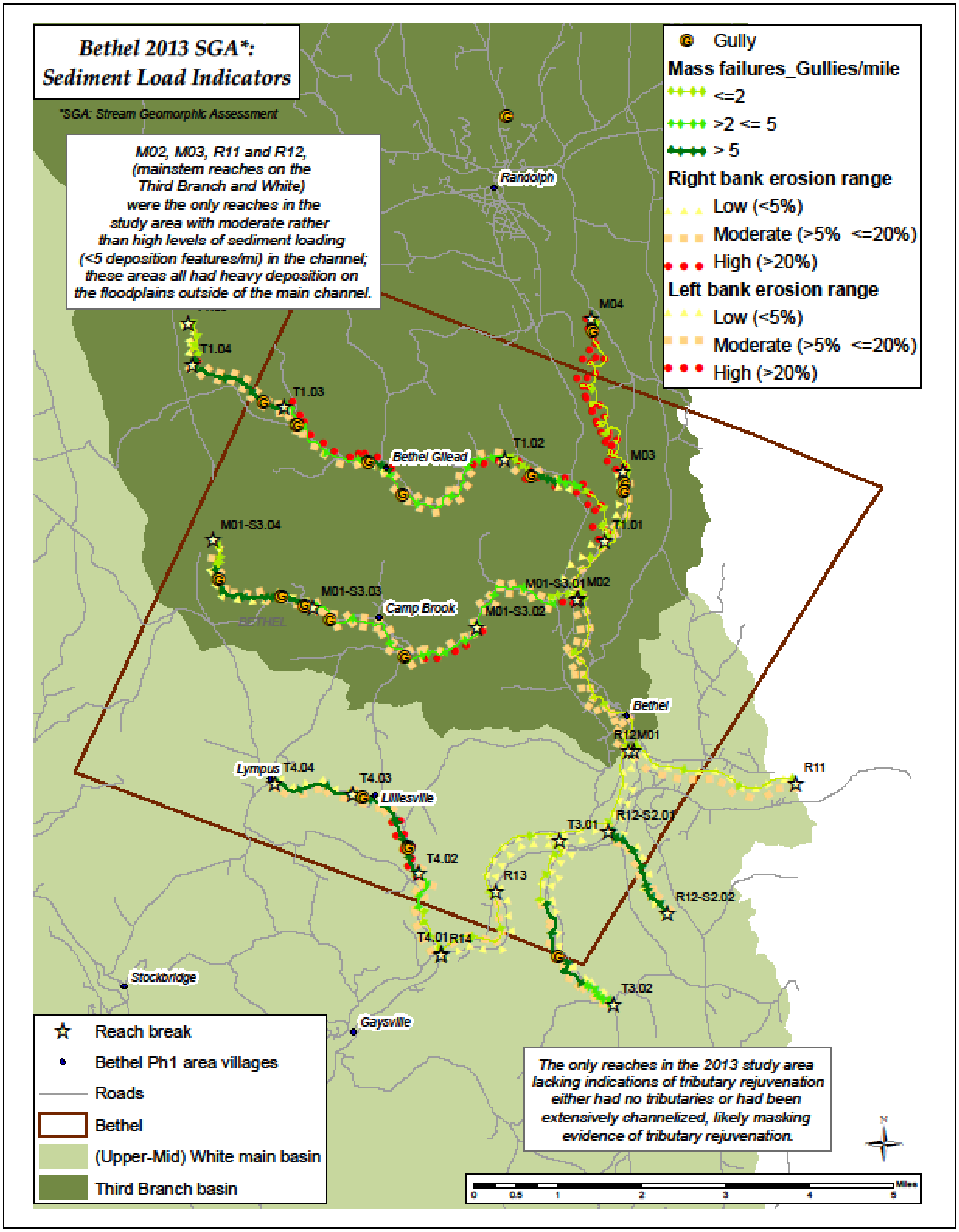


Figure 37. Sediment load indicators map for the 2013 Bethel study area.

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

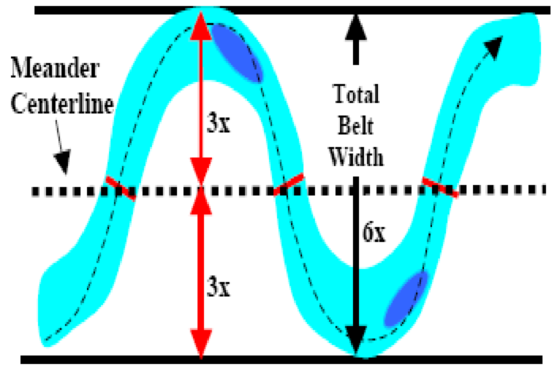
> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments….sediment erosion and deposition patterns, unique to the equilibrium conditions of a stream reach, create habitat. In all but the most dynamic areas (e.g., alluvial fans), they provide for relatively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

Many of these processes typically unfold over a time period of decades, with the "channel-forming" flows necessary to continue re-distribution of sediments (and other channel adjustments contributing to channel evolution toward greater stability) only occurring at 1.5 – 2-year intervals or even longer. During Irene numerous areas underwent rapid scour followed by heavy deposition and ***channel elevations actually rose and rebuilt access to historically abandoned floodplains in a single event*** in several areas of the narrow valleys in upstream portions of each of the tributaries as well as the downstream portion of Gilead Brook (segment T1.01A). In areas where large woody debris and coarse sediments have remained within the channel and adjacent accessible floodplains, channel adjustments such as rebuilding of floodplain access (Fig. 38) and establishment or extension of channel meanders (increasing channel sinuosity and thus decreasing channel slope; Fig. 39) occurred rapidly in Irene.

Figure 38. In narrow valleys where wood and sediment are available, a stream can actually rebuild meanders and access to floodplain; new channel in reach T1.03 on Gilead Brook (at right of photo) was several ft. higher in elevation than the old channel.

Figure 39. While meandering streams typically exhibit much lower slopes than mountain trails, the meanders provide a critical function of decreasing slope (and thus energy in high flows) similar to trail switchbacks. "Trails that go straight up and down steep hills don't stay nice trails for long. Erosion turns those trails into gullies because water moves faster down steep straight-aways…"(Conway 1998). ***Graphic credit: Steven Hill*****.**

Figure 40. Studies on hundreds of streams worldwide indicate that a meandering stream will naturally migrate through a fairly predictable belt-width over time, providing the critical function of reducing slope (and thus stream power) (VT-RMP_ApxH 2009)



In many areas the rapid channel evolution that occurred in Irene, which might typically take decades, left formerly straightened streams in more stable condition due to more natural planforms and slope gradients resulting from heavy sediment deposition and retention behind downed woody debris. While mass failures on steep side slopes, undercut banks and large wood "tip-ups" are likely to continue for the next several years as Irene's impacts stabilize, Phase 2 assessments in 2013 indicated that overall channel adjustments in areas where these processes do not conflict with corridor encroachments and infrastructure appear to be stabilizing relatively quickly. This was particularly evident in the upstream reaches of Gilead (T1) and Camp (M01-S3) Brooks as well as along much of Cleveland Brook (R12-S2).

Following Irene a good deal of wood was removed from portions of Lilliesville Brook (T4) and Locust Creek T3), and both wood and coarse sediments were removed from the stream channel along extensive portions of mid- and down-stream portions of Camp and Gilead Brooks. As noted in the 2012 Vermont Fish and Wildlife Annual Report (Kirn 2012),

> "Damage suffered from Tropical Storm Irene required immediate and in some cases extensive stream channel alteration to protect life and property and rebuild critical transportation infrastructure. However, a significant amount of in-stream activity was also conducted without proper consultation and oversight or for reasons beyond necessary flood recovery…. long-term monitoring studies in Vermont indicate that, in the absence of post-flood channel alterations, wild trout populations generally recover within 2-4 years. Where aquatic habitat has been severely altered through streambed and natural wood mining, channel widening and straightening…recovery of longer reaches may take decades and will depend upon the availability and mobility of upstream sources of coarse streambed material and natural wood, as well as the magnitude and frequency of future flood events."

While the cited report was geared to the impacts of Irene on trout populations, much the same can be said in terms of recovery toward more flood-resilient human communities in relation to streams. Coarse streambed materials and natural wood are particularly important in terms of reducing the impacts of stream power from straightened and incised streams by permitting the formation of more stable planform and slope patterns as well as restored floodplain access. Recovery from Irene (as well as other flood events) and greater stream stability “may take decades and will depend upon the availability and mobility of upstream sources of coarse streambed material and natural wood” and will be greatly prolonged when these materials are not available within the channel and adjacent accessible floodplains.

As noted above regarding hydrologic regime stressors, the very fine sediments on the Third Branch are highly mobile and sediment deposits there are frequently observed “washing out” quickly in high flows - typically transporting large amounts of fines and dramatically increasing turbidity levels following heavy rains. During 2013 fieldwork similar dynamics were observed on Gilead Brook when instream work for bridge replacements began upstream of portions of the stream that were bulldozed and highly channelized following Irene. With few coarse sediments and little large woody debris left in the channel, fine sediments were readily kicked up and not depositing on anything, and quickly turned the water opaque in areas lacking these materials in the channel; further downstream in the vicinity of ledge grade controls (which limited access for heavy equipment access and thus meant less material, including both coarse sediments and large wood, was removed from the channel) turbidity levels were sufficiently lower to permit some visibility in the water. These dynamics highlight the “wash load” that is transported long distances when “bed load” sediments and woody debris regimes are disrupted. Similar dynamics were observed near undersized bridge and culvert structures that were “cleaned out” after Irene on all of the tributaries assessed in the 2013 Bethel area phase 2 work, as well as longer sections of stream in Lilliesville Brook reach T4.01 and White mainstem reaches R12 and R13, and much longer sections of stream on Gilead Brook reaches T1.01 and T1.02 and Camp Brook reaches M01-S3.01 and M01-S3.02.

Bed load sediments are currently moving through the stream network in the Bethel area in “sediment slugs” associated with impacts from flooding as they redistribute and become more sorted in ensuing high flows. In reaches that were not windrowed or dredged following Irene deposits included a still relatively unsorted mix of boulders and large cobbles along with smaller materials; large point bars in portions of White mainstem reaches R12 and R13 also included numerous chunks of asphalt from the former Rte. 107 mixed in with these other size sediments. Depositional features that were tallied in reaches that had extensive streambed mining following Irene (Camp Brook, Gilead Brook, and the downstream portion of Lilliesville Brook in particular) were primarily composed of small cobble or gravel sediments being moved and redistributed in high flows, as many larger materials are lining the banks and are not within the current stream channels at lower flows.

In summary, sediment regime stressors in the Bethel area following Irene are largely related to the disruption of natural sediment regimes and redistribution of flood related discharges in areas where windrowing and dredging (streambed mining) and snagging (natural wood mining) offset major channel evolutions toward more stable stream planforms and slopes. These planform and slope adjustments included rebuilding of access to historically abandoned floodplains and re-establishment of more sinuous meanders, and in areas where the wood and sediment contributing to these changes have remained in place (Cleveland Brook, upstream portions of Gilead, Camp and Lilliesville Brook) the streams surveyed in 2013 appear to be stabilizing relatively quickly – good news for a greater degree of flood resiliency in areas downstream. Areas where these materials were removed will be passing heightened stream power impacts downstream for years to come until some type of channel evolution occurs, and raw materials for this evolution – sediment, wood, water – will need to be closer to the current channels for this to occur.

The hydrologic and sediment load watershed-scale stressors described above form a hierarchical pretext for understanding the timing and degree to which reach-scale modifications are contributing to field-observed channel adjustments (Kline 2010). Modifications to the valley, floodplain, and channel, as well as boundary (bank and bed) conditions, can change the hydraulic geometry, and thus change the way sediment is transported, sorted, and distributed (Table 12). Phase 1 and Phase 2 assessments provide semi-quantitative datasets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified.

Table 12. Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (Kline 2010).

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

Channel Slope and Depth Modifier Maps (Sections 5.1.2a and b, respectively) are used to determine whether stream power has been significantly increased or decreased. A Channel Boundary and Riparian Modifiers Map (Section 5.1.2c) helps explain whether resistance to stream power has been increased or decreased. The analysis here attempts to portray general trends in contributions these various features contribute to stream dynamics; primary reach-scale, stressors in each reach are noted in section 6 for Project Identification.

5.1.2a Channel slope modifiers

Analysis of channel slope modifiers in the 2013 Bethel Phase 2 study area indicates that channel straightening is the predominant stressor in the area, with indications of straightening (largely associated with road and development encroachments and the effects of undersized bridges and culverts) observed in 17 of 18 reaches (31 of 36 segments) assessed in Phase 2 (Fig. 41 map).

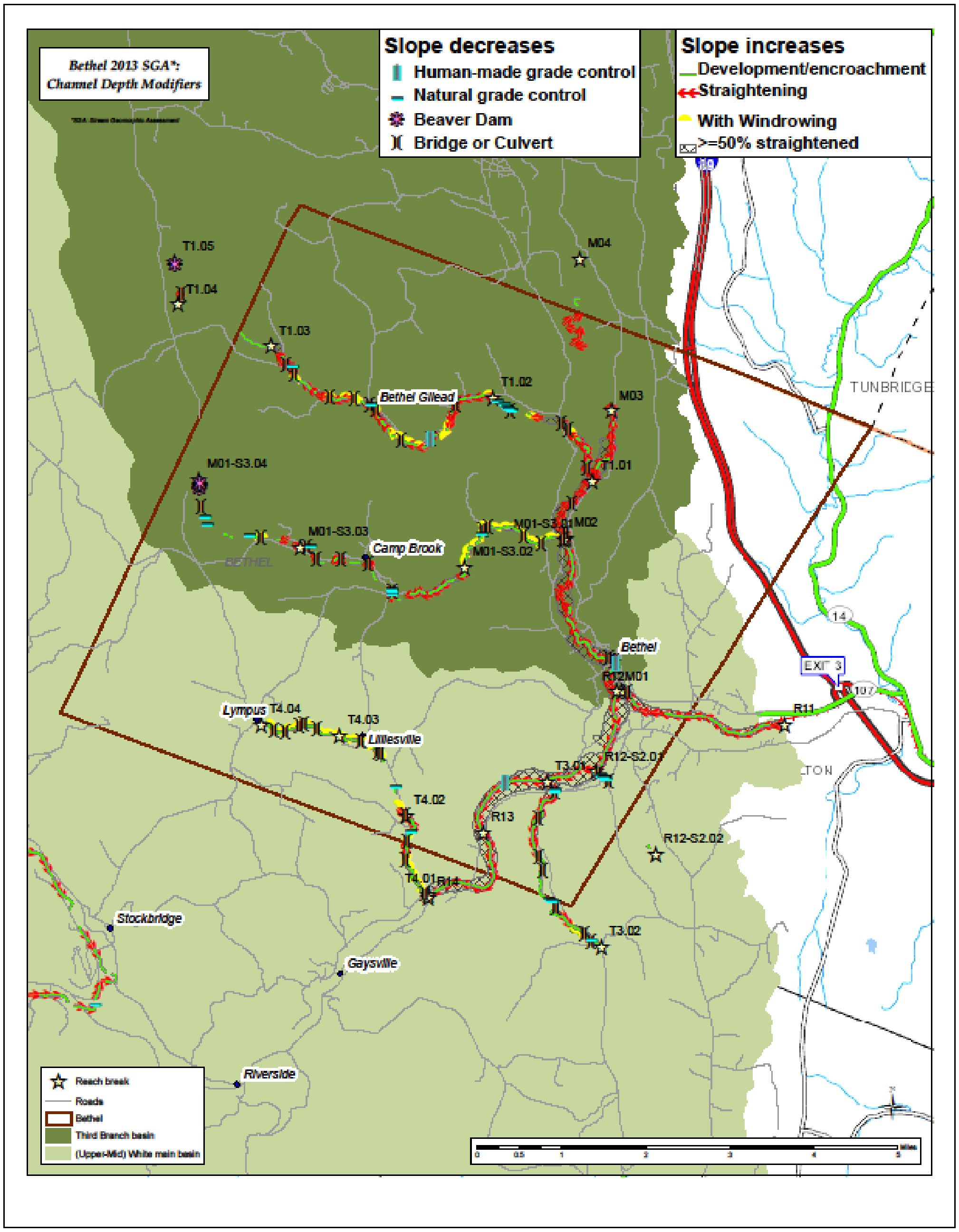


Figure 41. Channel Slope Modifiers map for the 2013 Bethel Phase 2 study area.

As noted in section 3.1.3 of this report, a large degree of historic channel straightening occurred in relation to the embankments built to locate and/or elevate railroads along the White and Third Branch mainstems in the Bethel vicinity, with roads later occupying portions of the White River valley no longer occupied by the railroad bed. Route 107 headed south and west from Bethel also contributes to a high degree of straightening along the White mainstem, occupying the opposite bank from the former location of the railroad and representing a frequent site of recurrent conflicts with river processes (Fig. 42).

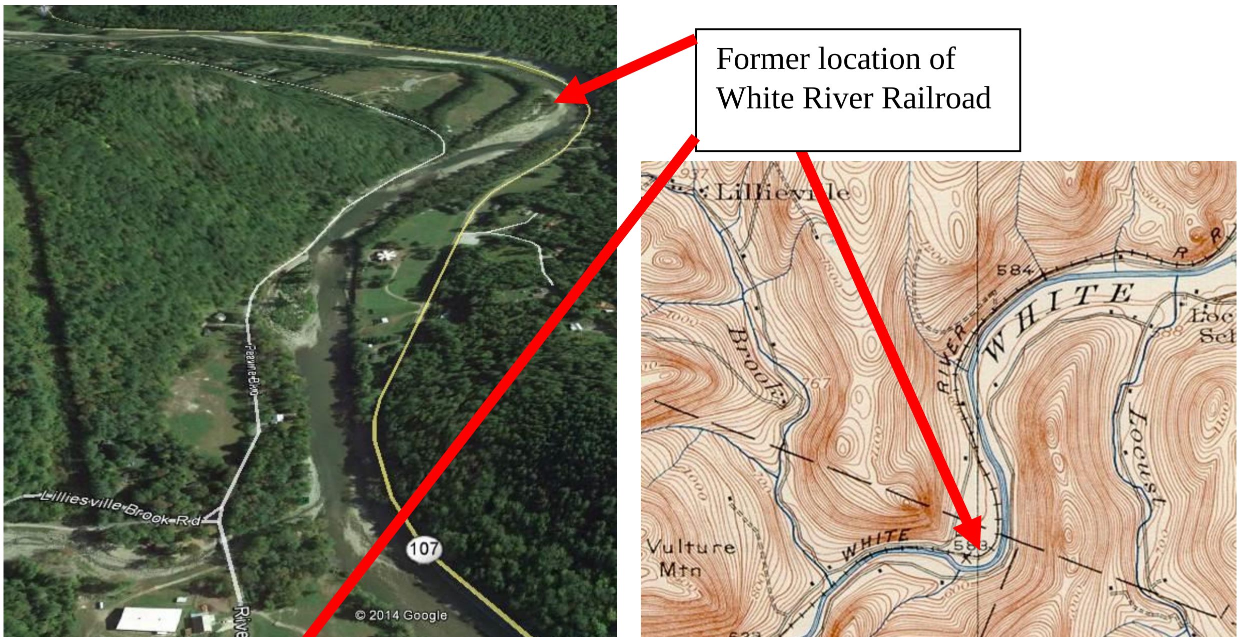


Figure 42. Although the White River Railroad (aka "the Peavine") no longer occupies the terrace downstream of the mouth of Lilliesville Brook, the portion of Rte. 107 along White mainstem reach M13 opposite this location reflects long-term impacts of straightening as a spot of recurrent conflicts between stream processes and infrastructure location. A limited amount of development and agricultural fields now occupies this terrace, which did not appear to have flooded in Irene.

Some channel straightening appears to have occurred historically through direct channel manipulation to supply mills on Gilead (T1), Camp (M01-S3.01) and Lilliesville Brooks (and likely other small tributaries of these basins as well). In addition, straightening has occurred through a combination of incremental impacts including: road and development encroachments; structural measures such as riprap and bank toe stabilization; less direct maintenance of the channel "in its place" through field cultivation and ditching; and remediation of flood damage through windrowing of stream sediments, removal of debris jams, and channel "clean-outs" in the areas of undersized bridges and culverts.

Channel straightening can heighten stream power when slope increases occur as a stream loses its meanders (similar to putting a driveway straight up a steep slope rather than installing switchbacks). In areas with erodible bed materials (true throughout most of the Bethel 2013 study area), elevated stream power may contribute to bed downcutting (channel incision) that further enhances stream power and sediment transport capacity as a result of the increased slope and depth at flood stage. The deep historic incision noted on almost all streams in the study area was dramatically amplified by the impacts of Irene, leaving streams even more entrenched in what were already diminished floodplains and valley bottoms.

5.1.2b Channel depth modifiers

With very deep soils and few grade controls evident in the Bethel area, the high degree of historic and more recent channel incision has vastly reduced floodplain and valley widths leading to current increased depths in flood flows. Only 4 of 36 segments have incision ratios of <2.0, indicating loss of access to historic floodplains in the other 32 segments.

As discussed above in this Section 5 Departure Analysis, the commonly narrow valleys of the Bethel region frequently feature heavy deposition combined with large woody debris falling into the stream in a dynamic whereby the stream may actually rebuild access to abandoned floodplains and extend or re-establish meanders. In areas where the channel has historically incised, the process often initiates with mass failures contributing large sediment inputs, which are then trapped behind trees that have fallen into the stream (Fig. 35), and may include plugged channels followed by avulsions or similar rapid channel relocations. This issue bears particularly close attention in areas where high levels of encroachments along the stream corridor (frequently with attendant bank armoring) further contribute to heightened channel depths in flood flows. High levels of historic incision throughout the Bethel study area give heightened channel depths a sort of "baseline" status and diversion of these flows around large sediment plugs or deposits can quickly lead to escalated damage to encroachments in the corridor. This combination is notable in the Bethel 2013 study area along the White mainstem reaches, Locust Creek and Lilliesville Brook, downstream portions of Camp Brook and much of Gilead Brook (Fig. 43).Given the high current level of stream entrenchment and the necessity of these dynamics to mitigate the impacts of increased flood depths, a strong case is presented for limiting further development in these areas and leveraging opportunities to reduce current levels of encroachment on these streams.

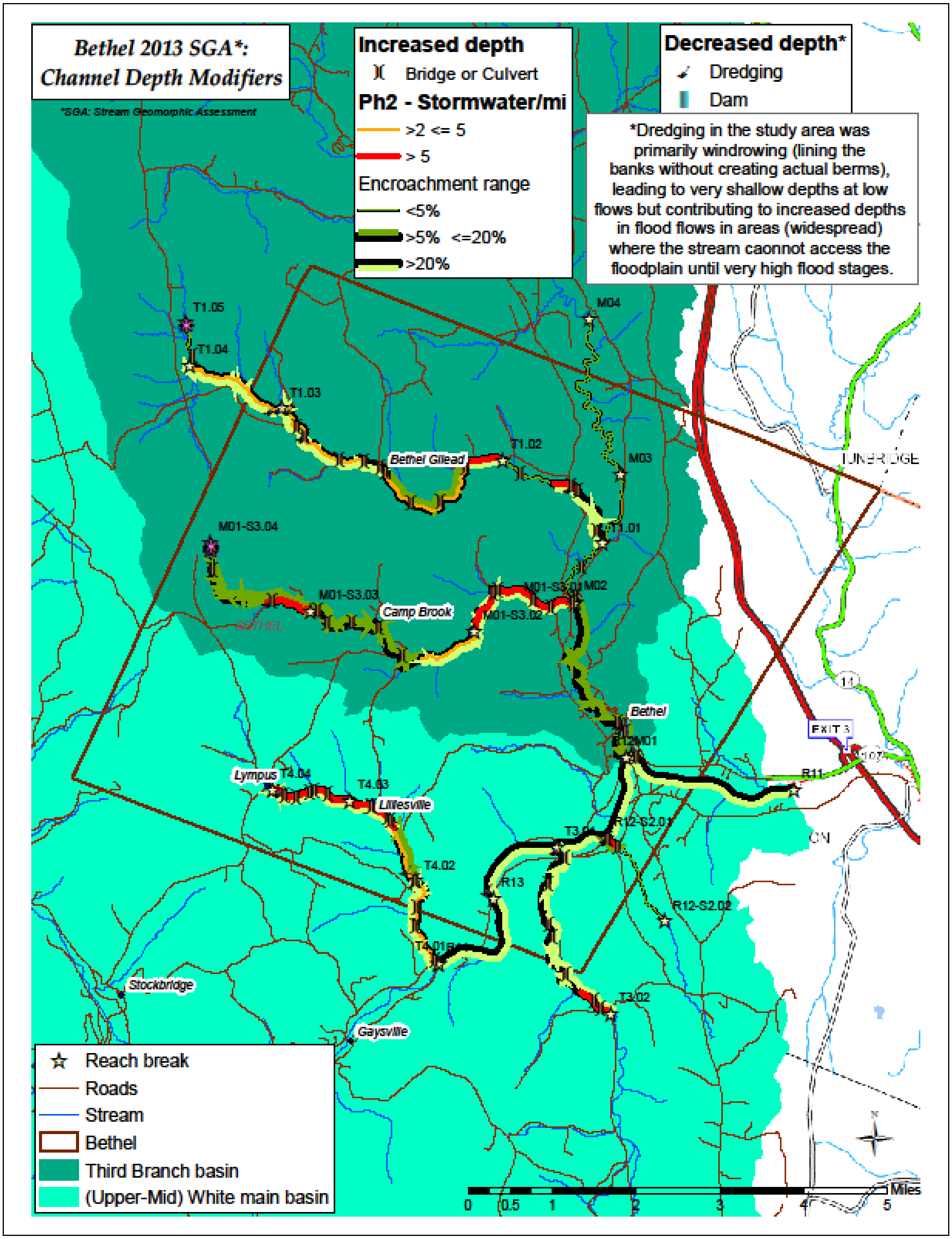


Figure 43. Channel Depth Modifiers map for the 2013 Bethel Phase 2 study area.

Further modifiers toward increased depth are frequently related to transportation infrastructure (Fig. 44).

Figure 44. Increased depths in flood flows are common at undersized structures and are frequently intensified by significant bank armoring upstream and downstream of these locations.

Roughly 70% of the bridges and all of the culverts assessed in the Bethel area were sized below both floodprone and channel bankfull widths, so high level flows increase depths when being funneled through these locations. The large majority of these channel and floodprone constrictions are located on the tributaries assessed in 2013 (Camp, Gilead, Lilliesville and Cleveland Brooks plus Locust Creek). The increased depth factor is further intensified by the fact that 10 segments (out of 36 total) listed with ‘High’ impacts from stormwater inputs were all located on these same tributaries.

Although there are instances where roads are at the same grade as the surrounding terrain, elevated roads within the river corridor increase the depth of flood flows and thus increase stream power. Phase 1 and 2 data collection indicate encroachments (primarily from roads) exceeding 20% of the length of the stream segment on 20 of 36 segments (in 12 of 18 reaches assessed in Phase 2) in the Bethel 2013 study area. An additional 7 segments have encroachments along 5-20% of the segment length, leaving 9 segments in 6 reaches (all on the Third Branch, Cleveland and Gilead Brooks plus the most upstream segment of Camp Brook) without significant road encroachments in the stream corridor.

Following Irene, modifiers toward decreased channel depths in the Bethel area included widespread depositional features, not uncommonly exceeding ‘High’ thresholds of a depth greater than half the channel bankfull stage, at ‘High’ levels (>5 depositional features/mi.) everywhere except mainstem reaches along both the White mainstem (R11 and R12) and Third Branch (M02 and M03). In the large majority of these areas these sediments are playing a vital role in re-establishing meanders and occasionally (in conjunction with large woody debris) rebuilding floodplain access, and single thread channels with alternating scour (at outside bends and below steps) and deposition (at steps and inside bends) features were re-establishing fairly quickly in many of these areas. Where channel depths at normal flows were extremely shallow (and frequently braided) however was in heavily channelized portions of Camp, Gilead and Lilliesville Brooks. In these areas, especially Gilead Brook segments T1.02 B and C and Lilliesville Brook segment T4.01A, extensive windrowing and dredging of coarse sediments from the channel has left extremely shallow depths (and very few pools) at normal flows but elevated depths in flood flows due to the lining of the channel perimeter with these sediments (few ramps or floodplain benches to be accessed). Some work has been done to re-establish better channel and floodplain dimensions on Camp Brook reach M01-S3.01, visible just upstream from Rte. 12 (Pleasant St.), but channel evolution toward a more meandering stream with better pool formation and varied habitat features will take some time and may require more wood or large stone to be restored to the channel.

Modifiers toward decreased channel depths in the Bethel area were also found in areas of beaver activity (upstream portions of Camp and Gilead Brooks) and upstream of the Bethel Mills dam. Beaver dams were breached in Irene and rapid incision through these sediments was currently offsetting some of these depth decreases. This is likely to be a temporary situation as beavers will likely re-occupy these areas.

Other depth decreases associated with delta and backwater deposits formed upstream of channel constrictions (primarily undersized bridges and culverts) or alluvial fans at the bases of steep tributaries (Cleveland Brook crossing under Rte. 107, Lilliesville Brook crossing under River Rd.) were “cleaned out” following Irene. While this was necessary for protecting these structures and their associated roads, it is also likely to increase future impacts from elevated depths in high flows. Adoption of Vermont Agency of Transportation 2013 Bridge and Culver Standards by all of the towns in the Bethel area will help ensure that future bridge replacements will be sized at 100 percent of bankfull stage, but Bethel and surrounding towns may wish to consider whether 120 percent bankfull stage sizing for bridge and culvert replacements would better protect infrastructure investments on the steeper tributaries (esp. Lilliesville, Camp, Cleveland Brooks).

5.1.2c Boundary condition and riparian modifiers

Stream boundaries include bed and banks, and are strongly affected by the underlying geology and the state of buffer vegetation in the riparian corridor. Root systems from woody vegetation (and, to a lesser extent, herbaceous vegetation) help bind stream bank soils and diffuse stream power.

As frequently noted in this River Corridor Plan, one of the most distinguishing factors about the streams assessed in the Bethel 2013 study area is the extremely deep soils through which they flow and the relative scarcity of ledge or other grade controls to limit channel incision (downcutting of the bed). The high erodibility of stream beds in the Bethel area is accompanied by similar erodibility along the banks, but erodibility of banks is mitigated by decent buffers throughout much of the 2013 study area. Primary expanses lacking adequate streamside buffers are in agricultural areas concentrated along the Third Branch, White mainstem and to a lesser degree along Gilead Brook.

With highly erodible soils throughout the study area, increased bank armoring is widely used to offset elevated erosion in areas lacking buffers (diminishing bank roughness and the effects of intertwined roots that might otherwise provide some dissipation of stream energy in high flows). This effectively transfers additional erosive power to the erodible stream beds and has contributed to extensive historic channel incision noted throughout the study area, with multiple abandoned former terraces frequently indicating stages of successive floodplain abandonment. Development encroachments and intermittent longer lengths of road encroachments thus represent a significant modifier of bank boundary conditions (Fig. 45), but only one short segment (T3.01C on Locust Creek between TH-80 and the upstream end of Old Rte. 12

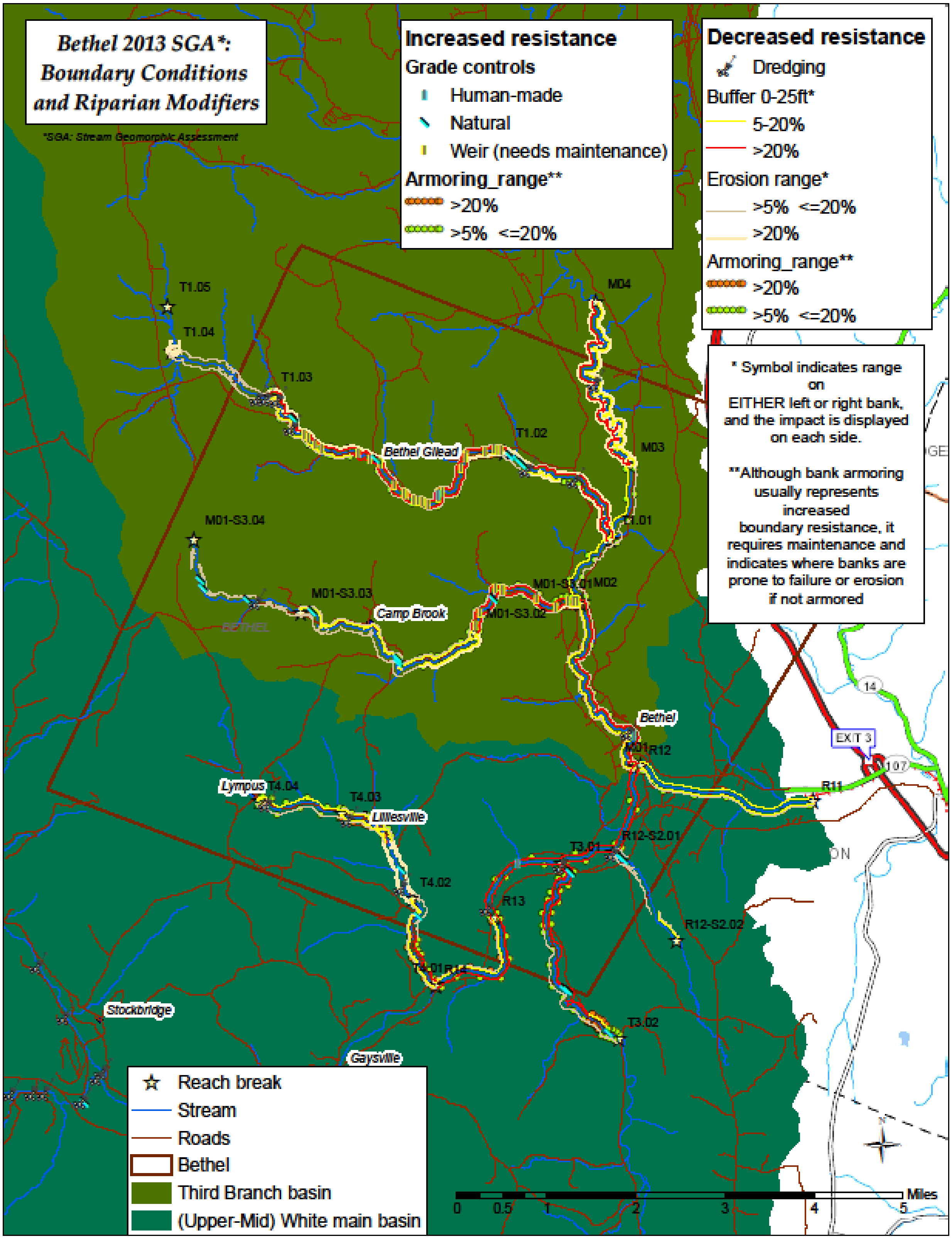


Figure 45. Boundary Conditions and Riparian Modifiers map for the 2013 Bethel Phase 2 study area.

in Barnard) indicated ‘High’ levels (>20% of channel length) of bank armoring on both banks. Six additional segments or reaches indicated ‘High’ levels of bank armoring on at least one bank: three in village settings -Third Branch M01 in Bethel village, T1.02 in Bethel-Gilead and T4.02 in Lilliesville; White mainstem reach R13 including the heavily damaged Rte. 107 section downstream of Lilliesville Brook; and tributary segments at the base of Camp and Lilliesville Brooks (M01-S3.01A, T4.01A).

Although all of the 36 assessed stream segments are listed with ‘Coarse’ native bed substrates, the lack of ledge grade controls leaves these streambeds still susceptible to erosion in high flows, even more so in areas where bank armoring is increased and/or native coarse bed substrates (‘natural bed armoring’) are disturbed or removed from the channel. The high erodibility of stream beds is offset to some degree in areas that have accumulated a natural bed armoring of coarse sediments over time, but the impacts of Irene clarified that without grade controls even areas that have some natural bank armoring are subject to bed degradation in high flows (Fig. 46).

Figure 46. Stream ford on Lilliesville Brook (left) and spring box on Camp Brook (right) indicate depth of recent channel incision that lowered the stream bed in relation to this infrastructure.

Limiting further bed incision and consequent loss of access to floodplains thus remains of high concern in the Bethel area, and the Boundary Conditions and Riparian Modifiers Map (Figure 45) denotes areas where temporary weirs were installed post-Irene to help limit further channel incision, particularly in heavily channelized areas where coarse sediments were windrowed out of the stream channel (removing natural ‘bed armor’) and along the sides of the stream where they function more like bank armoring, thus heightening erosive impacts transferred to the stream bed. Due to high current instability and likelihood of ongoing channel evolution in these areas, these structures are temporary at best and will need to be monitored as to their ongoing effectiveness in limiting channel incision and the necessity of further maintenance in relation to whether native stream sediments and large woody debris might start to play more of a role in providing these same functions, as is more typical for evolving streams in these settings. Although these structures can play an important role in stream dynamics they do not provide anywhere near the same benefits as natural materials in terms of habitat diversity or have the same capacity for self-maintenance over the long term.

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

Within a reach, the principals of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Leopold 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium in the balance of these forces and lead to uneven distribution of power and sediment (Fig. 47). Whether a project works with or against the physical processes at play in a watershed is primarily determined by examining the source, volumes, and attenuation of flood flows and sediment loads from one reach to the next within the stream network. If increasing loads are transported through the network to a sensitive reach, where conflicts with human investments are creating a management expectation, little success can be expected unless the restoration design accommodates the increased load or finds a way to attenuate the loads upstream (Kline 2010).

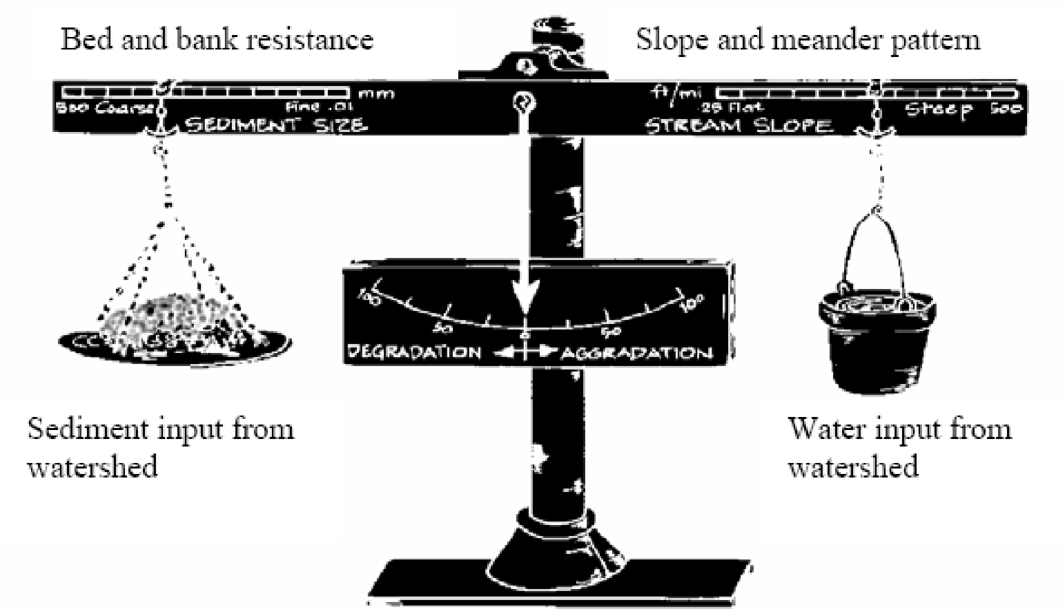


Figure 47. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955)

When stream power and sediment are relatively balanced, the streams located in narrower valleys on steeper gradients in a watershed (primarily A- and some B-type streams) tend to exhibit a “Transport” sediment regime, contributing minor amounts of various sized sediments to downstream reaches but not storing many sediments. Streams in wider valleys with lower slope gradients (primarily C- and E- type streams) provide for sediment storage in a dynamic balance with water moving through the system (in = out: i.e., stream power, which is produced as a result of channel gradient and hydraulic radius, is balanced by the sediment load, sediment size, and channel boundary resistance). Under reference conditions, these streams would provide for coarse particle equilibrium and fine sediment deposition at annual flood flows, largely on the floodplains and at bendways and meanders (Coarse Equilibrium and Fine Deposition sediment regime, Fig. 48; Kline 2010, p.43).

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/or natural entrenchment of the channel.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bed forms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late Stage IV, and Stage V.

Figure 48. Pertinent characteristics for Phase 1 classification of reference sediment regimes in 2013 Bethel study area reaches.

Based primarily on valley slope and confinement, Phase 1 assessments in the 2013 Bethel study area classified just 3 of the 18 reaches assessed with Transport sediment regimes under reference conditions (Fig. 48), including the downstream (M01-S3.01) and upstream (M01-S3.03) ends of Camp Brook and the upstream end of Lilliesville Brook between Lilliesville and Lympus (T4.03).

Two other reaches assessed in Phase 1 (Gilead Brook T1.01 and Cleveland Brook R12-S2.01) indicated indeterminate or mixed stream types needing further field assessment to determine the sediment regime, while the remaining 13 reaches would be expected to have Coarse Equilibrium and Fine Deposition (CEFD) sediment regimes under reference conditions.

Sediment regime departure

Phase 2 sediment regimes (which help identify current departures from reference conditions) are determined based on a number of parameters measured in rapid field assessments (Kline 2010, p. 44). These include signs of active adjustment processes indicating that streams are in a state of disequilibrium, including a likely stage of channel evolution (Fig. 49; criteria listed left to right in order of relative importance).

Sediment Regime	Delimiting criteria related to sediment supply, transport, and storage	Stage of Channel Evolution Geomorphic Condition	Common Existing Stream Type	Natural Valley Type
Confined Source and Transport	Incision ratio > 1.3	Stage II-IV Fair-Good	A3, B3*	NC, SC, NW
	Incision ratio > 1.3	Stage II-IV Fair-Good	A4, A5 B4*, B5*	Any Type
Unconfined Source & Transport	Bank armor > 50% Straightening > 50% W/d < 30 Incision ratio > 1.3	Stage II - III Poor-Fair	G3, G4, G5 F3, F4, F5	NW, BD, VB
		Stage II - III Poor-Fair	E3, E4, E5 C3, C4, C5 B3c, B4c, B5c	NW, BD, VB
Fine Source & Transport and Coarse Deposition	Bank armor < 50% W/d > 30** Incision ratio > 1.3	Stage II-IV Poor-Fair	E3, E4, E5 C3, C4, C5 B3c, B4c, B5c F3, F4, F5	NW, BD, VB
	Bank armor < 50% Incision ratio > 1.3	Stage II-IV Poor-Fair	D3, D4, D5	NW, BD, VB
Coarse Equilibrium (in = out) & Fine Deposition	Incision ratio < 1.3	Stage I -V Fair-Good-Ref	D3, D4, D5	NW, BD, VB
	W/d < 30 Incision ratio < 1.3	Stage I -V Fair-Good-Ref	C2, C3, E3	NW, BD, VB
	W/d < 30 Incision ratio < 1.3	Stage I -V Fair-Good-Ref	C4, C5 E4, E5	NW, BD, VB

Figure 49. Pertinent parameters for characterizing existing sediment regime using Phase 2 data.

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

** Depositional Features may include multiple channel avulsions and multiple chute cut-offs

The only stream segment noted in a stable stage (V) of channel evolution during 2013 field assessments was Locust Creek segment T3.01D near Rattner Rd. along Rte. 12 in Barnard, likely due in large part to bedrock grade controls in the bed as well as along the margins of the channel.

Once a stream has entered a state of disequilibrium, it will begin a series of channel adjustments or evolutions to fulfill the physical mandates of restoring equilibrium. Schumm (1977 and 1984) has described five stages of channel evolution for reaches where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time (“F-model” evolution; Fig. 42). The five stages of channel evolution for F-model evolution are paraphrased from the SGA protocols (VT-RMP_ApxC 2007) as follows:

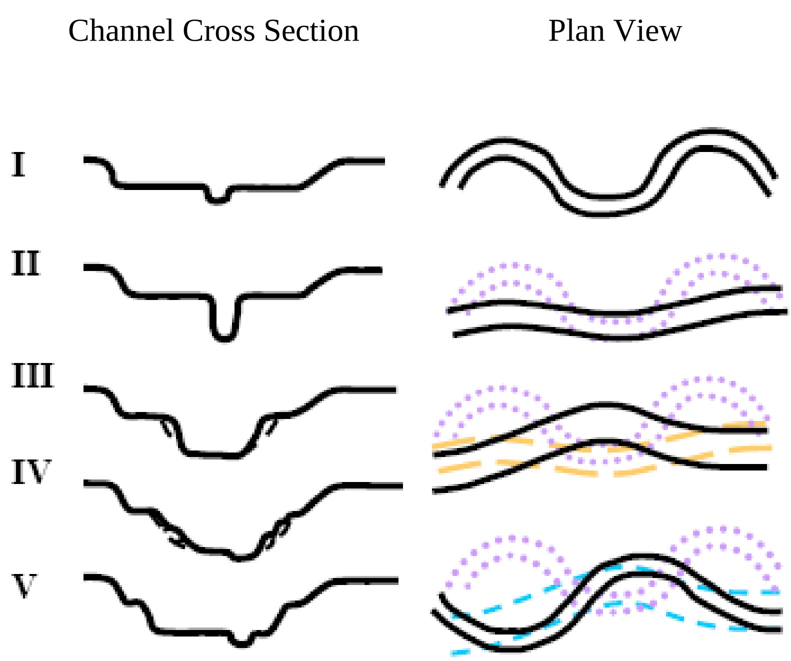
I. Stable — In regime, reference to good condition. Insignificant to minimal adjustment; planform is moderately to highly sinuous.

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

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

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

V. Stable — In regime, reference to good condition. Insignificant to minimal adjustment.



One stream segment in the 2013 Bethel study area, bedrock-controlled cascade R12-S2.01A at the downstream end of Cleveland Brook, exhibits a second model of channel evolution ("D-model" evolution) that is more typical in areas where stream banks are more erodible than the bed. Under these conditions the stream does not significantly incise and instead evolves primarily through widening and/or lateral movement. The three stages for D-model channel evolution are paraphrased from the SGA protocols (VT-RMP geoassesspro 2007, Appendix C) as follows:

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

Then either of the following Stage II scenarios may occur:

Stage IIc. Widening/Migration — Widening and migrating laterally through bank erosion caused by increased stream power. The balance between stream power and boundary materials is re-established when the slope flattens after a process of channel lengthening and increased sinuosity.

Stage IId. Braiding — Extreme deposition and braiding, with water flowing in multiple channels at low flow stage ("D" stream type). Channel width narrows through aggradation and the development of bar features. Main channel may shift back and forth through different channels and chute cut-offs, continuing to erode banks or terraces.

Stage III. Stable — Channel adjustment process is complete (back to a B, C or E stream type).

With field-assessed measures such as bank armoring, straightening, channel incision, and stage of channel evolution accounted, Phase 2 assessment helps identify an existing sediment regime for each stream segment. Comparing reference sediment regimes (Phase 1 assessments) side by side with field-assessed existing sediment regimes (Fig. 51) gives a sense of sediment regime departure within the watershed.

Phase 2 assessments in the Bethel area during 2013 indicated that, in contrast to 13 Phase 1 reaches that would function as Coarse Equilibrium and Fine Deposition (CEFD) areas under reference conditions, there are currently no net CEFD sediment regimes in the 2013 study area; *all 36 segments in 18 reaches currently function with some sort of Transport sediment regime*. While sediments from Irene clearly deposited on floodplains during that storm, these floodplains are currently only accessed at extremely high flows and the extensive loss of access to floodplains in the Bethel area means vastly diminished functions for sediment, nutrient and floodwater storage within the watershed. Soils and nutrients are being exported at a high rate, and the impacts of high flows and fine sediment transport in particular are being transferred downstream - to the pronounced detriment of streamside properties and instream habitats. While many water quality issues in Vermont have been prominently highlighted by impacts to Lake Champlain, the fact that there is not a Lake on the downstream end of many streams and rivers on the eastern side of the state should not obscure the impacts that are currently being passed downstream (Fig. 50).

Figure 50. This sediment plume entering Long Island Sound from the mouth of the Connecticut River was evident in satellite imagery nearly a week after Irene had moved through the state of Vermont, indicating the tremendous amounts of erosion and accompanying sediment and nutrient export in response to the storm. (*Photo credit: NASA 2011*)

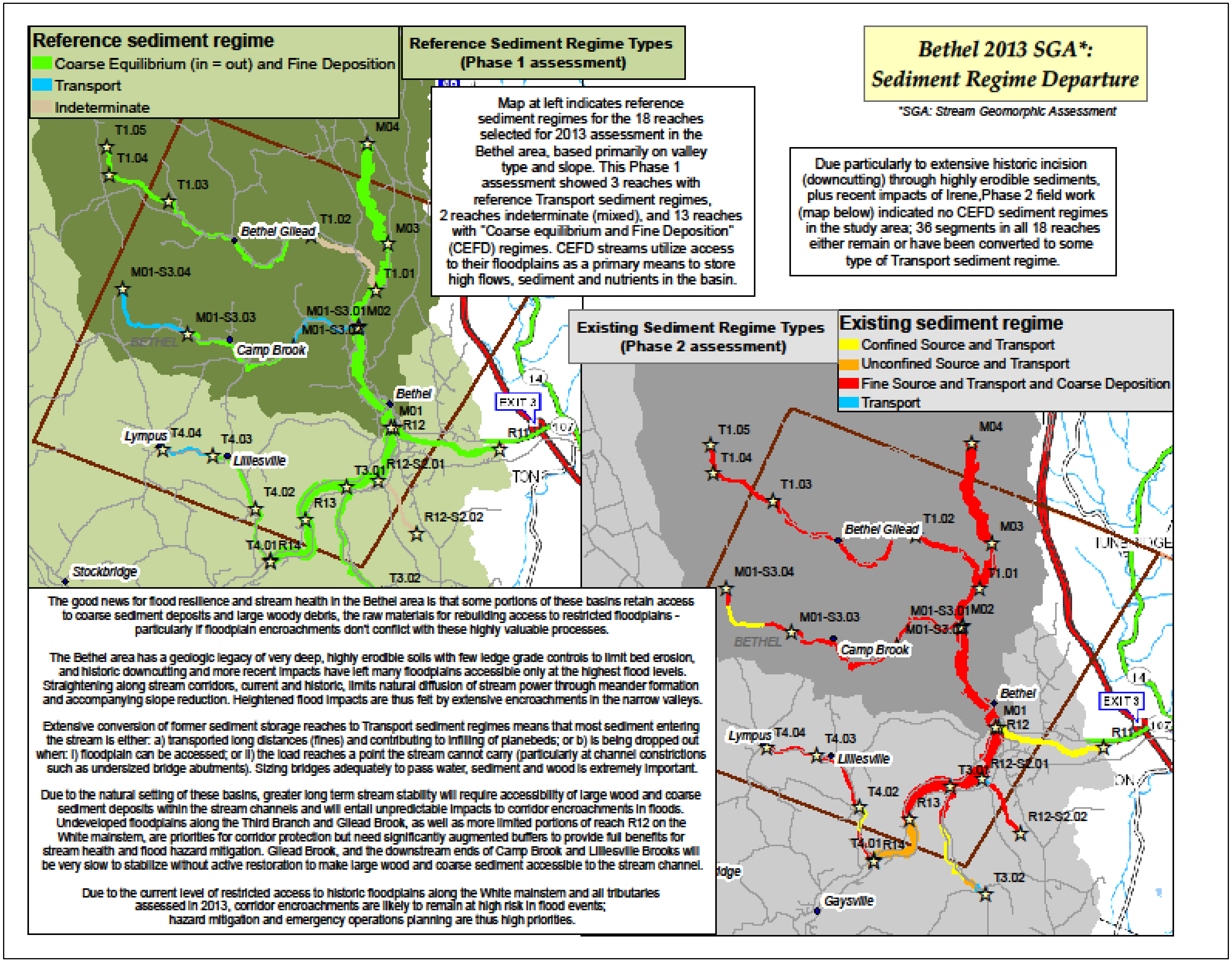


Figure 51. Sediment Regime Departure map for the 2013 Bethel Phase 2 study area.

Fine Source and Transport and Coarse Deposition regimes (coded red in Fig. 51) now exist in 27 (of 36 assessed) stream segments that lack extensive bank armoring and are characterized by channel widening, elevated levels of erosion and concentrated deposition at channel constrictions (including upstream of undersized bridges and culverts and old abutments), tributary mouths, and over widened sections of the stream. These segments are widely distributed throughout the basin on both mainstem and tributary reaches.

Unconfined Source and Transport sediment regimes (coded orange in Fig. 51) currently exist in 3 segments:

- White mainstem reach R13 downstream of Lilliesville Brook to Tozier's and including the Rte. 107 "Last Mile" of post-Irene damaged highway reconstruction in Vermont;
- Locust Creek segment T3.01C between the upstream end of Old Rte. 12 and the TH-80 bridge in Barnard; and
- T1.02A, which runs in close proximity to Gilead Brook Rd. downstream of Mitchell Drive.

These areas include a relatively high percentage of bank armoring, appear to have repeat dredging or "clean-out" areas upstream of undersized structures and valley/floodplain pinch points, and have had large stone removed from the channel to line the banks through either windrowing or more deliberate riprapping and bank toe stabilization. While these areas would have better floodplain access and storage under reference conditions, historic and current channel management practices leave little ability to store sediments or high flows and thus transfer impacts to downstream reaches.

Confined Source and Transport sediment regimes (coded yellow in Fig. 51) currently exist in 4 segments situated in Semi-confined valleys, including one White mainstem reach and three segments in the even narrower valleys of tributary reaches:

- White mainstem reach R11 tucked below the railroad embankments near the Vermont Castings plant and Bethel wastewater treatment plant and extending across the Bethel/Royalton town line, and including the vestiges of a former crib hydroelectric dam near Power Station Rd.;
- Camp Brook segment M01-S3.03B, which receives water from multiple tributaries draining the extremely steep side slopes below Charlie Wilson Rd. as well as a series of beaver ponds in the headwaters that were likely breached in Irene;
- Locust Creek segment T3.01B, with multiple historic terraces reflecting successive floodplain abandonment along the sides of Old Rte. 12 and current Rte. 12; and
- Lilliesville Brook segment T4.01B, which is also lined by multiple historic terraces reflecting successive floodplain abandonment along the sides of Lilliesville Brook Rd

These areas all show signs of significant historic downcutting through highly erodible sediments, in part due to glacial processes and in part due to the effects of straightening. This is part of the legacy of glacial Lake Hitchcock, which left behind narrow valleys post-glacially when the Lake drained and incised deeply through these highly erodible sediments. These areas are prone to mass failures and erosion along the valley walls that contribute sediment discharges that quickly transfer to downstream reaches due to elevated stream power in these narrow valleys. Although the glacial processes explain part of the confinement, more recent historic incision has also contributed to the abandonment of multiple terraces that are frequently visible along these valley walls, indicating former access to much broader floodplains. With the exception of the upstream portion of Camp Brook, these streams are further “locked in” by roads leaving them subject to possibilities for further bed incision if the banks are armored.

Segments T3.01D (Locust Creek near Rattner Rd. along Rte. 12 in Barnard) and R12-S2.01A (between Cleveland Brook Rd. and Rte. 107) are in bedrock-controlled Narrowly Confined valleys and would be Transport reaches under reference conditions as well.

Channel adjustments due to increased flows can be difficult to remediate in downstream reaches (Booth and Jackson 1997; Doyle et al. 2000; Fitzgerald 2007), potentially prolonging the stages of disequilibrium in these streams and leaving them open to heightened flood impacts in future events. This places a premium on attenuation of high flows and sediment discharges in the shortest distance downstream possible, and increases the importance of:

a) limiting development and encroachments within stream corridors;

b) restoring, protecting and maintaining floodplain access even on small streams high in the watershed, including current beaver-controlled areas;

c) establishing and maintaining woody buffers in riparian corridors and

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

Constraints to channel evolution

As noted frequently in this report, there are few constraints to vertical channel evolution in the Bethel 2013 study area, with ledge grade controls present in 15 of 36 assessed stream segments but only 6 of 36 segments containing more than a single grade control (Fig. 52): Gilead Brook T1.01D near Messier Rd.; Camp Brook M01-S3.02B (Camp Brook village near Dartt Hill) and M01-S3.03B (stream diverges from road between Pond and Charlie Wilson Rds.); R12-S2.01A (downstream end of Cleveland Brook between Cleveland Brook Rd. and Rte. 107); and Locust Creek segments T3.01A (between Rte. 12/107 and the White mainstem) and T3.01B, particularly in the vicinity of a popular swimming hole near one of the Old Rte. 12 bridges. In part due to this scarcity of grade controls, 31 of 36 segments show an incision ratio of >2.0 (indicating loss of access to former floodplains during “channel-forming flows” typically experienced on a 1-2 year basis). This means additional erosive power contained within the channel at moderate flood levels transfers to both banks and bed and increases the risk of further bed degradation - particularly in areas where natural bed armoring has been disturbed or banks have been armored.

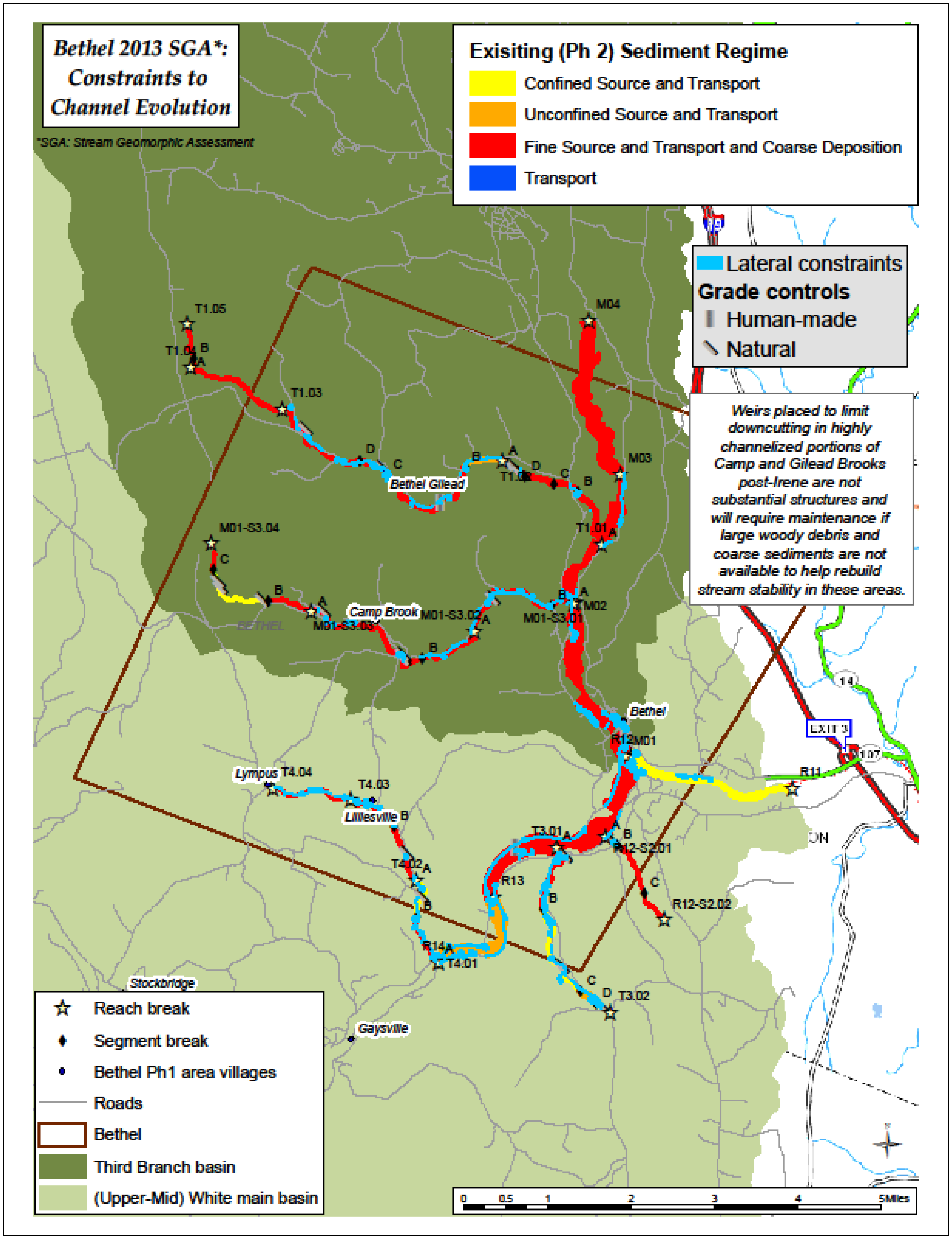


Figure 52. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution in the Bethel 2013 Phase 2 study area.

None of the streams assessed in the 2013 study area have the natural lateral constraint of dominantly cohesive banks (with the lone exception of a 300 foot long bedrock gorge that comprises only a small portion of segment M01-S3.02B near Dartt Hill Rd.). As is visible in the lateral constraints denoted in the Constraints to Channel Evolution Map (Fig. 52), however, road and development encroachments are common and present a primary lateral constraint to channel evolution (human constructed and maintained), thus increasing risks for these structures and infrastructure in the course of lateral channel evolution (planform changes) or further bed degradation when banks are armored to protect these encroachments. With little bedrock to limit downcutting, further bed degradation amplifies stream power as noted above (more erosive power contained within the channel and increasingly limited floodplain) and eventually poses risks for undermining even well-constructed lateral constraints, feeding into a progressively expensive cycle of damage and repairs.

Under reference conditions for most of the streams in the Bethel 2013 Phase 2 study area large woody debris and coarse sediments would present some natural checks to bed erosion and channel evolution would lead to pool formation alternating with runs and riffles or steps so that these streams would undulate both vertically and laterally, balancing sediment transport and stream power.

Attenuation assets

Given a significant degree of lateral constraints in the Bethel area, particularly along roadsides in the narrow tributary valleys and along the White mainstem, protection of existing floodplains as "attenuation assets" is challenging but plays a critical role in mitigating flood impacts by accommodating and diffusing high flows and storing sediments and nutrients. Although attenuation assets would be widely distributed (though often limited in extent due to the narrow valleys) under reference conditions, the current configuration of lateral and (scarce) vertical constraints severely curtails the value of many stream segments as attenuation assets except in high-level floods such as Irene (Fig. 53; Tables 13-14).

Figure 53. Heavy sediment deposits visible in 2011 Google Earth imagery looking upstream along the White River mainstem (left) and Third Branch (below) indicate where floodplains were accessed in Irene (attenuation assets).

Table 13. Departure Analysis Table for the Third Branch and some of its tributaries, 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.

	Constraints		Transport		Attenuation (storage)		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
Third Branch (M) and tributaries (Camp Brook: M01S3; Gilead Brook: T1)							
M01	natural-human (falls-dam)	human		x	x		limited
M02	none	human		x		x	limited
M03	none	none		x	x		x
M01-S3.01A	human	human		x	x		limited
M01-S3.01B	human	human	x			x	
M01-S3.02A	none	human	x			x	
M01-S3.02B	natural	human & natural		x	x	x	limited
M01-S3.03A	none	human	x			x	x
M01-S3.03B	natural	none	x			x	limited
M01-S3.03C	none	human	x			x	limited (beaver)
M01-S3.03D	none	none			x		x (beaver)
T1.01A	none	human (limited)		x	x	x	x
T1.01B	none	human (limited)			x	x	x
T1.01C	none	none		x	x		x
T1.01D	natural	human (limited)		x	x		x
T1.02A	human	human		x	x		limited (incised)
T1.02B	human	human		x	x		x
T1.02C	human & natural	human		x	x		x
T1.02D	human	human			x	x	x
T1.03	none	none		x	x	x	limited (incised)
T1.04A	none	none		x	x	x	limited (incised)
T1.04B	none	none		x	x		x

Table 14. Departure Analysis Table for the White mainstem and some of its tributaries, 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.

	Constraints		Transport		Attenuation (storage)		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
White Mainstem (R) and tributaries (Cleveland Brook: R12-S2; Locust Creek: T3; Lilliesville Brook: T4)							
R11	none	human		x	x		
R12	human-Hatchery weir	human		x	x	x	limited
R13	none	human		x	x	x	limited
R12-S2.01A	natural	human	x			x	
R12-S2.01B	none	none		x	x	x	limited (incised)
R12-S2.01C	none	none		x	x	x	limited (incised)
T3.01A	natural (limited)	human		x	x	x	limited
T3.01B	natural	human		x	x	x	limited
T3.01C	none	human		x	x	x	limited (incised)
T3.01D	natural	human	x			x	
T4.01A	none	human		x	x	x	limited
T4.01B	natural	human		x	x	x	limited (incised)
T4.02A	natural (limited)	human (limited)		x	x	x	limited (incised)
T4.02B	none	human		x	x	x	limited
T4.03	none	human	x			x	

5.2 SENSITIVITY ANALYSIS

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain current sediment regime departure in the Bethel 2013 Phase 2 assessment 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 (VT-RMP 2009, Phase 2, Step 7.7; Kline 2010, Section 5.1.3). While every stream changes in time, a sensitivity rating indicates that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment.

Due primarily to the strong geologic influence of glacial Lake Hitchcock, none of the stream segments assessed in the Bethel area in 2013 were rated with Moderate or Low sensitivity. All fully assessed stream segments in the basin are Highly to Extremely sensitive to disturbance and stressors, and thus also capable of a relatively rapid response (channel evolution to reestablish equilibrium conditions) if stressors are addressed (Fig. 54; Table 15).

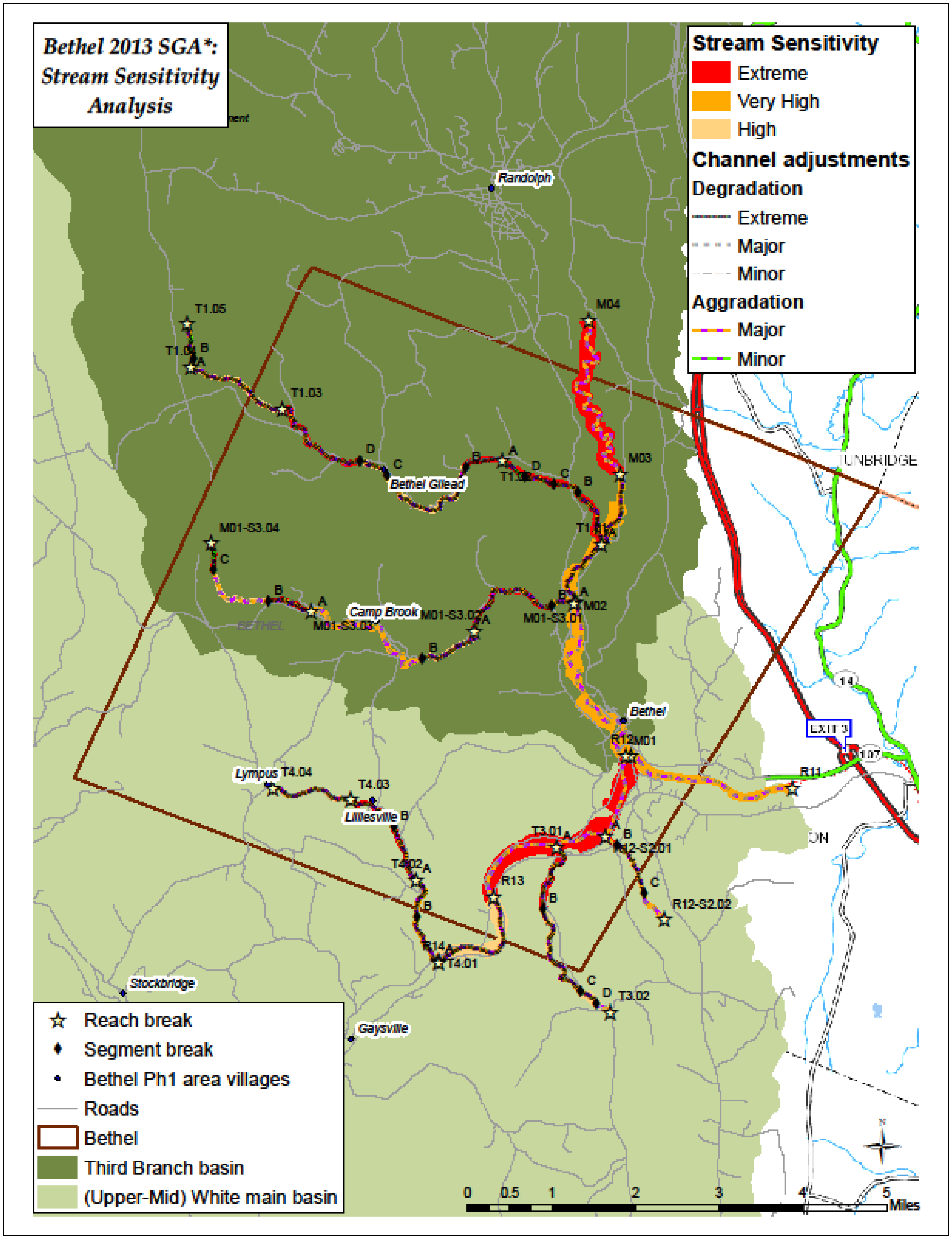


Figure 54. Stream sensitivity and current adjustments map for the Bethel 2013 Phase 2 study area.

Table 15. Stream sensitivity and current adjustments for stream segments in the Bethel 2013 Phase 2 study area.

Sensitivity	Count
Extreme	15
High	10
Very High	11

Current Adjustments	Count
Lateral and aggradation	27
Lateral	4
Aggradation and degradation	4
Stable	1

With all of the assessed streams indicating High to Extreme levels of sensitivity (Table 15) the proximity (time-wise) of the impacts of Irene to the 2013 Phase 2 study had much to do with a high degree of instability observed during fieldwork. 'Extreme' degradation scores noted on the Stream Sensitivity and Current Adjustments map (Fig. 54) are representative of the deep scouring of Irene's deluge in combination with already historically incised streams in much of the area, and is particularly notable on the tributaries as well as the narrow valleys along Third Branch reach M02 and highly channelized White mainstem reach R13 ("Last Mile" area along Rte. 107).

Sediments scoured out from the tributaries tended to drop out in less steep portions of the stream channel, and in a number of areas actually offset some historic downcutting and left the stream channel in a new location at a higher elevation than the abandoned channel. This appeared to be the case in Spring Hollow at the downstream end of Gilead Brook, and observations of concurrent aggradation and degradation there are indicative of current nickpoints and headcuts working their way upstream through recently deposited sediment slugs. Concurrent aggradation and degradation noted in 3 additional stream segments on Gilead Brook is more indicative of adjustments occurring in response to bulldozing of the channel in segments T1.01C, T1.02C and T1.02D.

Weirs were placed post-Irene to arrest some of the headcutting (bed incision) in response to heavy channelization in Gilead Brook segments T1.02 C and D as well as M1-S3.01A on Camp Brook (just upstream of Rte. 12 along Camp Brook Rd.) and T4.01A just upstream of Peavine Blvd./River Rd. along Lilliesville Brook. High (T1.02C), Very High (M01-S3.01A, T4.01A) and Extreme (T1.02D) Sensitivity on these segments may be helpful in establishing priorities for monitoring and maintenance (if necessary) of these weirs (Extreme, Very High, High in descending order of priority).

Gilead Brook T1.01C (upstream of the Rte. 12 Bridge 38) is more distant from roads, and no such weirs were placed in this segment. Extreme Sensitivity in this segment, along with removal of large wood and stone from the channel, increases the priority for further monitoring of this segment and consideration of whether high priority corridor protection and /or floodplain restoration may be warranted.

The widespread extent of lateral adjustments along with High to Extreme Sensitivity on all of the assessed streams places a high priority on preventing new and/ or reducing current corridor encroachments as both a safety measure and means to reducing long-term costs in living with streams that are highly responsive to indications of a changing climate.

6.0 PROJECT IDENTIFICATION

6.1 REACH DESCRIPTIONS — PRELIMINARY PROJECT IDENTIFICATION

Within the context of the overarching considerations discussed in previous sections of this report, reach descriptions highlighting factors leading to preliminary project identification are presented on a reach-by-reach basis in the following pages.

"Left bank" and "right bank" in the reach descriptions are referenced looking downstream. Reach maps include a "belt width corridor" drawn on either side of the stream. The width of this corridor (generally a minimum of 3-4 times the stream channel width) is based on over 30 years of research and data collected from hundreds of streams around the world, and approximates the extent of lateral adjustments likely to occur over time in a meandering stream type (VT ANR 2009 Protocols, Appendix H). "Human investments within the belt width inevitably result in structural constraints placed on the channel adjustment process to protect those investments and address associated threats to public safety. These threats will be largely avoided by recognizing the hazards created by development, incompatible with channel adjustments, within the critical belt width" (VT ANR 2009 Phase 2 Protocols, p.17).

Background imagery for the reach maps is from natural color orthoimagery with a source scale of 1:5000. For most of the reaches in the Bethel 2013 Phase 2 project area this imagery was obtained in the spring of 2012 (VCGI orthos 2012); the most recent imagery at this scale for reaches along the southern tier of the project area were flown in 2011 (VCGI orthos 2011).The scale of these maps can make it difficult to read in a single-page format as in this report, so readers with high-speed internet access are strongly encouraged to further reference the Vermont Agency of Natural Resources Atlas to access the data from these assessments in an interactive format (VT-ANR 2013).

Third Branch and tributaries

6.1 Reach M01 – Third Branch mainstem from confluence with the White mainstem (River St. /Rte. 12/107 in Bethel) to Findley Bridge

Reach M01 is a relatively developed reach on its downstream end, situated in Bethel village and extending from the confluence of the Third Branch with the White mainstem (at Peavine Park between the River St. and Peavine Blvd. bridges) past a run-of-river dam situated atop a natural waterfalls at Church St, and then past a mixed residential- commercial-industrial area including Bethel Mills and the Bethel Athletic Fields in close proximity to the river (Fig. 55). The upstream half of the reach, while similar in valley width and stream type, is less developed and is pinned against the New England Central Railroad bed on the eastern flank and lined by agricultural fields to the west (with one small residential development at Stafford Meadows). The reach was not segmented for Phase 2 assessment.

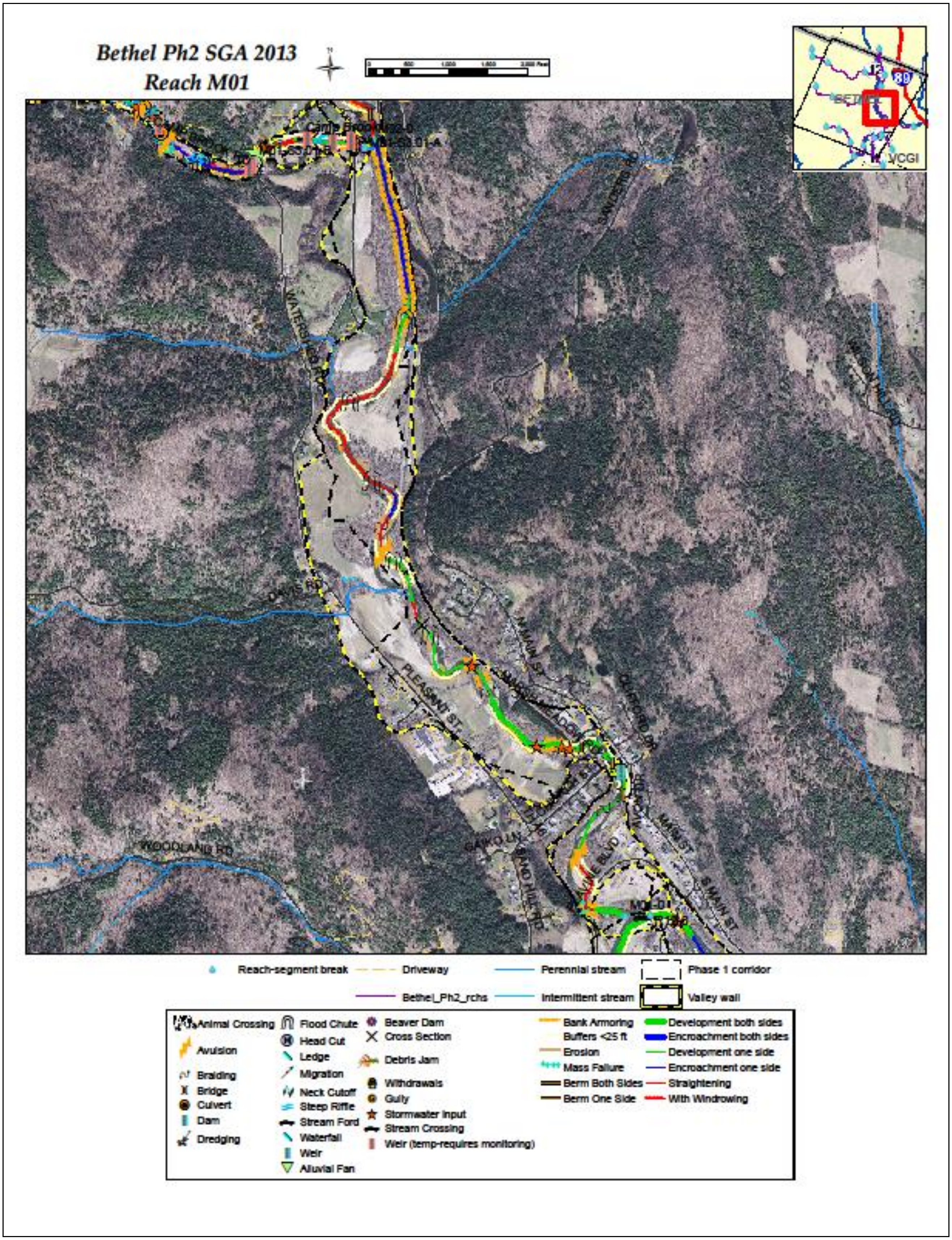


Figure 55. Bethel M01 reach map - Third Branch mainstem.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M01	13,478	C	none	Gravel	Riffle-Pool	Very Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M01-0	13,478	B	c	Gravel	Riffle-Pool	Broad
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
M01-0	Fair	Very High	2.1	III	F	C to B

The New England Central Railroad line effectively cuts the Third Branch valley nearly in half in reach M01, and disconnected oxbows (both wetlands and areas converted to ag fields) are visible behind the tracks in several locations. The stream appears to be entrenched historically (possibly due to post-glacial processes but exacerbated as a result of this straightening), and the dam/waterfalls toward the downstream end of the reach is the only grade control present to restrict further incision; localized downcutting can be expected in high flow events. Post-Irene scour pools were quite deep in several areas and often just downstream of steep faces of mid-channel bars and braided areas at sediment drop-outs. These ‘sediment plugs’ were composed of fine materials, not very stable, and will likely 'wash out' quickly - but recruitment of sediments for this replacement are coming from erodible banks, mass failures, and steep tributaries.

Primary Stressors:

- Straightening (>50% of segment length) primarily by virtue of extensive encroachments by railroad, development and roads augmented by bank armoring
- Corridor urbanization
- Extremely erodible banks (sand), buffers lacking
- Confinement of valley by elevated railroad embankments
- Bethel Mills dam contributing to upstream deposition, downstream “sediment starving”
- Loss of access to historic floodplains (incision ratio 2.1)
- Impacted/lost wetlands in corridor

Table 16. M01 Projects and Practices Table – Third Branch mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M01	Protect River Corridors	Very High	Medium	Y	Municipal corridor protection to limit development, channel management easements on key areas (visibly sedimented in 2011 imagery) should insist on buffers. Consider reorienting athletic fields to place parking on outside banks, minimize infrastructure investments; combine with boat take-out.
M01	Stream Buffers	Very High	Very High	Y	Create/protect buffer; passive regeneration or low-cost plantings due to lateral instability; be clear about belt-width and assume high instability near banks. Marsh Meadow buy-out site: plant full-width buffer to maximum amount acceptable to stakeholders (ideally close buffers on this side), consider a ***wooded*** trail; will regenerate naturally but site invites public participation for planting choices. WOOD IS CRITICAL TO STREAM STABILITY DUE TO GEOLOGY (fine sediments due to glacial Lake Hitchcock legacy). Consider relocation of two riverside baseball fields to allow buffers; bank armoring elevates risk to pump station-consider large wood design (WRP 2012-13).
M01	Remove/ Replace Structures	Next Highest	Medium	Y	Highest priority for replacement would be Peavine Blvd. bridge; would increase flood resiliency of areas immediately DS. Dam has some sediment retention above but is located on bedrock that is a natural barrier; 3 other bridges in segment (2RR and Church St.), all undersized or width reduced to undersized by angle of alignment, but would have limited gains thru replacement
M01	Watershed Strategies	Very High	Medium	N	Large wood and coarse sediments necessary to rebuild access to abandoned floodplains and/or meanders, erosion to be anticipated in this reach to establish wider floodplains and meanders at lower elevation but bank materials are mostly fines - large wood critical (BUFFERS); municipal corridor protection

6.1 Reach M02 – Third Branch mainstem from Findley Bridge upstream to where Third Branch becomes more sinuous, east of Gilead Brook Rd.

As with reach M01 further downstream, reach M02 is bisected by the New England Central Railroad bed, which effectively cuts the valley in half. This is especially evident in the disconnection of the Third Branch from a broad floodplain formerly shared with the mouth of Gilead Brook (Fig. 56). M02 is highly straightened, historically maintained against the left valley wall in the upstream portion of the reach and passing through both a railroad bridge and under Findley Bridge Rd. in the downstream portion. The reach was not segmented for Phase 2 assessment.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M02	10,220	C	none	Gravel	Riffle-Pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M02-0	10,220	C	none	Gravel	Plane-bed	Broad
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
M02-0	Poor	Very High	2.0	III	F	None

The historically shared floodplain at the confluence of the Third Branch and Gilead Brook is one of several alluvial fans in reach M02 that were likely deltaic formations deriving from tributaries at the edges of glacial Lake Hitchcock, contributing to the presence of very fine (and highly erodible) soil materials (fluvial sands, pebbly sands, and lake gravel) along much of the reach. The fine sediments present along the stream channel extend into the terraces along both banks, and the reach is primarily dominated by cropland use that is more extensive along the right bank due to the maintenance of the stream along the left valley wall.

Steep riffles composed of large deposits of these fines evidenced steep faces on their downstream ends, tapering into deep scour pools carved into the highly erodible bed by the high flows of Tropical Storm Irene. Despite the presence of bedrock outcrops on the banks along portions of M02, there were no channel-spanning grade controls in the reach and the high degree of straightening contributes to long stretches of relatively deep runs with only one relatively stable riffle noted in the reach (as opposed to sediment slugs composed of highly unstable fines).

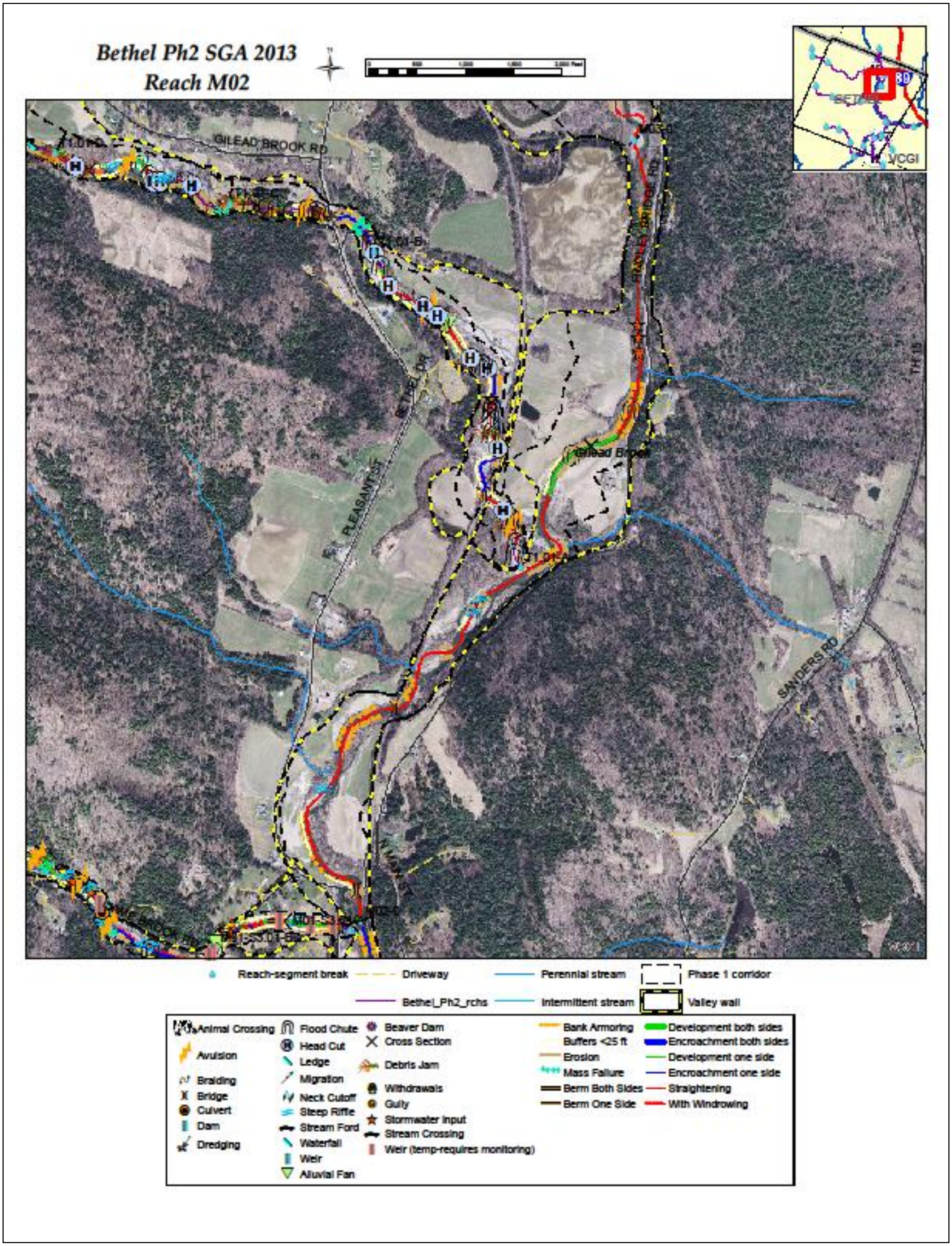


Figure 56. **Bethel M02 reach map - Third Branch mainstem.**

Primary Stressors:

- Straightening (>50% of segment length) primarily by virtue of encroachments by railroad, effects of two bridges, bank armoring and maintenance against left valley wall
- Extremely erodible banks (sand), right bank buffers lacking
- Loss of access to historic floodplains (incision ratio 2.0)
- Stormwater inputs (2 road ditches, 2 field ditches)

Table 17. M02 Projects and Practices Table – Third Branch mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M02	Protect River Corridors	Very High	Medium	Y	Municipal corridor protection to limit development; river incised, widening will be next stages but floodplain gains likely to be limited; channel management easements on key areas (visible in 2011 imagery - US Findley Bridge; across Third Branch from mouth of Gilead) should insist on buffers - this is crucial US of Gilead Brook mouth where deep incision has left "Valley wall" that is largely sand
M02	Stream Buffers	Very High	Very High	Y	Create/protect buffer; passive or low-cost due to lateral instability; be clear about belt-width and assume high instability near banks. WOOD CRITICAL TO STREAM STABILITY (fine sediments due to Lake Hitchcock legacy)
M02	Remove/ Replace Structures	Low	Low	Y	Two bridges in segment (RR and Findley Bridge), both undersized or width reduced to undersized by angle of alignment, would have limited gains thru replacement - Findley Bridge higher priority
M02	Watershed Strategies	Next Highest	Medium	N	Large wood and coarse sediments necessary to rebuild access to abandoned floodplains and/or meanders, erosion to be anticipated in this reach to establish wider floodplains and meanders at lower elevation but banks are mostly fines - large wood critical (BUFFERS); municipal corridor protection and channel easements - priority in M03

6.1 Reach M03 – Third Branch mainstem from where Third Branch becomes more sinuous, east of Gilead Brook Rd., to downstream end of oxbow between Landfill Rd and 1923 Stock Farm Rd (Beanville)

Reach M03 is a sinuous reach in the broadest portion of the Third Branch valley in Bethel, largely due to the fact that the New England Central Railroad departs from its closer proximity to the stream as in the reaches further downstream toward Bethel village. The reach was not segmented for Phase 2 assessment and is strikingly and consistently lined by deep, extensive stretches of fine-grained and highly erodible soils (Fig. 57). The reach is highly dynamic, and old abandoned channels and disconnected oxbows are visible on both sides of the stream in aerial photography (Fig. 58).

Figure 57. Third Branch reach M03 near the Bethel –Randolph town line had several mass failures where the highly erodible valley walls had fallen away for stretches exceeding hundreds of ft. in length and 40-60 ft. in height.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M03	16,267	E	none	Gravel	Riffle-Pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M03-0	16,267	F	none	Gravel	Riffle-Pool	Broad
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
M03-0	Poor	Extreme	2.3	III	F	None

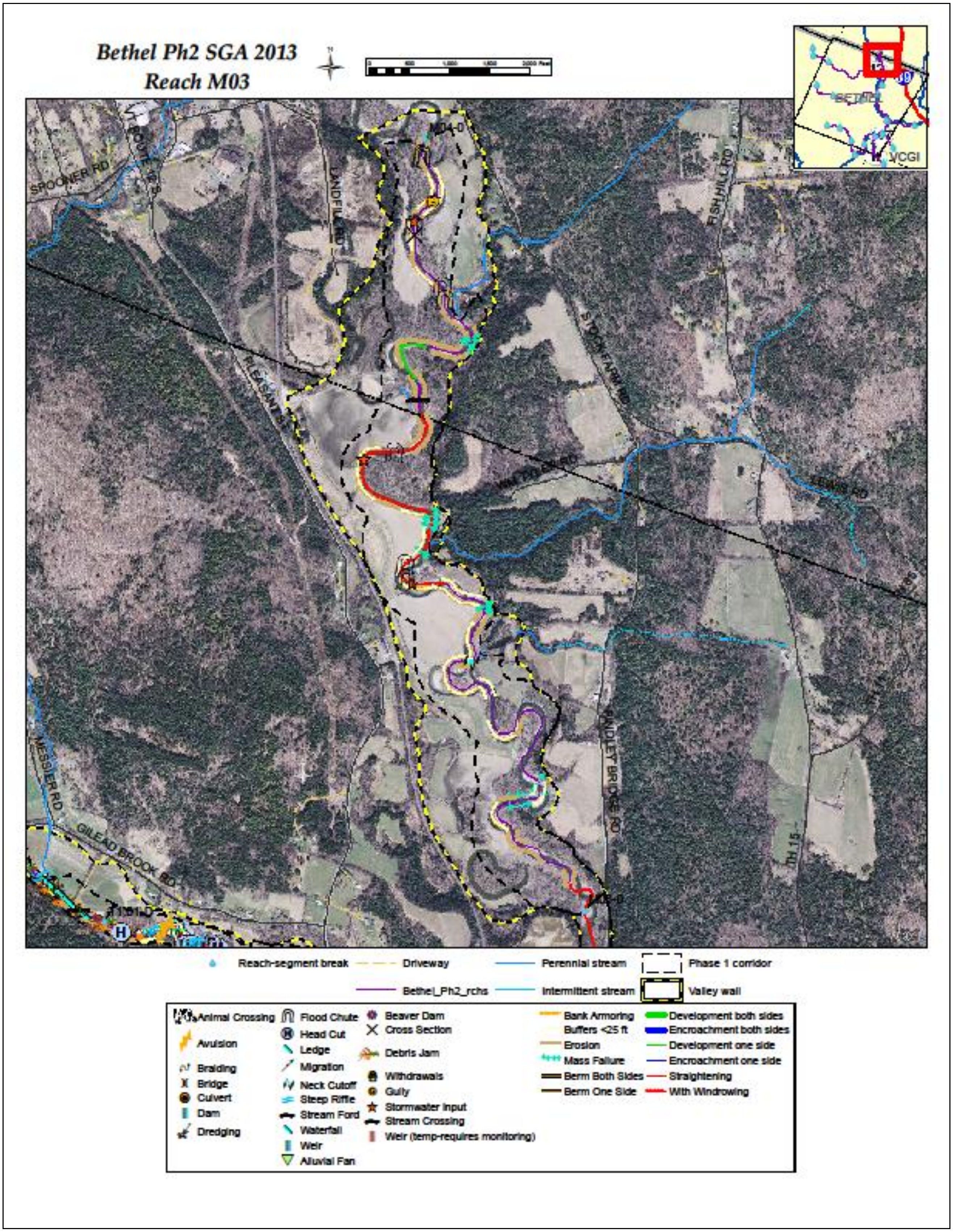
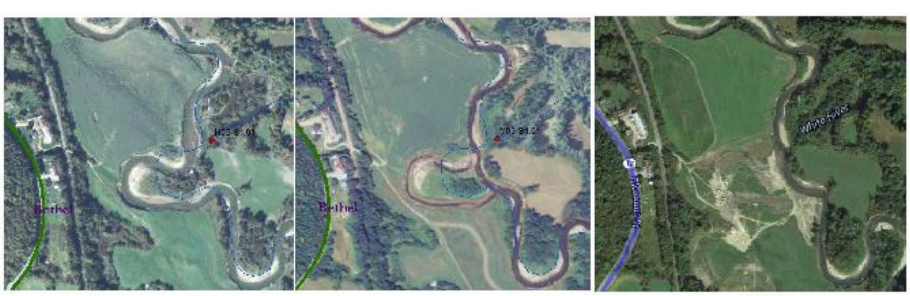


Figure 58. Bethel M03 reach map - Third Branch mainstem.

The soils along reach M03 are fertile and rich and the reach is lined by numerous stretches of relatively intact early successional floodplain forest, with similar stretches continuing upstream to Randolph village and collectively comprising a ‘Rare’ (in Vermont; not ranked globally) Significant Natural Community (Sugar maple – Ostrich fern Riverine Floodplain Forest; VT-ANR 2013). Part of the reason this type of floodplain forest is rare in Vermont is because these largely Prime agricultural soils (some requiring drainage to be cultivated) have been converted to and maintained in agricultural use. Along this portion of the Third Branch these patches of floodplain forest are interspersed with a very limited amount of development and more extensive agricultural lands (~30% of the corridor land use is crop and hay fields) that are the primary locations of riprap and bank toe stabilization that have been installed along this reach over the years, often in areas where fields have extended to the bank edge with minimal or no buffers present. Much of this bank armoring has failed over time, along with impressive stretches of highly erodible valley walls that have collapsed in several extensive mass failures (Fig. 57). The largest of these mass failures was approximately 90 ft. high and 600 ft. long, representing a significant fine sediment contribution to the stream “wash-load” (as discussed in Sec. 5.1.2, Sediment regime stressors, of this report). The fact that the banks along this reach are almost entirely comprised of similar soils explains a lot about the sediment plumes that can be observed at the downstream confluence with the White mainstem in high flow events.

The large numbers of mass failures and stretches of relatively intact floodplain forest along this reach have contributed a fair degree of large woody debris to the stream, but full debris jams were uncommon due to the size of the channel in comparison with the relatively small trees present along the banks. There were numerous partial debris jams contributing to sediment retention and formation of alternating depositional features and scour pools. The reach thus appears to have a relatively high capacity to re-establish a more stable planform in terms of slope (through formation of new meanders), but lack of grade controls predisposes the bed to further downcutting that can exacerbate the current lack of access to historic floodplains. The lack of full debris jams indicates the stream is limited in its capacity to actually rebuild access to abandoned floodplains (though channels sometimes end up at a higher elevation after an avulsion routes the stream to a new location), and further channel evolution is likely to continue to manifest as rapid widening, channel avulsions and neck cut-offs in response to high flows contained within the incised channel (Fig. 59).

Third Branch White River – Bethel, VT



2011 (pre-Irene) 2012 2013

An exaggerated meander was primed for neck cut off, which presumably occurred during TS Irene in 2011. The resulting oxbow has subsequently been filled in (land use is agricultural) and the channel armored in a straight alignment where the neck-cutoff occurred.

Figure 59. Neck cut-off along the Third Branch before and after Tropical Storm Irene.

Figure 60. Bank along the neck cut-off was roughly 8 ft. high and completely eroded in August 2013 (left) and by October 2013 had been riprapped (right) with relatively small stone that is likely to be subject to failure in future high flows along this dynamic reach.

These dynamics place a high value on minimizing stream encroachments throughout a wide corridor and retaining, protecting and restoring wide stream buffers that can further mature along reach M03. Bank armoring observed along the reach is likely to be temporary due to the highly dynamic nature of the stream in this area (Fig. 60), and limiting further installations (this may require compensation for foregoing current agricultural land use in some areas) is highly recommended as a means to reduce further erosion and mass failures downstream as well as allowing the stream to establish a wider floodplain at a lower elevation.

Primary Stressors:

- Extremely erodible banks (silt and sand), buffers lacking on both banks (and intensive ag use/manure spreading)
- Straightening (<50% of reach length) primarily by railroad embankments (less than M01 and M02) and bank armoring
- Road density within subwatershed
- Loss of access to historic floodplains (incision ratio 2.3)
- Impacted/lost wetlands in corridor

Table 18. M03 Projects and Practices Table – Third Branch mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M03	Protect River Corridors	Very High	Very High	Y	Municipal corridor protection to limit development; channel management easements on key areas (deposition visible in 2011 aerial imagery); high priority area due to both benefits for geomorphic equilibrium and Significant Natural Community (Sugar Maple-Ostrich fern floodplain forest) extending up to Randolph; neck cut-off area at Townsend Farm was filled, increased risk of mass failures on opposite bank; emphasizes importance of channel management easements
M03	Stream Buffers	Very High	Very High	Y	Create/protect buffer; passive or low-cost due to lateral instability though some larger stock possible for outside edge of belt-width in areas of existing buffer; be clear about belt-width and assume high instability near banks. WOOD IS CRITICAL TO STREAM STABILITY DUE TO GEOLOGY (fine sediments due to Lake Hitchcock legacy)
M03	Restore Incised Reach	Very High	Very High	Y	Passive restoration highlighting corridor protection and channel management easements; extreme sensitivity and relatively few corridor encroachments
M03	Watershed Strategies	Very High	Very High	N	Large wood and coarse sediments necessary to rebuild access to abandoned floodplains and/or meanders, erosion to be anticipated in this reach to establish wider floodplains and meanders at lower elevation but bank materials are mostly fines - large wood critical (BUFFERS); municipal corridor protection, explore possibilities for tying protections to Randolph Floodplain Forest

6.1 Reach M01S3.01 – Camp Brook from the confluence with the Third Branch of the White River upstream ~1.5 mi to downstream end of fields at 1523 Camp Brook Road

Reach M01-S3.01 runs roughly parallel with Camp Brook Road for most of its length (Fig. 61). It was broken into two segments based primarily on differences in valley width. Differences in corridor encroachments, slope and substrate, and banks and buffers provided secondary reasons for segmenting. Downstream segment M01S3.01A is underlain by pebbly and fluvial sands on an alluvial fan where Camp Brook enters a broad floodplain shared with the Third Branch.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M01-S3.01	8,811	B	none	Cobble	Step-Pool	N/A

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M01-S3.01A	1,492	B	None	Gravel	Plane bed	Very Broad
M01-S3.01B	7,319	F	None	Gravel	Plane bed	Narrow
	Geomorphic condition	**Stream sensitivity**	**Incision ratio**	**Channel evolution stage**	**Channel evolution model**	**Stream Type Departure**
M01-S3.01A	Poor	Very High	3.0	III	F	C to B
M01-S3.01B	Poor	Extreme	2.6	III	F	B to F

M01S3.01A (1,491 ft. in length) is the shorter of the two segments. As Camp Brook enters the larger valley of the Third Branch, valley walls are essentially shared between these streams and slopes are greatly reduced from the upstream segment of this reach. Historically this segment of stream, located on an alluvial fan in a flat valley, would likely have changed location frequently. However, USGS topographic maps dating back as far as the 1920s (UNH Dimond 2014) and Google Earth historical aerial imagery since the 1990s appear to indicate long-standing channelization and straightening of this section of stream.

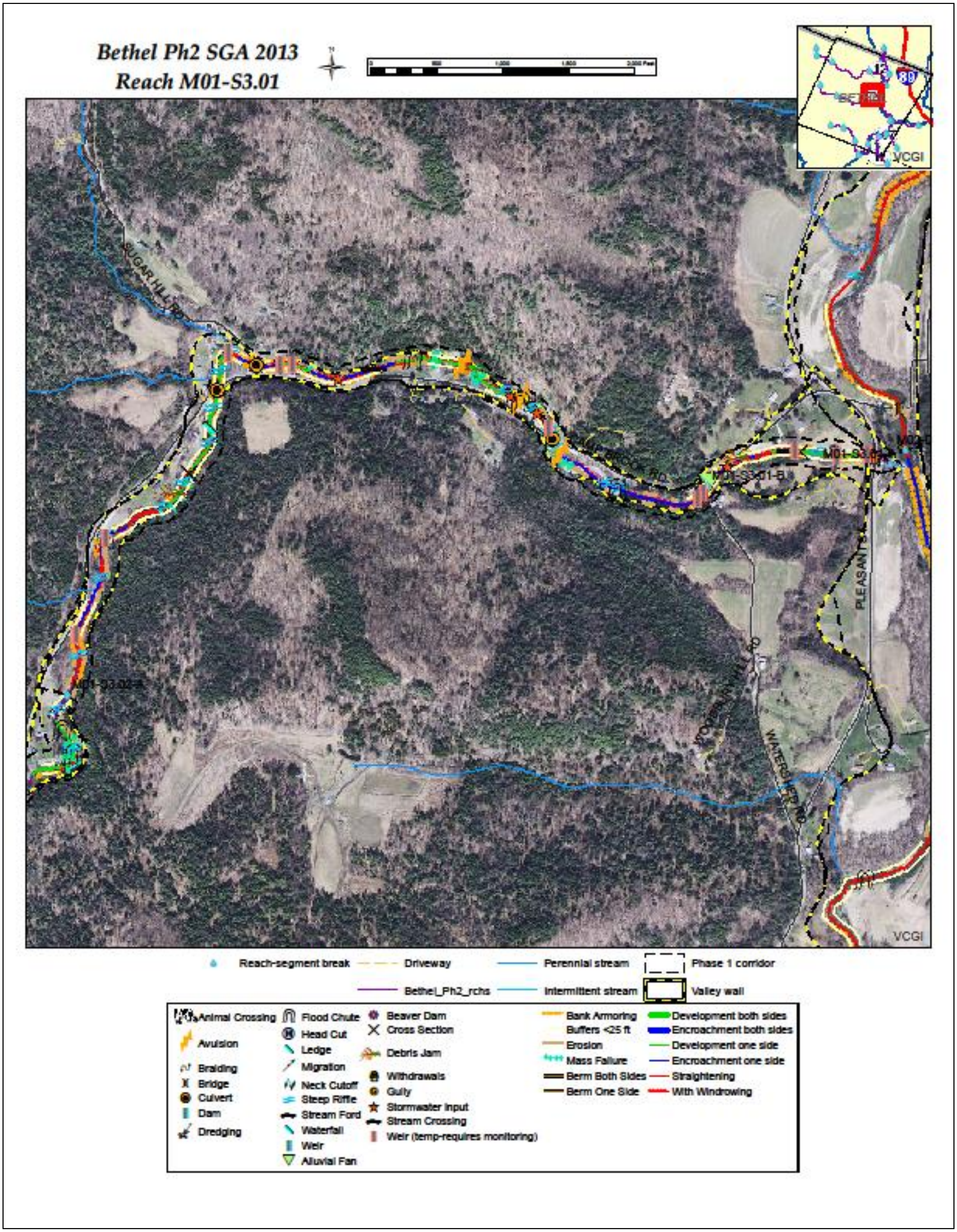


Figure 61. Bethel M01S3.01 reach map – Camp Brook.

Maintenance of road and house encroachments essentially pins the stream in place in M01S3.01A at this point in time, and the segment has lost access to its original floodplain. Human encroachments are common and extensive in this lower segment, and wooded buffers are generally absent (Fig 62). This may have been the case pre-Irene, but post-Irene dredging (with windrowing) served to exacerbate this issue. A major bridge on Route 12 lies at the lower end of this segment and there is a town bridge on Watershed Rd on the upstream end of the segment, and post-Irene dredging was conducted in the vicinity of both these structures. As part of a mitigation project to offset the impacts of extensive dredging and straightening, with consequent downcutting, numerous steps were constructed to arrest additional incision (pers. comm. Jim Ryan, VT DEC White River Watershed Basin Coordinator, May 2013). In the lower portion of the segment where the road is not right at the stream bank a restoration project on the Floyd property (funded through crowd-sourcing, CWF 2012; pers. comms. Mary and Greg Russ, White River Partnership Executive Director and Project Manager, respectively) installed rock weirs and log veins and planted native shrubs to help re-establish more natural channel dimensions and move the stream more quickly toward equilibrium conditions (Fig. 62). Flood benches created in this effort are considerably less substantial than the historic valley floodplain, but are likely to help to dissipate energy in high flows and significantly improve flood resiliency and instream habitat; the project will be monitored by the White River Partnership for five years.

Figure 62. Left and right: M01S3.01A encroachment is common, as seen with road work, new riprap following Irene storm damages, and house located in the floodplain. Right: View from the Route 12 bridge shows post-Irene mitigation including rock weirs constructed to arrest head cutting in a dredged area. Scour was frequently noted in the vicinity of these weirs, but the photo (right) shows evidence of recent sedimentation. More difficult to see is a recent planting of native shrubs along the right bank where a new flood bench was created.

M01S3.01B is the much longer of the two segments (7,318 ft. in length). This segment has more hilly terrain and a narrower valley with steep walls. Corridor encroachments and post-Irene manipulations are common for this segment, but relative to the length of the segment are much less dominant than in segment A. Bank erosion and mass failures are more noticeable here, as the valley wall is steep sided and equipment alterations have not so thoroughly obscured indications of stream-powered impacts (Fig. 63). Buffer widths vary, but forested buffer is generally present on at least one bank and is quite often present on both banks. Multiple terraces indicate historic incision, and post-Irene excavations have further degraded the streambed and decreased the possibility of accessing historic floodplains (Fig. 63).

Figure 63. Left: Forested buffers and considerable bank erosion are common in M01S3.01B. Right: Stream channel after post-Irene dredging/windrowing.

Most of the extreme erosion noted in M01S3.01B appears to be due to the high flows and transport of debris and sediment in a relatively narrow valley during Irene, and complete loss of access to historic floodplains leaves little room for the stream to establish a more stable slope and planform. In a setting such as this large woody debris and sediment retention are a means to step-pool formation and rebuilding floodplain access, which would provide a pressure relief valve and means for dissipating stream power in areas that these processes can proceed without conflict with corridor encroachments. Steep riffles, indicating a build-up of sediments, were common in this segment following Irene. Some reconstruction of flood benches and installation of weirs has been done to help mitigate high-flow stress and arrest further incision in those areas. Unless wider floodplains are re-accessed and greater channel roughness is developed, however, this segment is likely to continue experiencing and transferring heightened flood impacts.

Additional stressors in M01S3.01B include three culverts and one bridge, all of which create severe channel constrictions. Road encroachment is generally found in these areas as well, and the presence of new riprap and culverts indicate that these areas were damaged during Irene or in high flows since Irene (Fig. 64). The new culverts are still major channel constrictions and are likely prone to fail again in the future. The small size of the new riprap also appears susceptible to failure in future high flows. Landowners along this section of stream indicated multiple flooding events since Irene with water backing up at undersized culverts under Camp Brook Road. One landowner watched as the stream avulsed into a new channel and then as a road crew put it back where it had been originally (Fig. 64).

Figure 64. Left: New undersized culvert placed after Irene. Right: This landowner says the stream avulsed closer to Camp Brook Road (left in the picture) in a storm since Irene, and a road crew came and put it back in the original channel as seen here.

Primary Stressors:

- Historic incision and post-Irene dredging/windrowing have reduced access to floodplain (incision ratios: M01-S3.01A: 3.0, M01-S3.01B: 2.6)
- Extensive straightening (virtually all of both segments), primarily due to road encroachments but also near buildings and through the effects of undersized road crossings
- Multiple stormwater inputs (M01-S3.01: 3, M01-S3.01B: 11)
- Small riprap along road edges that abut the stream channel
- Road crossings with undersized culverts/bridges (M01-S3.01B).

Table 19. M01-S3.01 Projects and Practices Table – Camp Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M01-S3.01A	Stream Buffers	Medium	Medium	Y	Passive or low-cost due to lateral instability, depositional area. Some plantings in place post-Irene (in conjunction with restoration of channel dimensions); monitor and augment.
M01-S3.01A	Watershed Strategies	Very High	Next Highest	Y	STRUCTURES; Municipal corridor protection to limit development; hazard mitigation plan in process: ensure landowners are aware of buyout and elevation options (emergency operations plan in place, 2013 bridge and culvert standards adopted; kudos); create buffer connectivity
M01-S3.01B	Stream Buffers	Medium	Medium	N	Upstream of Sugar Hill Rd esp.; passive or low-cost due to lateral instability; full buffers may trap wood that created jam at culvert;
M01-S3.01B	Remove Berms	Medium	Low	Y	Limited opportunity for cuffing off windrow at US end of reach; minor gains in floodplain accessibility, could be combined with similar opportunity in next segment US
M01-S3.01B	Remove/ Replace Structures	Very High	Next Highest	Y	1 bridge, 3 culverts in segment undersized and prone to repeat failure (bridge 27 ft, culverts 13.5, 17, 9; ref bkf 32, field 41.8); well sized culverts limit hourglass effect lending to debris jams
M01-S3.01B	Watershed Strategies	Very High	Very High	Y	STRUCTURES replacements; Municipal corridor protection to limit development; hazard mitigation plan in process (emergency operations plan in place, 2013 bridge and culvert standards adopted; kudos); close buffers as much as possible.

6.1 Reach M01S3.02 – Camp Brook from downstream end of fields at 1523 Camp Brook Road to upstream end of field upstream of Pond Road bridge

M01S3.02 was separated into two segments for Phase 2 assessment, primarily based on differences in channel encroachments, but also due to differences in valley width, channel dimensions, and substrate type. Segment A was classed as a subreach because it actually appears to have a different reference stream type due to its location in a narrower portion of the valley with less available floodplain even under reference conditions. Road encroachment is a major factor for the entire reach, but is particularly extreme in segment A (Fig. 65). Channel constrictions are abundant throughout but more numerous in segment B. Storm impacts from Irene and more recent flooding were noticeable throughout the entire reach.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M01-S3.02	14,638	C	b	Cobble	Riffle-pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M01S3.02A	4,418	F	none	Cobble	Plane bed	Narrow
M01S3.02B	10,217	C	b	Gravel	Plane bed	Broad

Segment ID	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
M01S3.02A	Poor	High	4.5	III	F	B to F
M01S3.02B	Poor	Very High	2.3	III	F	none

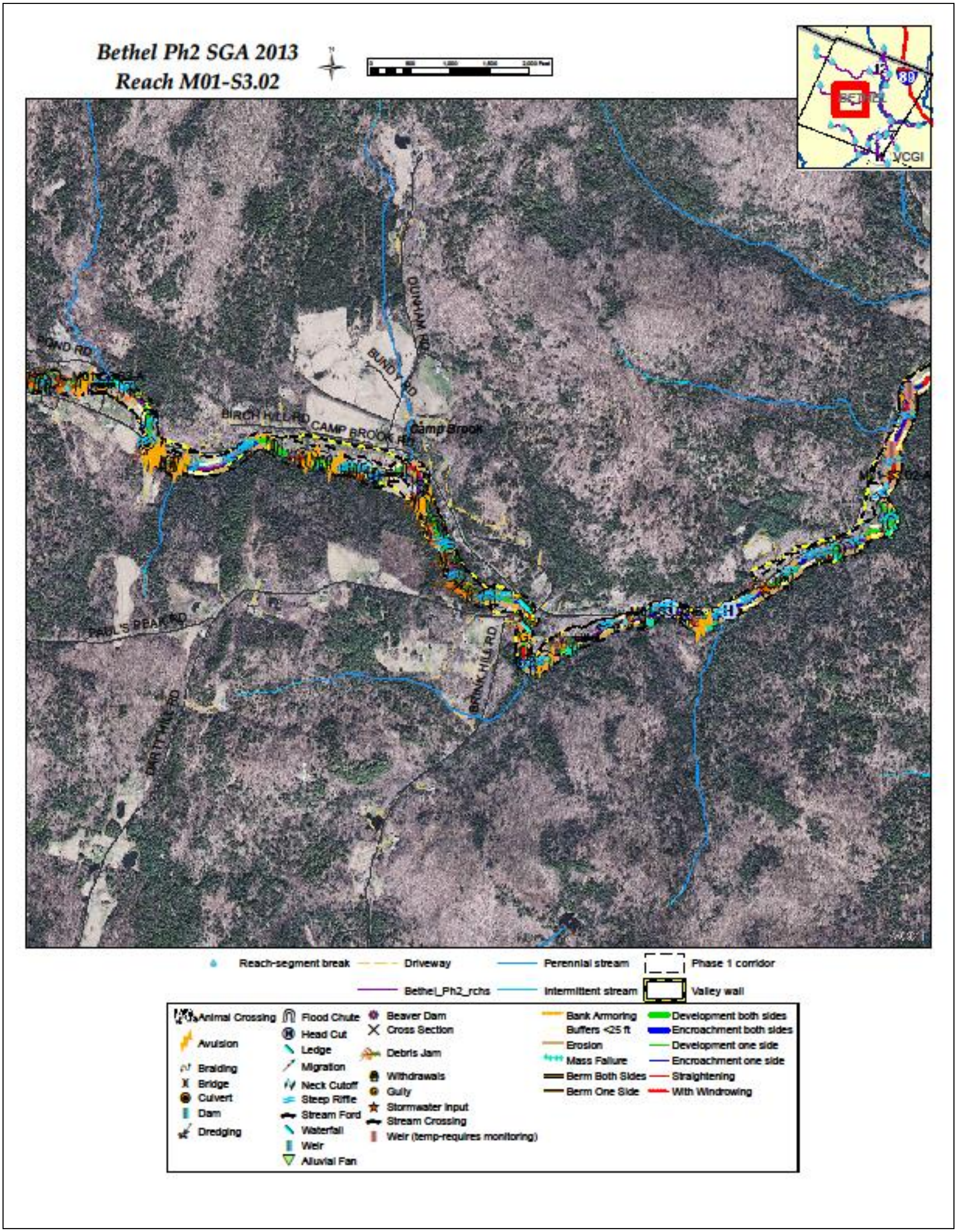


Figure 65. Bethel M01S3.02 reach map – Camp Brook.

Segment M01S3.02A, the shorter of the two segments (4,418 ft.), has a Narrow valley confinement type and road encroachment for its entire length. Approximately 75% of this segment is straightened by virtue of road encroachment, development impacts, and bank armoring, and there are three surface water inputs from the road. Mass failures are common and large (Fig. 66). Snagging and dredging (with windrowing) were common post-Irene. The stream has lost all access to floodplain in this segment, and multiple terraces indicate several historic incision processes. Steep riffles, a buildup of sediments, were common in this segment and are likely related to mass failures and road/bridge/culvert impacts during recent storms.

Figure 66. Left: Road encroachment typical of entire length of M01S3.02A; new riprap indicates Irene damage. Typical of this segment, riprap appears small and likely to wash in subsequent storms. Right: A particularly large mass failure in the downstream portion of Segment A.

M01S3.02B is the longer of the two segments (10,217 ft.). Areas of extreme widening alternated with areas of deeply incision or occasional sections that looked relatively un-impacted by recent floods. Encroachments are common, but roughly 60% of the segment is free of encroachment and forested buffers are commonly present on both sides of the stream. Approximately 30% of the segment length appears straightened by virtue of encroachments and the effects of undersized stream crossing structures; primary encroachments in this segment include occasional road encroachments and buildings within the stream corridor (Fig. 67). At least one private bridge in M01S3.02B failed during Irene (or another recent storm event) (Fig. 67).

Figure 67. Left: New culvert to replace structure washed out in Irene is still very undersized and likely to wash again. Right: Development encroachment in the stream corridor of M01S3.01B.

As with segment A, steep riffles, bank erosion, and mass failures were all common in M01S3.02B. In addition, segment B had numerous debris jams and channel avulsions (Fig 68). The abundance of these features was likely due to the combination of abundant woody material along the stream banks and a broader valley providing sufficient room for the stream to avulse around debris jams. Avulsions often leave behind dry channels that can be accessed as flood chutes in future high flows, and frequently establish meanders that reduce the slope of the stream and thus diffuse stream power in high flows (though in situations where the avulsion shortens stream channel length, the slope - and attendant stream power in high flows - may be increased). In a setting such as this, high levels of erosion and mass failures can provide raw materials for rebuilding access to abandoned floodplains (particularly when trapped behind large and stable woody debris that can sometimes be seen forming new steps) as well as the deposition that forms point bars on inside bends and starts more pronounced meander formation. These processes are vital to diffusing stream power, lessening the impacts of high flows, and providing greater stream stability; if development and encroachments are in conflict with these processes, efforts to arrest these processes may lock the stream in a cycle of repeat damage from high flows contained and amplified in a straightened and incised channel. Until current open areas of erosion and mass failures re-vegetate and benefit from more diffuse flows in high flow events, they are likely to remain unstable and prone to further failure and continued sediment contributions.

Figure 68. Left: Site of failed bridge in M01S3.01B with temporary footbridge (left) and abutment form (right), presumably for a new bridge. Right: Stream avulsion with old channel on the right.

A major feature within reach M01S3.02 (centrally located in the overall reach, which is in the downstream portion of Segment B) is a 300 foot long bedrock gorge at the Brink Hill Road Bridge, with a bedrock channel constriction of 12.8 ft.. There are, additionally, three other grade control features in this segment – two in the vicinity of the gorge and one at the upstream end of the segment. Bedrock features serve to limit incision and provide a stabilizing force for this reach as a whole, and likely explain why segment B has retained more floodplain access than other parts of Camp Brook (and is not so incised as to cause a reclassification of the stream type). There are multiple terraces in evidence that do indicate a history of incision, however, and an exposed spring box that apparently was once sitting in the stream channel gives a good indication that recent incision was experienced in portions of the segment where bedrock grade controls were not limiting downcutting (Fig. 69).

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Figure 69. This exposed spring-box was reportedly sitting on the stream channel bottom in the recent past, previous to bed incision (downcutting) in Irene and other high flows.

Primary Stressors:

- Restriction of access to historic floodplains (incision ratio: M01S3.02A, 4.5; M01S3.02B, 2.3)
- Straightening (approximately 75% of M01S3.02A and 30% of M01S3.02B), primarily due to road encroachment but also near buildings and through effects of undersized road crossings
- Small riprap along road edges that abut the stream channel
- Road crossings with undersized culverts, likely reconstruction of bridge on a bend, damaged in Irene (M01S3.02B).
- Abundant mass failures and erosion, heavy sediment loads

Table 20. M01-S3.02 Projects and Practices Table – Camp Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M01-S3.02A	Stream Buffers	Medium	Medium	Y	Opportunities limited as primary areas lacking buffers are road embankments; investigate Better Back Roads design guidelines
M01-S3.02A	Remove Berms	Medium	Low	Y	Limited opportunity for cuffing off windrow at DS end of reach; could be combined with similar opportunity in next segment DS -better floodplain gain in M01-S3.02A but stream more deeply incised
M01-S3.02A	Watershed Strategies	Next Highest	Next Highest	Y	Explore opportunities for stormwater BMPs, esp. ditching practices and increasing infiltration; investigate Better Back Roads designs for road embankments; Municipal corridor protection to limit development
M01-S3.02B	Stream Buffers	Medium	Medium	Y	Create/protect buffer; primarily passive as buffers generally decent, lateral and vertical instability; could use augmentation to belt-width in several areas particularly near Dunham Rd
M01-S3.02B	Remove/ Replace Structures	Very High	Very High	Y	1 bridge and 2 culverts in segment undersized - Pond Rd culvert esp. - likely to avulse but sedimentation consistent with channel evolution DS; temp footbridge in place near Birch Hill Rd after former bridge destroyed in Irene - appeared headed for replacement; permit process should require bankfull sizing but recommend 120 pct in this setting
M01-S3.02B	Watershed Strategies	Very High	Next Highest	Y	STRUCTURES replacements - sediment continuity and ability to pass large wood critical to channel evolution and flood hazard mitigation; municipal corridor protection; hazard mitigation plan in process-highlight funding options for buyouts and relocations. This segment is least incised attenuation asset on Camp Brook. Close buffers as much as possible.

6.1 Reach M01S3.03 – Camp Brook from upstream end of field upstream of Pond Road bridge, ~1.8 miles upstream to beaver ponds east of Charlie Wilson Road

Reach M01-S3.03 was broken into 4 segments for phase 2 assessment. Segmentation was based primarily on changes in channel dimensions, but differences in banks and buffers, valley width, and encroachments were also important. Overall topography for the reach is wide-ranging and explains some of the reason for segmentation. Downstream segment M01-S3.03A is similar in many respects to the upstream segment B of M01-S3.02. Slopes are generally 2-4%, and the valley is Narrow with steep to extremely steep sides. In M01-S3.03B the valley narrows further to become Semi-confined with extremely steep valley walls. Bedrock grade controls are found in this segment and the channel is steeper (>4%). In M01-S3.03C the valley broadens again (to Narrow). Slopes return to 2-4% and the valley has moderately steep to steep walls. There is evidence of historic beaver dams in segment C, but no recent activity. M01-S3.03D was not assessed (per protocols) due to active beaver dams and lack of a clear stream channel (Fig. 70).

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
M01-S3.03	10,427	A	none	Cobble	Step-Pool	Narrow

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
M01-S3.03A	3,300	F	none	Gravel	Plane bed	Narrow
M01-S3.03B	5,207	B	a	Cobble	Step-pool	Semi-confined
M01-S3.03C	1,264	B	none	Cobble	Plane bed	Narrow
M01-S3.03D	656	NA (Beavers)	NA	NA	NA	Very Broad
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
M01-S3.03A	Poor	Extreme	3.7	III	F	C to F
M01-S3.03B	Fair	High	2.1	III	F	None
M01-S3.03C	Fair	Extreme	2.9	III	F	C to B
M01-S3.03D	NA	NA (Beavers)	NA	NA	NA	NA

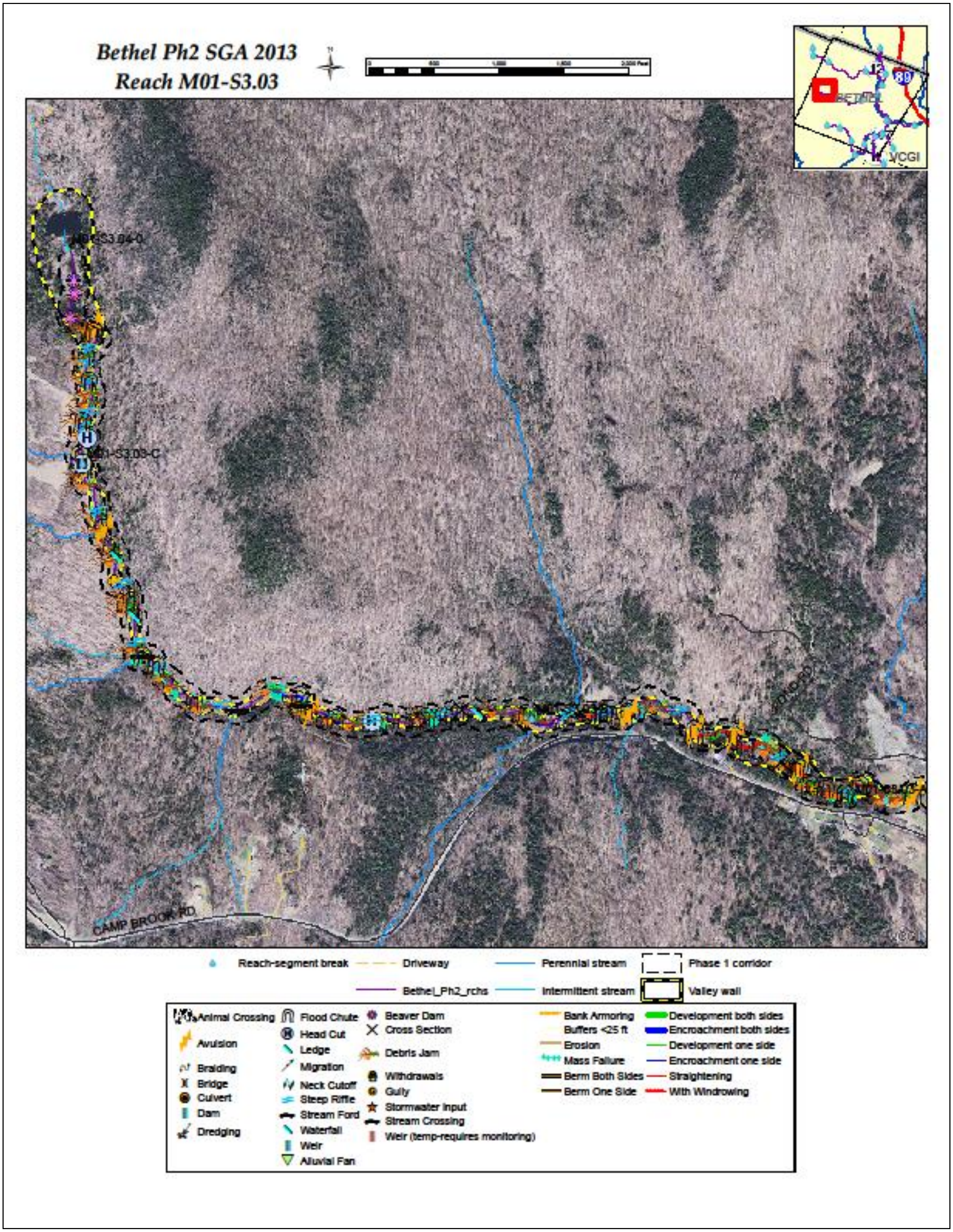


Figure 70. Bethel M01S3.03 reach map – Camp Brook.

Tropical storm Irene initiated significant adjustments in reach M01S3.03, with impacts becoming more and more dramatic from the upstream to the downstream end. There are two main tributary inputs to the reach. The first enters at the upstream end of Segment B, bringing drainage water in from the west. A culvert on Charlie Wilson Road that crosses this tributary appeared to have failed in recent flood events, creating significant gullies and mass failures on Camp Brook. The second tributary enters at the upstream end of Segment A, bringing drainage flow from the southwest. There are wetlands associated with the headwaters of this tributary, and road surface water enters as the tributary crosses and then runs alongside Camp Brook Road. These tributaries bring significant additional water into the system and channel enlargement and storm flow impacts related to Irene were distinctly visible below the confluences of these streams.

All three of the segments assessed on M01S3.03 show considerable downcutting and loss of available flood plain, with abandoned floodplains evident in older terraces that attest to historic incision processes. For the upstream segments, historic incision is likely due in part to pulse flows resulting from historic beaver dam failures upstream. Downstream segment M01S3.03A has the addition of frequent human encroachments that contribute to straightening and increase the stream's tendency to incise when stream power is not diffused by the reduced slope created by meanders. Tropical Storm Irene contributed to recent incision in many areas along this reach, gouging out the stream channel and leaving the stream at a lower level than it was previously. In intermittent areas sediment was deposited in large "slugs" or retained behind large woody debris, raising the stream bed. Overall the bulk of sediment continued downstream, and this reach remained primarily incised.

M01S3.03A (3,300 ft.) has been the most extensively affected by human activity. Camp Brook Road parallels the entire length of the segment and is sometimes less than 150 ft. from the right bank. Surface water inputs from the road are common and there are gullies associated with some of these inputs. A small woods road runs along the right stream bank in the northern part of the segment, interrupting the forested buffer and contributing some sediment inputs from road runoff. A house encroaches on the right bank mid-segment (Fig. 71), and there was extensive mining-dredging activity in the vicinity of this homestead related to post-Irene "clean up" work. The wider valley found in this segment (compared with upstream Segment B) allows for greater movement of the stream within the valley. The stream edges are almost entirely buffered by forest and erosion from recent storm events (Irene in particular) has caused much of this wood to enter the stream channel. This wood was providing abundant material for debris jams (11), sediment retention, and resulting avulsions (4) (Fig. 71).

Figure 71. Left: Encroachment in segment M01S3.03A, with junk vehicles visible along a road along the right bank and signs of gravel mining and dredging in the stream channel. Right: Abundant woody material in this wider valley has created opportunities for debris jams and channel avulsions.

M01S3.03B is the longest of the three segments (5,207 ft.). Human impacts are fewer here, with timber harvesting being the primary human impact within the stream corridor. Old woods roads alongside and crossing the stream attest to periodic harvesting activity. Recent harvesting has occurred within the last few years and included crossings as well. It appeared that the harvesting probably took place in the winter and some skidding was done in the stream channel (Fig. 72). This segment is characterized by a narrow, steeper, valley which is entirely forested. Mass failures were abundant, with bank erosion and occasional gullies also present (Fig.72). As a result of these erosional processes abundant woody material has entered the stream channel and debris jams were numerous. Channel avulsions were not common, likely due to the slope and shape of the valley in this segment.

Figure 72. Left: Recent harvesting activity, including stream crossings, in segment M01S3.03B. Right: Mass failures are a common feature of this segment.

Bedrock grade controls provide some stability to the stream bed in M01S3.03B and arrest incision immediately upstream (Fig. 73). The incision level for this segment is lower than for Segments A and C, largely due to the presence of bedrock in the channel.

Figure 73. Bedrock grade control in segment M01S3.03B.

M01S3.03C is high in the watershed and somewhat buffered from storm flows by having impounded wetlands upstream (although these same wetlands can contribute significant amounts of water when beaver dams burst or a saturation point is otherwise exceeded). The channel is significantly narrower in width than downstream segments, but despite its smaller size there was still extensive evidence of recent bank erosion and incision in the segment. Human disturbance is minimal in M01S3.03C, and although there is evidence of past harvesting in the area there were no signs of recent activity. Recent impacts here appeared to be largely due to the failure of upstream beaver dams, and high degrees of incision noted in this segment likely also reflect downcutting through fine sediments formerly deposited behind historic beaver dams (Fig. 74).

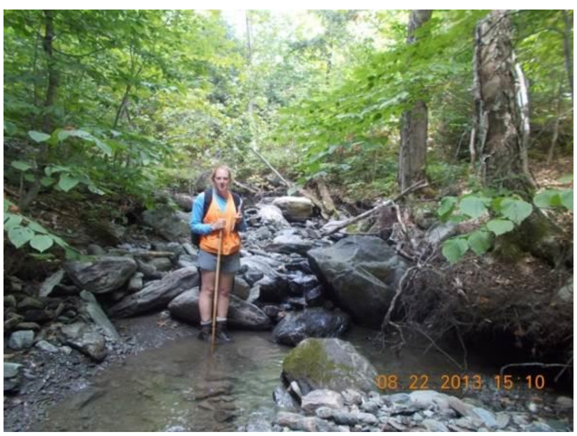


Figure 74. High incision ratio noted in M01S3.03C maybe be due to a combination of failure of upstream beaver dams and downcutting through fine sediments accumulated during historic times of impoundment within the segment.

Primary Stressors:

- Loss of access to historic floodplains (incision ratios: M01S3.03A: 3.7; M01S3.03B: 2.1, M01S3.03C: 2.9)
- Straightening (50% of segment A) primarily due to road encroachment.
- Stormwater inputs from tributaries (segments A and B), and road ditch flows (segment A).

Table 21. M01-S3.03 Projects and Practices Table – Camp Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M01-S3.03A	Protect River Corridors	Very High	Next Highest	Y	Municipal corridor protection to limit development; Consider channel management easement at US end of segment (11 ac parcel) -Segment plays important role in attenuating inputs from US but is relatively steep, deeply incised; transport of coarse sediments is needed for DS channel evolution as well
M01-S3.03A	Remove/Replace Structures	Medium	Low	Y	undersized bridge is close to 90 pct bankfull, appears recently replaced; if opportunity arises again, recommend sizing at 120 pct in this setting
M01-S3.03A	Watershed Strategies	Medium	Medium	Y	assess sources of recent gullies and possible remediation strategies; priority only lower because of need for coarse sediments in DS channel evolution and presence of large wood already toppling into gullies, likelihood of relatively rapid self-remediation; municipal corridor protection; consider channel management easements with landowners in mid and US sections (where recent dredging occurred) to allow passive restoration

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
M01-S3.03B	Protect River Corridors	Low	Low	Y	Municipal corridor protection to limit development; priority only lower because of largely intact forested buffers and little apparent threat of encroachment, but educational outreach concerning importance of not snagging channel following floods would be valuable
M01-S3.03B	Restore Incised Reach	Very High	Very High	Y	Accommodate passive restoration, primarily through municipal corridor protection to limit development
M01-S3.03B	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development
M01-S3.03C	Protect River Corridors	Very High	Very High	Y	Municipal corridor protection to limit development; largely intact forested buffers and little apparent threat of encroachment
M01-S3.03C	Restore Incised Reach	Very High	Very High	Y	Accommodate passive restoration, primarily through municipal corridor protection to limit development
M01-S3.03C	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development
M01-S3.03D	Not assessed	NA	NA	NA	Excluded from assessment per protocols - Beaver influenced, no clear channel

6.1 Reach T1.01 – Gilead Brook from confluence with Third Branch to Gilead Brook Rd. pull-off upstream of cropland across from Messier Rd.

Reach T1.01 is nearly 1.5 miles long and roughly corresponds with the extent of glacial Lake Hitchcock along Gilead Brook; the Broad (likely Very Broad historically) valley confinement type and underlying soils (lake gravels and pebbly and fluvial sands) reflect that legacy. The reach was broken into four segments for Phase 2 assessment based on changes in valley width, bank and buffer conditions, and degree of post-Irene instream equipment work and channel alterations. The lake sediments present along most of the reach, particularly in the downstream sections, give the stream an Extreme level of sensitivity to changes in watershed inputs; there were numerous channel avulsions and migrations evident along the reach post-Irene (Fig. 75).

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T1.01	9,725	C	None	Gravel	Riffle- pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T1.01A	4,096	C	None	Gravel	Plane bed	Broad
T1.01B	1,722	F	None	Gravel	Riffle- pool	Broad
T1.01C	2,135	F	None	Gravel	Plane bed	Broad
T1.01D	1,772	F	None	Cobble	Riffle- pool	Very Broad

	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Depart ure
T1.01A	Poor	Extreme	2.1	III	F	None
T1.01B	Fair	Extreme	2.2	III	F	C to F
T1.01C	Poor	Extreme	2.3	II	F	C to F
T1.01D	Fair	Extreme	2.6	III	F	C to F

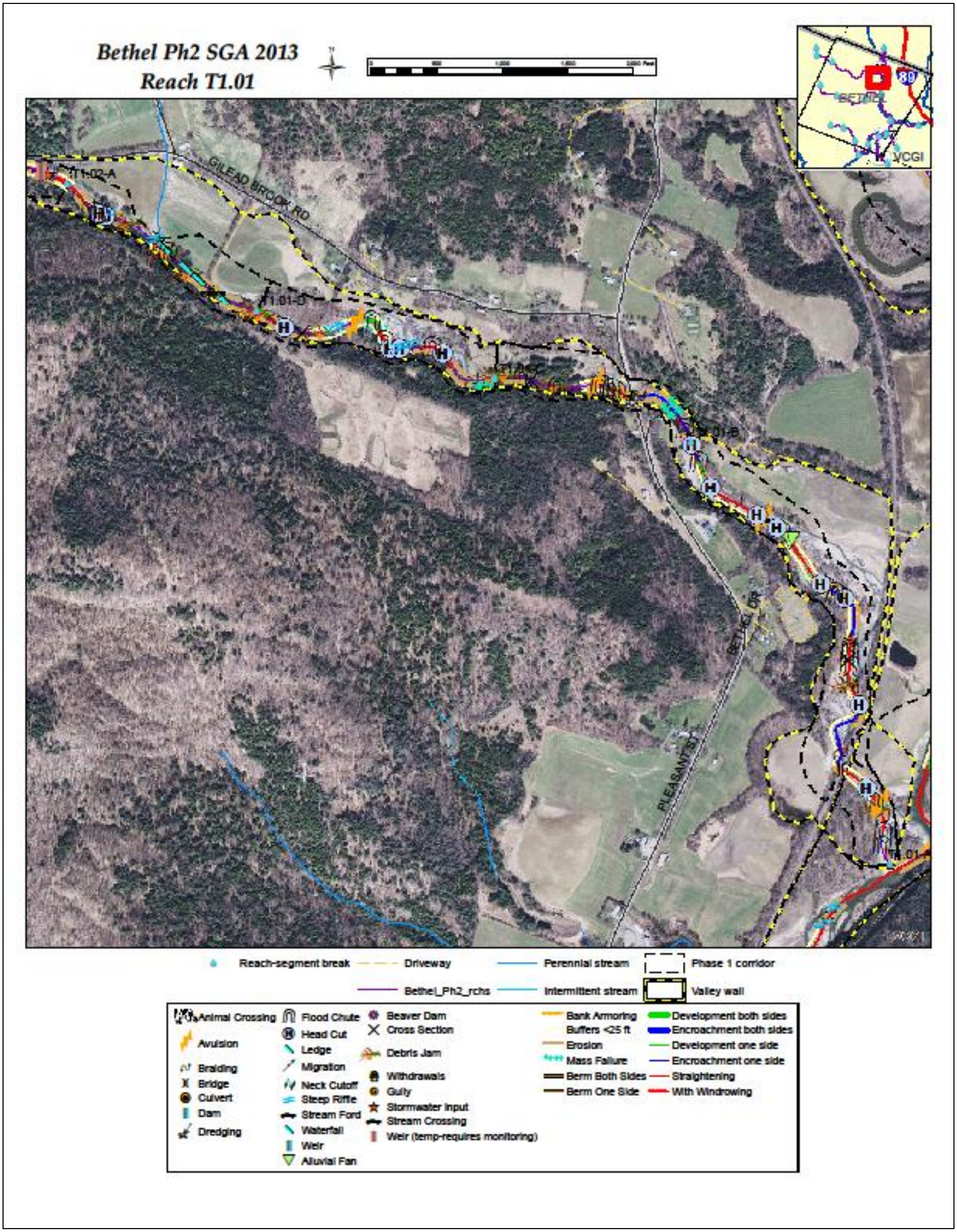


Figure 75. Bethel T1.01 reach map – Gilead Brook.

Segment T1.01A (4,096 ft. extending from the Gilead Brook confluence with the Third Branch upstream to Spring Hollow Rd. and the Rte. 12 (Pleasant St.) bridge) is located on a deltaic formation along the shoreline of glacial Lake Hitchcock, which has been disconnected (by railroad embankments) from much of its former floodplain shared with the Third Branch. With extremely deep, highly erodible loams and sands dominating the area and no grade controls present to limit downcutting, there appears to be ample indication that the stream has incised over time (likely due to the effects of straightening via encroachments, effects of undersized stream crossing structures, and restriction of the former floodplain by the railroad) but that this downcutting has frequently been offset by heavy aggradation (sedimentation) from upstream inputs.

It appeared that the T1.01A channel incised rapidly in the early stages of Irene, followed by significant aggradation and braiding, and is now evolving back toward a single thread channel (Fig. 75). There also appeared to be evidence that Gilead Brook has migrated multiple times across this valley, moving to a new location (possibly at a higher elevation, as was the case in Irene) and cutting a new channel before moving again. The mouth of Gilead Brook entering the Third Branch (east side of the railroad tracks) avulsed and relocated further upstream in Irene.

A house formerly located off the right bank at the upstream end of segment T1.01A (off Spring Hollow Rd) is no longer present, as it was damaged in Irene and opted for buyout. This house had not been eligible for flood insurance through the National Floodplain Insurance Program because it was not in a FEMA-mapped flood hazard area (pers. comm. Louise Ferris Burt, Bethel Lister, March 2014; TRORC 2013). Significant mass failures beneath the White River Valley Ambulance Service and Randall Drive-in exposed the extremely deep highly erodible soils of the area as well, and are close to further collapse under another house or cabin high on the valley wall (Fig. 76). Extreme sensitivity was assigned to this segment due to these considerations (typical sensitivity would be Very High for a C4 stream in Poor condition) and the stream dynamics clearly indicate a prudent approach would warrant corridor protection and minimal investments in this corridor.

Figure 76. A small house or cabin sits high on the valley wall (center) above these mass failures exposing the extremely deep, highly erodible soils of segment T1.01A following Irene.

The bridge across Gilead Brook to farm fields across from this former house location was outflanked on the left bank during Irene and has not been rebuilt (Fig. 77), as discussed further below in relation to segment T1.01B.

Segment T1.01B was broken out for Phase 2 assessment due to the presence of relatively intact buffers and minimal post-Irene channelization compared to the rest of the reach. Woody debris was playing a large role in sediment retention and pool formation and has potential to rebuild access to floodplain. With few encroachments in the riparian corridor these stream processes (critical to establishing greater stream stability and flood resilience in downstream reaches) can unfold with reduced risk of conflict, and this segment thus represents a high value asset to be considered for priority protection efforts.

The Spring Hollow Rd. bridge across Gilead Brook at the downstream end of segment T1.01B was washed out in Irene (Fig. 77), with the left bank abutment completely gone and Spring Hollow Rd. now gated near the Rte. 12 bridge. With the only former house downstream in this reach now gone and apparent alternate access to crop fields from Tyson Justin Rd. this bridge may be a possible candidate for removal, though it may also be the primary alternate route if the Rte. 12 bridge needs to be repaired or replaced. Considering the "hourglass effect" visible upstream and downstream of this area in aerial imagery following Irene, with a wide fan downstream of the Rte. 12 valley pinch point likely contributing to the damage of the former house downstream (as well as the mass failure beneath the White River Valley Ambulance Service), this bridge span will need to be sized significantly larger if it is to remain in service. Although regional hydraulic curves place the reference bankfull channel width for reach T1.01 at 41 ft., field-measured bankfull widths of 59 ft. at the T1.01B representative cross-section and 84 ft. at the T.01A cross-section suggest that a span of at least 50 - 60 ft. would be prudent for a replacement of this bridge if it is to remain in service.

Figure 77. Spring Hollow Rd. bridge on the border of segments T1.01A and B was outflanked in Irene and has not been rebuilt; Spring Hollow Rd. is now gated at its entrance from Rte. 12.

Segment T1.01C was heavily channelized post-Irene and appeared to have been bulldozed along most of the segment. Windrowing pushed stone from the channel against the banks but did not create any real berms that would restrict floodplain access, although one large pile of trees and other large woody debris (deposited by Irene, augmented with wood snagged from the stream) restricts floodplain access off the left bank across the road from 322 Gilead Brook Road. Historical aerial imagery in this area indicates a channel avulsion in the vicinity of this wood pile (visible in 2008 Google Earth historical imagery) likely occurred in July 2007 flooding (NOAA-BTV 2007; Figs. 78 and 79).

Figure 78. Google Earth historical imagery (left, 2006; right, 2008) indicates a channel avulsion in segment T1.01C (near 379 and 322 Gilead Brook Rd.) likely occurred in July 2007 flash flooding.

Figure 79. **Wood deposited by Irene (this aerial imagery is May 2012) and augmented with wood snagged from the stream now restricts access to left bank floodplain, hindering an important mechanism for enhancing stream stability and diffusing stream power in flood flows.**

These stream dynamics in T1.01C indicate that the lack of development constraints here represents an important asset for stream stability, as does a small pocket of young floodplain forest on the left bank just upstream of this area. This floodplain forest was quickly being colonized by Japanese knotweed that appeared to have been washed into the area and may have been introduced in the July 2007 flash flooding. Knotweed typically does not flourish as well under a canopy as in the open, but the large opening created by the channel avulsion just downstream and scoured by subsequent flooding in Irene is highly susceptible to having regeneration of native woody vegetation negatively impacted if knotweed becomes well established.

Downcutting in Irene left segment T1.01C with a full loss of floodplain access (a threshold indicated by an incision ratio of 2.0), with active head cuts/nick points (present following bulldozing) indicating potential for further loss of access to floodplain. Unlike other places along Gilead Brook there are no constructed steps/weirs that have been placed to limit further downcutting in segment T1.01C.

T1.01D is located on the upstream end of a "finger" of glacial Lake Hitchcock that roughly encompassed all of reach T1.01, underlain by lake gravels. This segment includes several runs of ledge grade controls, a rarity along much of Gilead Brook and likely a factor in precluding heavy equipment access in this area post-Irene. The segment is historically scoured to bedrock, with multiple terraces visible on both sides but particularly wide ones on river left; the channel is now functioning in a vastly reduced floodplain.

Primary Stressors:

- Full loss of access to historic floodplains (incision ratios from 2.1 to 2.6)
- Straightening (>50% of segments A&B, >20% segment C) primarily due to road encroachment, effects of undersized bridges, and channelization with windrowing in segments B and C
- Erodible banks and bed (bed armor removed in much of segments B and C), buffers frequently lacking
- Stormwater inputs mostly from upstream reaches

Table 22. T1.01 Projects and Practices Table – Gilead Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.01A	Protect River Corridors	Very High	Very High	Y	High value attenuation asset in otherwise halved former floodplain, includes buyout property; consider both municipal corridor protection and channel management easement on farmland
T1.01A	Stream Buffers	Medium	Medium	Y	important to establish, but passive or low-cost; extremely sensitive reach prone to rapid changes, currently cutting through Irene aggradation; seed sources distant from current channel but bigtooth aspen and others colonizing
T1.01A	Remove Berms	Very High	Very High	N	LB berm is long-standing enough to be vegetated with trees, so some disturbance to buffer outweighed by benefits of opening LB floodplain access; may have contributed to Randall Drive-in mass failure; should be accompanied by channel management easement; stream deeply incised but may wash out relatively quickly-would likely benefit by getting some of nearby wood accessible to channel
T1.01A	Watershed Strategies	Very High	Very High	N	STRUCTURES - numerous US need to be upsized; replace and upsize RR bridge, relocate to improve angle of alignment - would heavily impact fields on both sides of tracks but mass failures on RVW will continue otherwise; remove blown-out bridge abutments at Spring Hollow - actually in segment B but benefits this segment; stormwater management BMPs US - increase infiltration; attenuate sediment discharges US-wood and coarse sediments back in stream, passive floodplain restoration initiated by allowing/restoring wood and sediments in stream; T1.01 is priority reach for corridor protection due to value as attenuation asset DS of highly unstable T1.02 which will take a good deal of time to equilibrate

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.01B	Protect River Corridors	Very High	Very High	N	single ownership extends US (379 Gilead Brook) to more important area in segment C where snagged wood could be removed to open flood chute and floodplain (2007 channel avulsion area); area in segment B is closer to Rte. 12 bridge where dredging is likely to reoccur due to infrastructure
T1.01B	Stream Buffers	Medium	Medium	Y	create buffer area, passive or low-cost due to current instability; existing buffers decent except near bridge
T1.01B	Remove/ Replace Structures	Very High	Very High	Y	remove blown-out bridge abutments at Spring Hollow; see if Rte. 12 bridge can span without abutment
T1.01B	Watershed Strategies	Very High	Very High	N	STRUCTURES - numerous US need to be upsized; remove blown-out bridge abutments at Spring Hollow; stormwater management BMPs US - increase infiltration; attenuate sediment discharges US-wood and coarse sediments back in stream, passive floodplain restoration initiated by allowing/restoring wood and sediments in stream; T1.01 is priority reach for corridor protection due to value as attenuation asset DS of highly unstable T1.02 which will take a good deal of time to equilibrate
T1.01C	Protect River Corridors	Very High	Next Highest	N	Municipal corridor protection to limit development; further protection should be part of reach-scale restoration of incised reach
T1.01C	Stream Buffers	Medium	Medium	Y	Create buffer area, passive or low-cost due to current instability; existing buffers decent but may need some knotweed control to favor woody regeneration near floodplain forest by 379 Gilead Brook Rd

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.01C	Arrest head cuts and nick points	Very High	Very High	N	Evaluate status of headcuts/nickpoints in segment - several identified and this area did not have weirs installed post-Irene; priority only reduced by possibility of bed loading if upstream weirs are working adequately and more materials (wood and sediments) become accessible to channel - higher priority to projects in T1.02
T1.01C	Restore Incised Reach	Very High	Very High	N	explore active restoration near 379 Gilead Brook - installation of weirs, removal of snagged wood plugging flood chute, corridor protection and channel management easement
T1.01D	Stream Buffers	Next Highest	Medium	N	Create/protect buffer; passive or low-cost due to lateral instability, seed sources exist but buffers need augmentation - especially base of tributary from Messier Rd
T1.01D	Watershed Strategies	Very High	Medium	N	STRUCTURES - numerous upstream need to be upsized; storm water management BMPs upstream - increase infiltration; attenuate sediment discharges upstream - wood and coarse sediments back in stream, passive floodplain restoration initiated by allowing/restoring wood and sediments in stream; T1.01 is priority reach for corridor protection due to value as attenuation asset DS of highly unstable T1.02 which will take a good deal of time to equilibrate

6.1 Reach T1.02 – Gilead Brook from Gilead Brook Rd. pull-out on upstream end of corn/hay field across from Messier Rd. to confluence with tributary by Wright Farm (upstream of Wright Rd. bridge)

Reach T1.02 of Gilead Brook marks a transition beyond the historic influences of glacial Lake Hitchcock, with reference substrates thus changing from lake edge sands and gravels to glacial till-derived sediments dominated by cobbles. The reach extends nearly 4 miles through Narrow to Broad portions of the valley with Gilead Brook Road in relatively close proximity to the stream throughout most of its length (Fig. 80). The reach was divided into four segments for Phase 2 assessment, primarily on the basis of changes in valley confinement type as well as straighter planform and steeper slopes in the upstream segments. This reach was heavily channelized through most of its length following Irene.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T1.02	20,342	C	None	Cobble	Riffle- pool	Narrow

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T1.02A	2,514	F	None	Gravel	Riffle- pool	Narrow
T1.02B	8,258	B	c	Gravel	Riffle- pool	Broad
T1.02C	2,226	B	c	Gravel	Plane bed	Narrow
T1.02D	7,340	F	None	Gravel	Plane- bed	Narrow

	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T1.02A	Poor	Extreme	2.7	III	F	C to F
T1.02B	Poor	High	1.9	III	F	C to B
T1.02C	Poor	High	2.8	II	F	C to B
T1.02D	Poor	Extreme	3.1	II	F	C to F

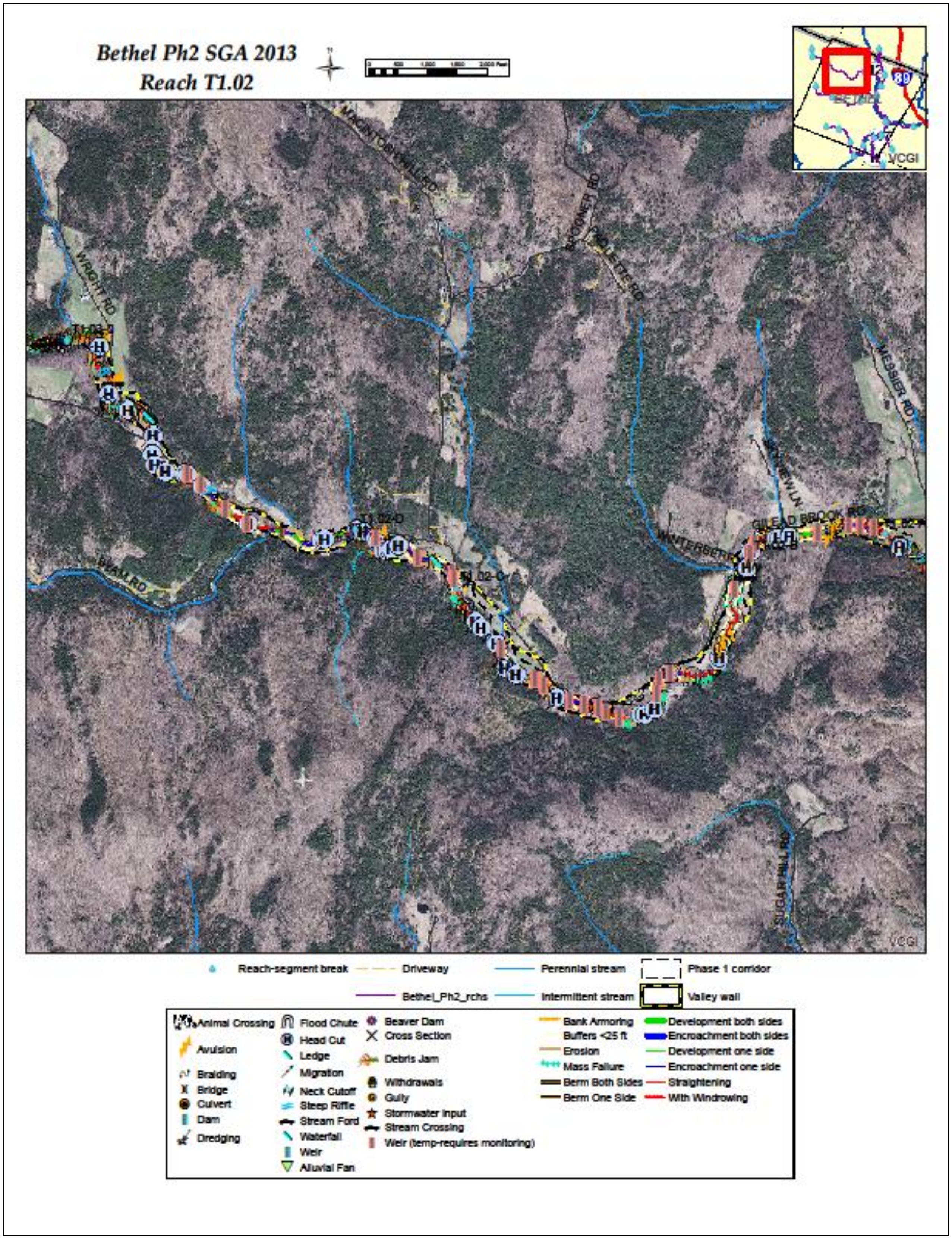


Figure 80. Bethel T1.02 reach map – Gilead Brook.

Segment T1.02A was likely situated in a borderline Narrow/Broad valley historically, but has deeply incised over time as well and now functions in a borderline Semi-Confined to Narrow valley. This segment is situated on soils dominated by fine sandy loams high in rock fragments, with a likely alluvial fan (current and historic/post-glacial) contributing additional deposition from the steep northern valley walls located at the base of a small tributary emptying just upstream of this segment. The segment was extensively windrowed and riprapped post-Irene, and constructed steps/weirs were placed at several locations to arrest headcuts (an indicator of rapid bed erosion) that occurred in response to the straightening and channelization; during 2013 fieldwork at least one of these appeared to have had stones dislodged so that nickpoints were forming again (Fig. 81).

Figure 81. Potential for further bed erosion in response to channelization in segment T1.02A is indicated by a nickpoint (inverted V-shape flow at center right of photo) forming at the dislodged stone in the center of this constructed weir.

Segment T1.02B was extensively channelized/bulldozed/windrowed post-Irene, and despite the placement of some constructed steps/weirs to limit active headcuts there were signs of potential additional bed erosion that would further restrict access to floodplains. Three bridges contribute to straightening in this segment, and all were impacted to some extent by Irene (though all appeared repaired rather than replaced). A concrete check-dam/apron at the Pinello Rd. bridge appeared to pre-date Irene; this was supplemented with some large stones post-Irene in an apparent effort to limit further downcutting and scour that could potentially undermine the structure and further restrict access to floodplain. Bulldozing near this bridge initiated a headcut that extended ~135 ft. upstream before a constructed step was placed to arrest the migrating headcut, and a scour pool on the left bank footer of this bridge was one of the deepest of the few pools observed in this segment after bulldozing. Due to the impacts on stream dynamics in the vicinity of this bridge it could be considered a priority for replacement (though the bridge appeared structurally sound), and if this were to occur it may be possible to lower the right bank abutment of this bridge to restore some floodplain access without threatening any other structures or infrastructure.

Constructed steps/weirs were placed to arrest headcuts in response to channelization in other spots along this segment as well, and one had a central stone dislodged enough to allow a nickpoint to start forming at the time of 2013 field assessment. Follow-up monitoring of these weirs (and repair if necessary) will be important to maintaining or rebuilding access to floodplains that will play a large role in ensuring better long-term stream stability and flood resilience along Gilead Brook, especially by dissipating the force of otherwise channelized and restricted flood flows. Several opportunities also exist in this segment to restore floodplain access by cuffing off the top of windrows that are 1-2 ft. higher than the floodplain behind the windrow; a windrow off the left bank just upstream of the cross-section measured for this segment during Phase 2 was fairly representative (Fig. 82). In addition, a high berm situated in the woods just west of 2577 Gilead Brook Rd. cuts off access to left bank floodplain downstream; although removal would gain significant floodplain access it would also likely pose risk to a shed 100 ft. downstream of the berm.

Figure 82. Windrow just upstream of the segment T1.02B cross-section (left of photo) is 1-2 ft. higher than the floodplain behind the windrow and is representative of several opportunities in this segment to restore floodplain access (without apparent impact to nearby structures or infrastructure) by cuffing off the top of the windrow.

Segment T1.02C was broken out due to the extreme nature and impacts of dredging/windrowing following Irene and represents a high priority project area for floodplain and habitat restoration. Impacts are due mostly to windrows, as the only real 'berms' are large piles composed of snagged wood; one of these piles plugs a dry former channel that ran alongside Gilead Brook Rd near Schoolhouse Rd, and limits access of this former channel as a flood chute. While this may superficially appear desirable in terms of limiting future flood impacts on the road, it actually restricts an important mechanism for diffusing such flows and instead increases impacts on downstream encroachments (including the possibility of triggering more mass failures on the right valley wall) as well as increasing the likelihood of bed erosion and further loss of floodplain. A former house located in this area opted for buy-out post-Irene and has been removed, and a trailer downstream of the town road bridge at Gilead Brook-Schoolhouse Roads (at the head of the abandoned channel/potential flood chute) appears unused; removing the plug of snagged wood at the head of the flood chute may thus present an opportunity for enhancing stream stability (and flood resilience for downstream areas) with less risk to occupied structures.

Constructed steps/weirs were placed in several portions of T1.02C to arrest major head cuts but there was still some active incision evident. Although there was some large woody debris recruitment (especially due to mass failures along the valley walls), much wood has been snagged or is distant from the current channel, forfeiting the value of this wood for sediment retention and maintenance (or rebuilding) of access to floodplains. One dead 5-inch brook trout was found lying in the stream, and although there was no way to confirm the cause it appeared likely this was due to shallow water, lack of refuge and overheating; there were no signs of visible trauma.

In segment T1.02D, unlike T1.03 (the next reach upstream), post-Irene in-stream work plays a significant role in current channel adjustments - but not as extreme as the next segment downstream (T1.02C). Two bridges in this segment (at Wright and Byam Rds.) were being replaced during Phase 2 assessment work, and the stream rapidly became opaque and difficult to read in bulldozed areas following workday start-ups. There was a notable contrast where the stream bed had not been disturbed (wood and larger size substrates were still present) and the stream got cloudy but not opaque. Nickpoints and small head cuts were common in windrowed/bulldozed areas, but high sediment mobility and relatively small particles remaining in the stream led to these areas quickly recruiting new sediments and “washing out” these nickpoints. Some large woody debris was being recruited, which appeared to be helping sediment retention in particular in this segment.

Primary Stressors:

- Nearly full loss of access to historic floodplains (incision ratio in T1.02B is 1.9, others from 2.7 to 3.1; windrows in T1.02B further restrict access intermittently and increase incision ratio to ~2.8).
- Straightening throughout reach due to extensive channelization and windrowing, road encroachment, and effects of undersized bridges.
- Stormwater inputs (3 road ditches segment A; 4 road ditches, 1 pond outlet segment B; 5 road ditches, 1 pond outlet segment D

Table 23. T1.02 Projects and Practices Table – Gilead Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.02A	Stream Buffers	Medium	Low	Y	Create/protect buffer; passive or low-cost due to lateral instability, seed sources exist but road embankments along left bank would likely need Better Back Roads BMPs implementation
T1.02A	Arrest head cuts and nick points	Low	Low	N	Multiple weirs placed in segment following post-Irene channelization; should be monitored but stream is deeply incised at this point and efforts should be part of reach-scale restoration of incised reach
T1.02A	Watershed Strategies	Very High	Medium	Y	Include Gilead Brook Rd in Emergency Operations Planning (if not already included) and Hazard Mitigation Plan as road is clearly at risk for future washouts along left bank; adopt River Corridor overlay or similar to limit further encroachments; STRUCTURES upsized; attenuate discharges US
T1.02B	Protect River Corridors	Very High	Very High	Y	limited but important opportunity in DS portion of segment (US of Winterberry Ln); highlights need for municipal corridor protection
T1.02B	Stream Buffers	Next Highest	Next Highest	N	Create/protect buffer; passive or low-cost due to lateral instability; some seed sources but likely to need augmentation; should be part of reach-scale restoration of incised reach
T1.02B	Arrest head cuts and nick points	Very High	Very High	Y	Highest priority for evaluation near 1745 Gilead Brook Rd, 2577 Gilead Brook Rd as no weirs were placed in these areas post-Irene; monitor weirs that were placed in other areas to evaluate functionality. Segment is less incised than other portions of Gilead Brook and is high priority for reach-scale restoration.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.02B	Remove Berms	Very High	Very High	Y	True berm by 2577 Gilead Brook is wooded at this point and removal would increase risk to shed 100ft DS; numerous windrows would be easier to cuff off. Part of restoration of incised reach
T1.02B	Remove/ Replace Structures	Very High	Very High	Y	Highest priority to Mitchell Dr. (most undersized), then Goodale Rd.; Pinello Rd. sized adequately and has concrete check-dam/apron supplemented with large stones - lower priority but replacement may allow lower RB abutment o give better floodplain access
T1.02B	Restore Incised Reach	Very High	Very High	N	Pursue removal of encroachments (highest priority monitor and maintain weirs if necessary; cuff off windrows; replacement of undersized bridges likely to be more expensive but is high priority)

T1.02C	Protect River Corridors	Very High	Very High	Y	Important step to restoration of incised reach, increased by value of buyout
T1.02C	Stream Buffers	Next Highest	Next Highest	N	Create/protect buffer; passive or low-cost due to lateral instability; some seed sources but likely to need augmentation; should be part of reach-scale restoration of incised reach
T1.02C	Remove Berms	Very High	Very High	Y	Highest priority to snagged wood plugging flood chute by Schoolhouse Rd.; wood may be able to be used DS as part of reach-scale restoration (wood and coarse sediments back in stream); sediment windrows can be cuffed off as well
T1.02C	Remove/ Replace Structures	Very High	Very High	Y	Highest priority to Gilead Brook Rd at Schoolhouse Rd; angle of alignment significantly reduces effective width. 3 bridges in segment, all floodprone constrictions that contributed to heightened Irene impacts

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.02C	Restore Incised Reach	Very High	Very High	N	Pursue removal of encroachments (highest priority monitor and maintain weirs if necessary; cuff off windrows; replacement of undersized bridges likely to be more expensive but is high priority)

T1.02D	Stream Buffers	Medium	Next Highest	N	Create/protect buffer; passive or low-cost due to lateral instability, may need Japanese knotweed control to allow trees to establish; road embankments would likely need Better Back Roads BMPs implementation
T1.02D	Arrest head cuts and nick points	Medium	Next Highest	Y	monitor (and maintain if necessary) post-Irene weir US of Byam Rd.; other headcuts washing out quickly and stream is deeply incised; evaluate as part of reach-scale restoration of incised reach
T1.02D	Remove/ Replace Structures	Medium	Next Highest	Y	3 bridges in segment all undersized; 2 were being replaced at time of 2013 assessment. Recent replacement decreases priority but Bethel's adoption of 2013 bridge and culvert standards was key as dynamic nature of stream at these locations demands adequate sizing to accommodate sediment, wood and concentrated flows-future replacements will likely follow failures or impacts
T1.02D	Watershed Strategies	Very High	Next Highest	Y	Corridor protection to limit development; hazard mitigation and emergency operations planning; Byam Rd. tributary likely rerouted to enter Gilead Brook US of Byam Rd. intersection, increasing flood hazard risk to house at that corner (40 Byam)-Gilead Brook Rd. likely to remain in conflict with stream processes here and DS, much bank armoring may be undersized; houses at 3270 and 3125 Gilead Brook Rd also at risk; 3125 is at disconnected oxbow from Gilead Brook or former channel of Byam Rd trib (or both); STRUCTURES - adequate sizing - although 2013 B&C standards spec 100 pct bankfull, recommend 120 pct bkf in this setting

6.1 Reach T1.03 – Gilead Brook from confluence with tributary by Wright Farm (upstream of Wright Road bridge) to upstream of a multiple tributary confluence east of 1892 Little Hollow Road

Reach T1.03 on Gilead Brook is a relatively undeveloped reach in a Narrow valley, largely forested with primary use for logging, hunting and recreational vehicles (primarily snowmobiles, occasional use by ATVs and off-road pick-ups; few signs of vehicular trail damage in the stream valley at the time of Phase 2 assessment). The reach was not segmented for Phase 2 assessment.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T1.03	7,220	C	b	Cobble	Step-Pool	Narrow

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T1.03-0	7,220	B	none	Cobble	Step-Pool	Narrow
	Geomorphic condition	**Stream sensitivity**	**Incision ratio**	**Channel evolution stage**	**Channel evolution model**	**Stream Type Departure**
T1.03-0	Poor	High	3.1	III	F	C to B

Irene cut a new channel through the mid-portion of reach T1.03 that is roughly five ft. higher in elevation than the old channel. It appeared that this is likely a characteristic dynamic in this reach: debris jams and sediment plugs lead to channel avulsions and relocations, with significant and rapid shifts in the channel location over time followed by stabilization and re-vegetation in a new location before the channel jumps to a new location (Fig. 83).

Figure 83. A debris jam and sediment plug in reach T1.03 led to a channel avulsion that left the current channel (right in photo) at a higher elevation than the former channel (left in photo). This wood and sediment provide channel roughness and rebuilt access to abandoned floodplain, critical to diffusing stream power and re-establishing stream stability.

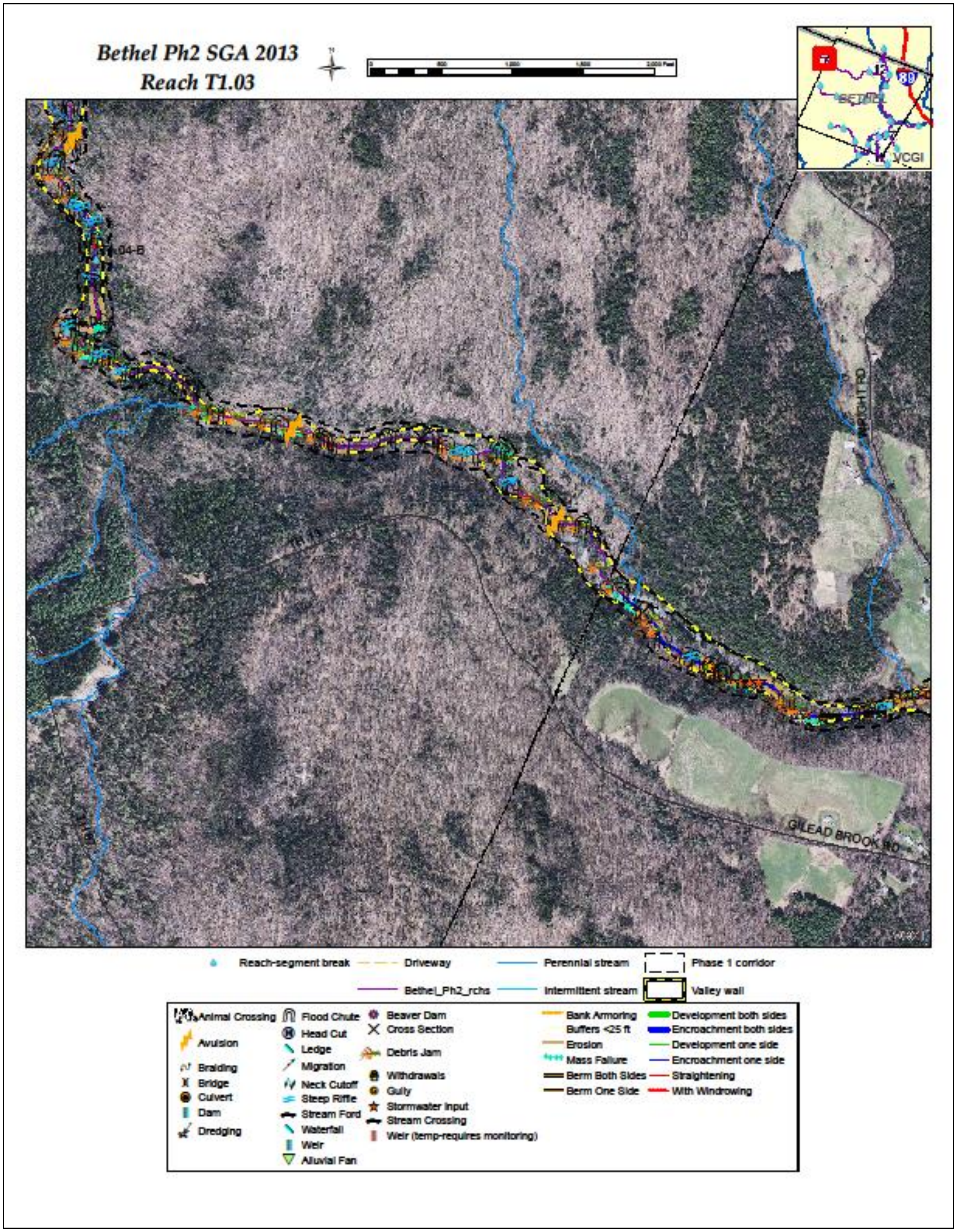


Figure 84. Bethel T1.03 reach map – Gilead Brook.

The natural valley ranges from 135-200 ft. along reach T1.03, and the stream has likely moved across much of this width over time – but the sand and cobble soils are unconsolidated and deep, and the stream cuts down quickly and then functions in a more entrenched floodplain until a new debris jam or sediment plug leads to a channel avulsion and relocation. Natural pinch points in the valley also drop to 50 ft. in several locations, leading to 'jet propulsion' of the stream through these pinch points. These dynamics lead to common mass failures, debris jams, sediment plugs and avulsions and demonstrate the importance of large woody debris and coarse sediments in a narrow valley setting such as that along much of Gilead Brook: when these dynamics are not in conflict with corridor encroachments the raw materials of wood and sediment diffuse stream power through additional meanders, channel roughness, and the possibility of rebuilding access to abandoned floodplains.

A Class 4 (i.e., not town-maintained on a regular basis) section of Gilead Brook Rd. that runs high on the southern valley wall of reach T1.03 (to Rochester Little Hollow), with numerous crossings of tributaries to this reach, appears to be a popular 'mudding' road and a number of the stream crossings are gullied. Gullies along tributaries and stormwater inputs on the extremely steep valley walls of this reach were common in Irene (and would be extremely difficult to repair at this point), and it appears beaver dams upstream may have breached and contributed to a storm surge in this reach as well. All of these inputs were contributing significant sediment deposits and large woody debris that are likely to contribute to stabilizing these areas over time, but the net effect is a significant extension of the stream network (rather than diffuse flows over a wider surface) that will contribute to more concentrated and rapid delivery of water to Gilead Brook in future downpours especially (Fig. 85).

Figure 85. Large woody debris and coarse sediments visible in this gully emanating from a field ditch on top of the T1.03 valley wall are beginning to help stabilize this slope, but the gully now effectively extends the stream network (rather than having sheet flows over broader portions of the slope) in heavy downpours.

There were no signs of dredging in reach T1.03 but wood was snagged in a couple areas with the apparent intention of preventing the stream from accessing woods roads and trails as flood chutes. Low lying sections of woods roads in a couple locations were erased by the stream in Irene, technically making these areas fords now (Fig. 86); location of these sections further upslope would be challenging but access to substantial portions of the woodlot may be limited without these sections of road.

Figure 86. Portion of a woods road reclaimed in part by Gilead Brook reach T1.03 during Irene now makes this effectively a ford rather than a road.

Primary Stressors:

- Full loss of access to historic floodplains (incision ratio 3.1)
- Stormwater inputs and ditching (2 field ditches, 4 overland flow) on highly erodible soils have led to intensified flows in a stream network extended by historic downcutting (gullies and bed erosion)
- Recent upstream beaver dam breaches
- Valley pinch points contribute to Bernoulli effect (increased pressure through small opening) in high flows

Table 24. T1.03 Projects and Practices Table – Gilead Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.03	Protect River Corridors	Next Highest	Next Highest	Y	Development threats low, channel management for woods roads more likely; priority increased by hazard mitigation for downstream areas and location DS of confluence of several steep tributaries, priority decreased by naturally narrow valley with somewhat limited possibilities for meander development and floodplain access
T1.03	Restore Incised Reach	Next Highest	Next Highest	Y	Corridor protection to accommodate passive floodplain and meander development; currently few encroachments but woods roads may be reworked; explore options for placement outside River Corridor

6.1 Reach T1.04 – Gilead Brook from upstream of a multiple tributary confluence east of 1892 Little Hollow Rd to beaver ponds east of 1300 Little Hollow Rd (not ponds closest to Little Hollow Rd, which are on a tributary of Gilead Brook)

As with reach T1.03, T1.04 is in a relatively undeveloped portion of the Gilead Brook valley that is largely forested and distant from town roads (Fig. 87). There are current beaver dams upstream of this reach, and it appeared that at least the upstream segment B of reach T1.04 has been occupied by beavers in the past. The reach was broken into two segments for Phase 2 assessment, primarily due to a greater degree of floodplain access in upstream segment B.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T1.04	3,479	C	b	Gravel	Riffle-pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T1.04A	734	B	none	Gravel	Riffle-pool	Narrow
T1.04B	2,746	C	b	Gravel	Riffle-pool	Broad

	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T1.04A	Fair	High	2.2	III	F	C to B
T1.04B	Fair	Very High	3.1	III	F	None

Recent incision observed in downstream segment T1.04A may be related to upstream beaver dam breaches in Irene, leaving the channel even more entrenched than it previously had been due to historic incision. Due to the moderately steep gradient and Narrow valley it appeared conceivable that the reference stream type for this segment might be a disorganized plane bed reference (with neither steps nor riffles setting up regularly) rather than the currently observed riffle-pool system. Rough field estimates suggested a slope of 3-4 percent in this segment. Multiple terraces along the stream corridor indicated historic incision and successive floodplain abandonment.

In segment T1.04B a high incision ratio of 3.1 is due to historic terraces on both sides of the stream, but the vastly diminished floodplain still permits sufficient floodplain access for typical dynamics of a C type stream.

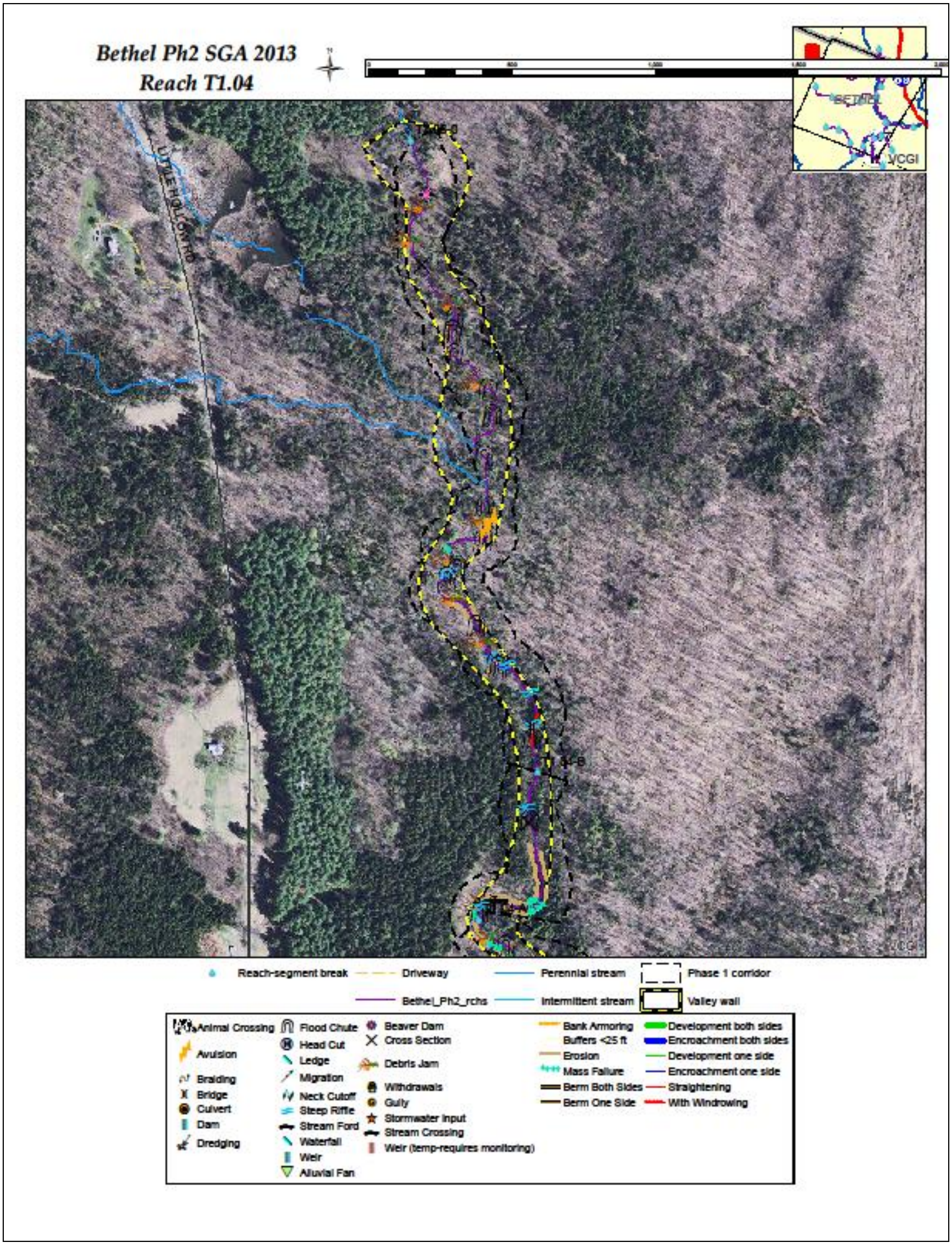


Figure 87. **Bethel T1.04 reach map – Gilead Brook.**

There was clearer evidence of beaver dam breaches upstream of segment T1.04B in Irene, and several flood chutes (numerous were accessed or formed in Irene) had headcuts at the downstream end. No Class 2 wetlands are mapped along the stream but much of the upstream portion of this segment is situated on Rumney soils - frequently flooded and hydric - that are contiguous with mapped Class 2 wetlands.

Table 25. T1.04 Projects and Practices Table – Gilead Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T1.04A	Protect River Corridors	Low	Medium	Y	Development threats low; priority increased by lower degree of incision than other portions of Gilead Brook, priority decreased by naturally narrow valley with somewhat limited possibilities for meander development and floodplain access
T1.04A	Restore Incised Reach	Low	Medium	N	Corridor protection to accommodate passive floodplain and meander development; currently few encroachments
T1.04B	Protect River Corridors	Very High	Medium	Y	Development threats low but channel management to maintain snowmobile trail more likely; priority increased by hazard mitigation for downstream areas and location downstream of confluence of several steep tributaries
T1.04B	Restore Incised Reach	Very High	Next Highest	Y	Corridor protection to accommodate passive floodplain and meander development; currently few encroachments; primary issue will be to maintain adequate sizing of snowmobile bridge and discourage channelization in vicinity of bridge as bed remains erodible

White River mainstem and tributaries

6.1 Reach R11 – White River mainstem from Behind Bethel/Royalton state police barracks and VTrans maintenance garage (1635 Rte. 107) upstream to confluence of White mainstem and Third Branch (River St Bridge)

Reach R11 is a popular boating/tubing reach spanning the Bethel-Royalton town line (put-in at Peavine Park at the junction of the Third Branch and White mainstem in Bethel; take-out at the Fox Stand Fish & Wildlife access by the Royalton Hill Rd. bridge in Royalton) that is not easily accessible from roads (Fig. 88). The river runs through a semi-confined valley in this reach; it appears likely but not entirely clear that the valley was semi-confined before the railroad was built. The railroad bed currently owned by the New England Central Railroad lines the left corridor throughout the reach and typically runs along the top of an extremely steep bank 30 ft. or more height above water, contributing to the current degree of confinement, and the natural valley wall off the right bank is extremely steep as well and comprised of highly erodible sands and gravels. Relatively dense commercial-industrial development (including the Bethel wastewater treatment plant and Vermont Castings) is located just behind the railroad tracks away from the river.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
R11	11,287	B	c	Cobble	Riffle-Pool	Semi-confined

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
R11	11,287	F	none	Cobble	Plane-bed	Semi-confined
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
R11	Fair	Very High	1.6	III	F	B to F

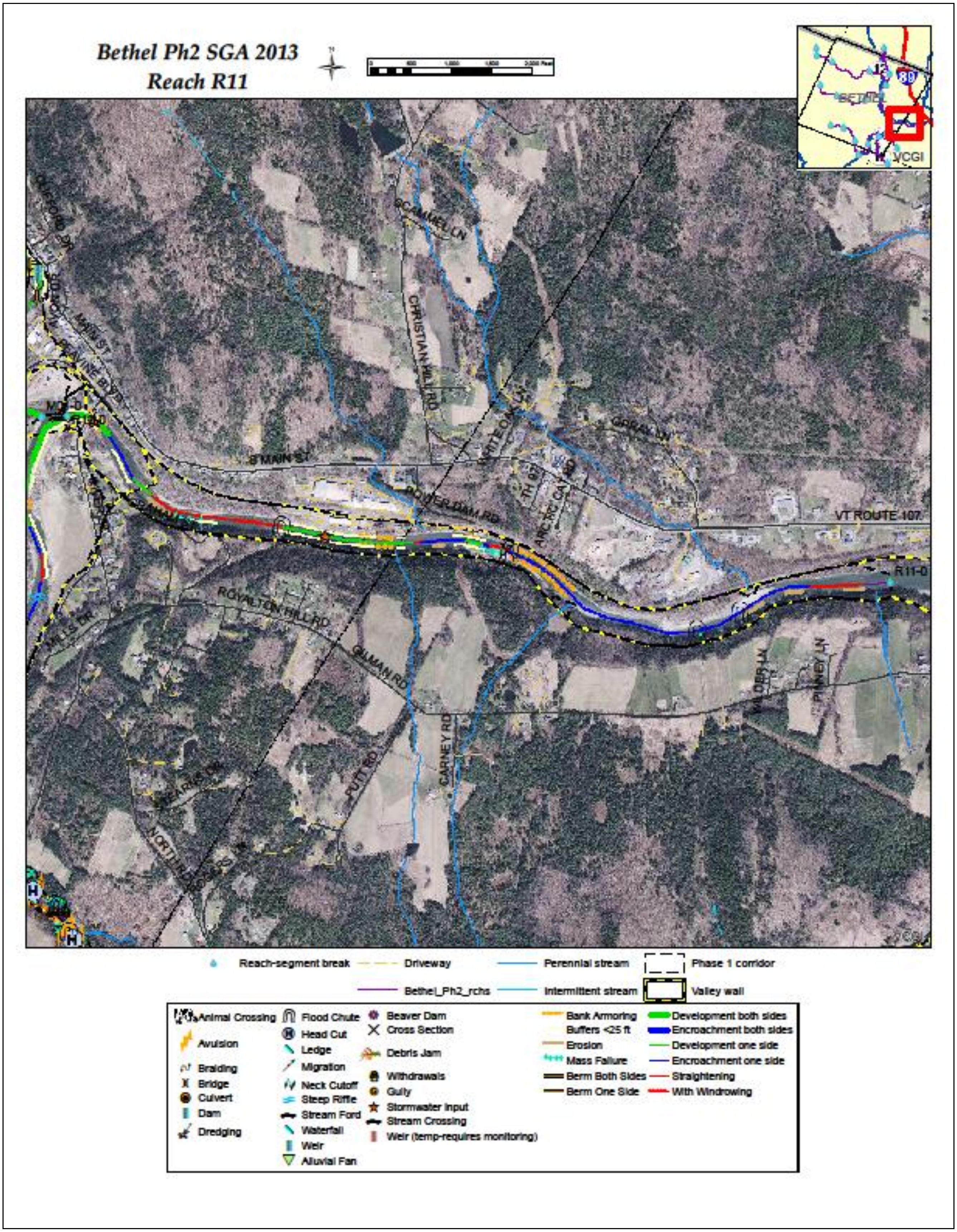


Figure 88. Bethel R11 reach map – White River mainstem.

Incision is long-standing in reach R11 and likely the combined result of glacial processes eroding through pebbly sands at the edges of glacial Lake Hitchcock as well as pulse flows and “hungry water” dynamics (see discussion in Ch. 5.1.1, Hydrologic Regime stressors, of this report) related to flow regimes at the former dam site off the end of Power Dam Road (Fig. 89).

Figure 89. Former power dam on the White River mainstem in reach R11 near the Bethel-Royalton town line.

Heightened stream power flowing through this semi-confined valley during Irene was evidenced by a strikingly deep scour pool at the old dam site and the apparent removal of much of the former cribbing that had been still evident at that site; the difference is visible in imagery pre- and post-Irene (Figs. 90 and 91).

Figure 90. Google Earth imagery from 2009 shows channel-spanning cribbing from the former Power Dam on the White River mainstem near the Bethel-Royalton town line.

Figure 91. Imagery from 2013 shows a large portion of the mid-channel cribbing gone and replaced by a scour pool.

While there was some evidence of deposition alternating with the scoured portions of reach R11, indicating typical feature establishment during channel evolution, overall dynamics in this reach were indicative of the impacts of stream power heightened by the confinement of the valley being passed further downstream, with large mass failures and the scour features noted above in reach R11 and large sediment deposits occurring in downstream reach R10 (outside of the 2013 Bethel assessment area).

Primary Stressors:

- Straightening (>50% of segment length) primarily by virtue of extensive railroad encroachment, some development and roads
- Restriction of access to historic floodplains (incision ratio 1.6)
- Subwatershed urbanization and road density
- Highly erodible banks (sand and stony loams), intermittent diminished buffers

Table 26. R11 Projects and Practices Table – White River mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
R11	Stream Buffers	Low	Low	Y	Create/protect buffer; passive or low-cost due to lateral instability, may need Japanese knotweed control to allow trees to establish
R11	Watershed Strategies	Medium	Low	N	Municipal corridor protection to limit development here but even more so US; include LB encroachments (vicinity of VT Castings esp.) in hazard mitigation planning and emergency operations plan, evaluate hazards indicated by river corridor zones in comparison with mapped FEMA floodplain

6.1 Reach R12 – White River mainstem from confluence with Third Branch at Peavine Park upstream to large midstream boulders and right bank bedrock below Tozier's Restaurant on Rte. 107

Reach R12 is an entrenched reach that historically cut down through highly erodible sediments associated with glacial Lake Hitchcock; it now receives heavy sediment inputs from similarly erodible soils and alluvial fans on kame terraces and historic deltas deriving from the tributaries feeding into the margins of that former glacial Lake (Fig. 92). With these tributaries mostly situated in steep and/or narrow valleys in the deeply dissected surrounding landscape, and significantly straightened streams resulting from road and development encroachments, flash flooding in this portion of the watershed in 2007 and 2008 was contributing to significant aggradation and planform adjustments even before Irene hit in 2011.

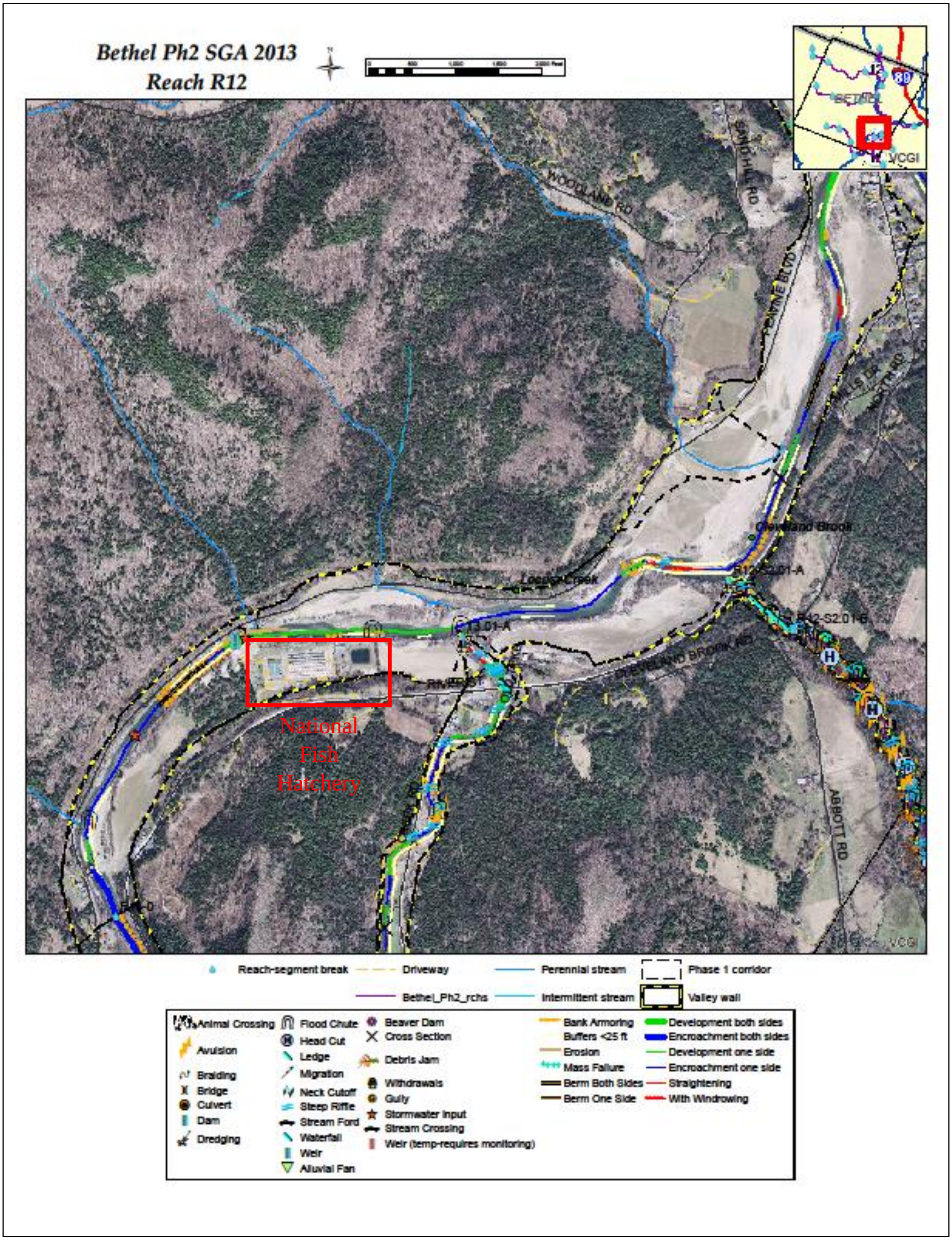


Figure 92. Bethel R12 reach map – White River mainstem.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
R12	15,327	C	none	Gravel	Riffle- Pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
R12	15,327	F	none	Gravel	Riffle- pool	Narrow

	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
R12	Fair	Extreme	2.1	III	F	C to F

Irene contributed to bed feature formation in numerous areas along reach R12, creating more defined riffles, point bars and scour pools, but material was removed from the channel following Irene as well and long stretches of sedimented featureless plane bed and the current degree of entrenchment leave this reach in a continuing state of evolution. Heavy equipment instream work was extensive in this reach and reach R13 upstream post-Irene, with the New England Central Railroad line at the confluence of the Third Branch and White mainstem in Bethel village (the reach break at the downstream end of reach R12) used as a staging area to bring in and load stone onto large trucks that forded the White at this confluence enroute to the most heavily damaged portions of Rte. 107 upstream (Fig. 93; hizzy19 2011).

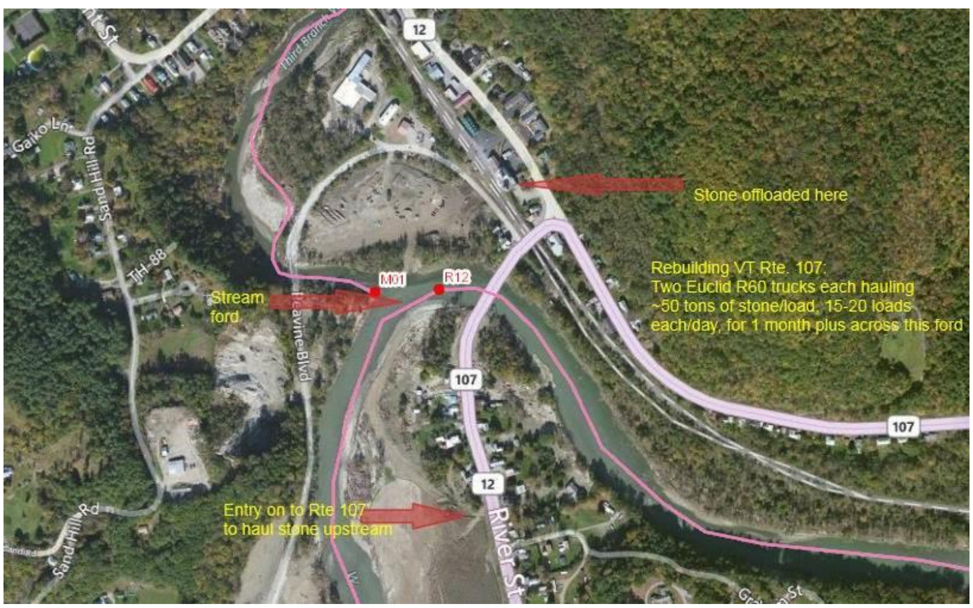


Figure 93. Stream ford at the R12 reach break was used to haul stone offloaded from the rail line in Bethel village across the White River and upstream to the most damaged portions of VT Rte. 107.

Entrenchment and straightening in

reach R12 are increased by a 750-foot long berm upstream of the White River National Fish Hatchery, highest in the vicinity of hayfields on its upstream end and tapering in height toward the Hatchery, as well as road encroachment on both banks. The Hatchery was built in 1982 while trees growing on the berm upstream appeared to be in the 60-80 year old range (Fig. 94), suggesting the berm may predate the Hatchery and was likely built for purposes other than protection of that facility from floodwaters. Regardless of the reason for its construction, the berm appeared to have prevented Irene floodwaters from accessing the high terrace hayfields representing historic floodplain off the right bank behind the berm and below Tozier's Restaurant (17 ft. height above water in this vicinity, lower toward the Hatchery) and instead encouraged the flooding river to drop some sediments on the vastly restricted floodplain within the confines of the berm (Fig. 94) but much more widely at and across from the Hatchery (Fig. 92). The hayfields upstream of the Hatchery represent an attenuation asset restricted from river access by a combination of the presence of the berm and gravel removal at the upstream end of the reach. Removal of the berm might be of value in reducing flood impacts further downstream but could potentially increase risks for the Hatchery. Restriction of floodplain access due to the presence of the berm greatly increases the attenuation value of the land immediately across the river and just downstream from the Hatchery, which was a high deposition zone in Irene (Fig. 92).

Figure 94. Trees along a 750 foot berm upstream of the White River National Hatchery appear to be significantly older than the Hatchery; post-Irene sediment deposition evident in this picture inside the berm was not observed outside of the berm.

The straightening and entrenchment along the White mainstem continue for significant portions upstream of this berm and on into Stockbridge, as discussed further in the reach description for R13. Downstream of this section the heightened stream power amplified by these dynamics contributed to significant damages including several houses (Fig. 95) and the River Street (Rte. 107/Rte. 12) Bridge, which required replacement with a temporary bridge while the damaged bridge was replaced.

Figure 95. Houses damaged in Bethel during Irene in the vicinity of the River St. bridge at the downstream end of reach R12. ***Photo credits: Ann Froschauer/US Fish & Wildlife Service***

Primary Stressors:

- Straightening (>50% of segment length) primarily by virtue of extensive encroachments, both development and roads (historically by Peavine Railroad as well), along with some bank armoring; berm upstream of hatchery
- Loss of access to historic floodplains (incision ratio 2.1)
- Highly erodible banks (fine sandy loams), buffers lacking and impacted by heavy use of ford at White-Third Branch confluence for hauling stone from railroad to Rte. 107
- Subwatershed road density
- Corridor urbanization and lost/impacted wetlands

Table 27. R12 Projects and Practices Table – White River mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
R12	Protect River Corridors	Very High	Very High	Y	Municipal corridor protection to limit development; channel management easements on key areas (visibly sedimented in 2011 imagery)-priority to attenuation assets in Bethel village (Washburn Farm) and across from National Fish hatchery; high priority area due to both benefits for geomorphic equilibrium and high incidence of Rare, Threatened and Endangered element occurrences; importance increased by high degree of straightening upstream
R12	Stream Buffers	Very High	Very High	Y	Highest priority upstream of River St. bridge, both for geomorphic reasons and flood hazard mitigation; primarily low-cost due to vertical and lateral instability, but consider larger stock on outside edge of corridor, especially in vicinity of Miller Dr. - also by Tozier's; explore Better Back Roads BMPs for road embankments
R12	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development, high priority due to upstream straightening and armoring (R13); include development encroachments in hazard mitigation planning and emergency operations plan, evaluate hazards indicated by river corridor zones in comparison with mapped FEMA floodplain; reach-scale corridor protection: attenuation assets in Bethel village and across from National Fish hatchery

6.1 Reach R13 – White River mainstem from boulders and right bank bedrock below Tozier's Restaurant on Rte. 107 upstream to mouth of Lilliesville Brook by intersection of Peavine Blvd. and Lilliesville Rd.

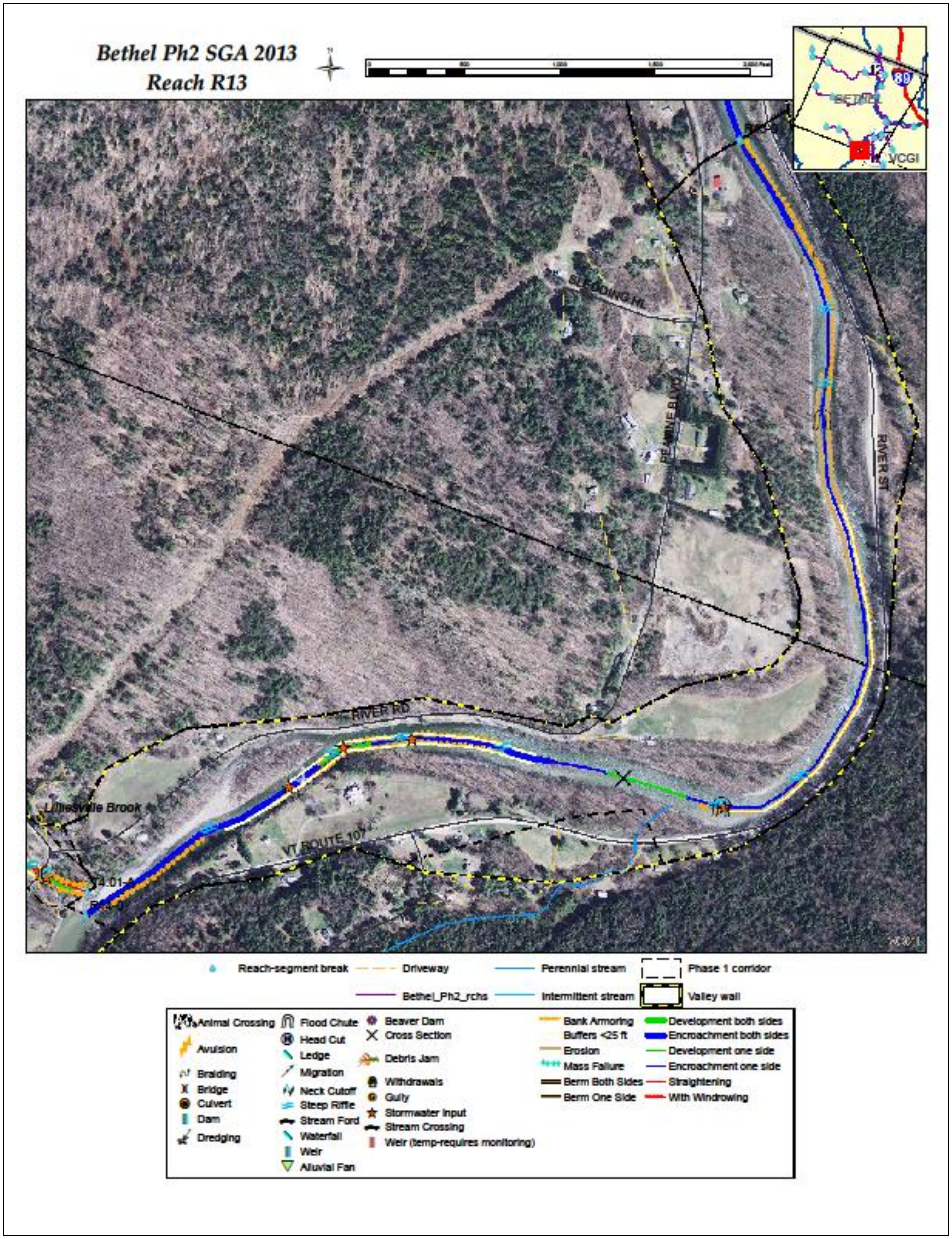


Figure 96. Bethel R13 reach map – White River mainstem.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
R13	7,704	C	none	Cobble	Riffle- Pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
R13	7,704	B	c	Cobble	Riffle- pool	Narrow
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
R13	Poor	High	2.3	III	F	C to B

Reach R13 straddles the Bethel-Stockbridge town line in a Narrow valley shared with VT Rte. 107, a primary east-west travel corridor, and is bounded by steep hills dominated by bedrock. This has been a repeat area for conflicts between infrastructure and stream processes in flood events (notably 1927, 1973 and more recently in 2007, 2008 and Irene in 2011), and Rte. 107 in this area and just upstream incurred costly repairs in Vermont following Irene in terms of both time and money.

> "In the three-mile section of road that was hardest hit, about 4,000 ft. of Route 107 road was completely gone….
>
> …it took two contractors, 250,000 tons of rock, at least 20,000 hours of heavy equipment time, 7,500 ft. of guardrail, 38 culverts and 46 companies over 16 weeks to repair the highway, according to information provided by the Vermont Transportation Agency." (Ring 2011; Fig. 97)

Figure 97. **Reconstruction of Rte. 107 along the southern flank of reach R13 included hundreds of thousands of tons of stone hauled in to force the White River back away from the former roadbed it had incorporated into the stream channel.** ***Photo credit: Matthew Cavanaugh for The New York Times.***

During the process of rebuilding Rte. 107, “A special “rock train” carts pink stone 100 miles from quarries near Burlington, and workers scoop washed-out stone and gravel from the river itself.” (Schwartz 2011; Fig. 98).

Figure 98. Dredging the White mainstem for material to rebuild Rte. 107 along reach R13. ***Photo credit: Adam Smith***

With large amounts of material mined from the riverbed and a high degree of entrenchment from rebuilding Rte. 107 (Fig. 99) contributing to heightened stream power that frequently erodes any sort of bed features, it was somewhat surprising to note a fair number of riffles already re-establishing in this reach during 2013 fieldwork.

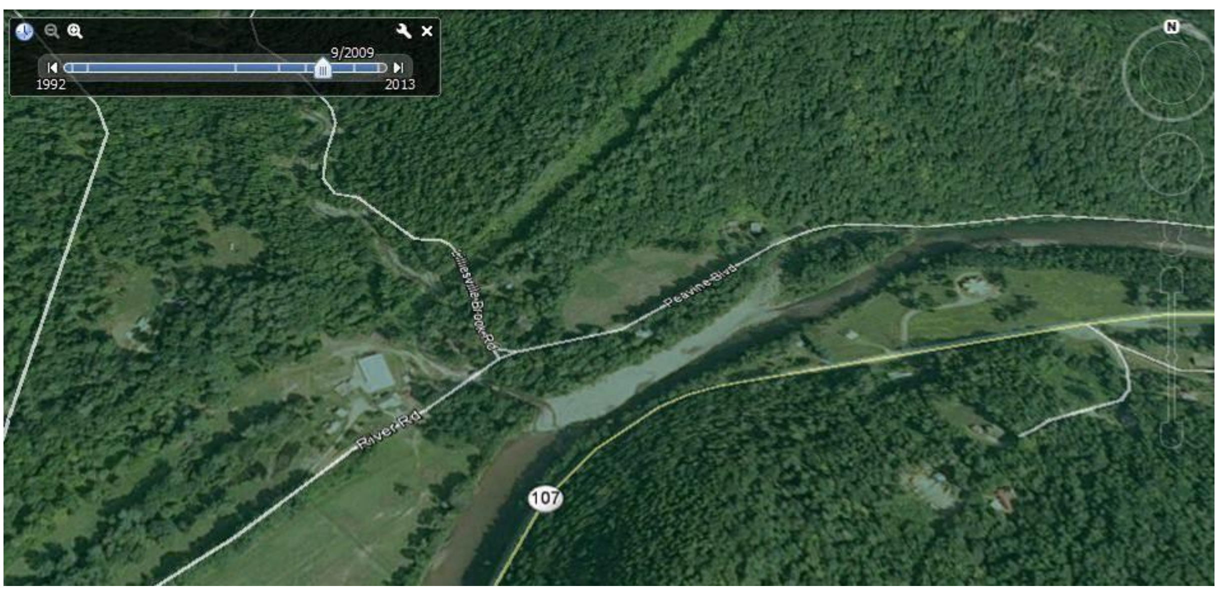
Figure 99. Combination of dredging, bank armoring and rebuilding of elevated roadbed for Rte. 107 have left a highly entrenched and straightened stream in significant portions of reach R13 and further upstream.

Rapid re-establishment of riffles in this reach is more understandable in light of cyclic patterns of management and river response. The river in reach R13 has lost access to much historic floodplain (C to B stream type departure and change of valley confinement from Broad to Narrow), probably due in part to historic incision through erodible sediments associated with glacial Lake Hitchcock – but also amplified by roadbed elevations and re-armoring in repeat repairs and reconstructions similar to those noted post-Irene. Heightened stream power contained within this entrenched and straightened channel has led to heightened erosion and mass failures, thus recruiting further sediments from upstream as well as a process of "tributary rejuvenation"; downstream redistribution of "sediment slugs"; and periodic repeat rounds of dredging and rebuilding following major floods.

Shallow rapids are common in the reach and impressive large deposits of cobble dominated sediments deriving from the tributaries and large expanses of bank and mass failures along the mainstem further upstream are easily visible from the road. This dynamic is particularly evident in the vicinity of an alluvial fan at the mouth of Lilliesville Brook (T4.01) at the upstream end of the reach (i.e., the R14 reach break; Fig. 100; Fig. 101).

Figure 100. At the upstream end of reach R13, alluvial fan at the base of Lilliesville Brook has evidenced significant discharges of cobble sediments in multiple flood events – mostly recently following Irene as visible in the 2012 imagery above (map per VT ANR Natural Resource Atlas).

Figure 101. The same alluvial fan is shown with repeat "tributary rejuvenation" from Lilliesville Brook in Google Earth imagery from 2003 (above, following 1998 and 2002 flash flooding) and 2009 (below, following 2007 and 2008 flash flooding). Cobbles from this fan have been moved through reach R13 in high flows, contributing to rapid re-establishment of riffles and shallow rapids, as well as being dredged and used in road reconstruction.



The seven-mile section of Rte. 107 between Bethel and Stockbridge, including Reach R13 on its downstream end, was the "Last Mile" of Vermont state highways to reopen after being damaged in Irene (Allen 2011), and this travel corridor is likely to continue in conflict with stream processes on this reach and further upstream. Despite the enormous investments of time, money and energy incurred, it appears evident that the value of this thoroughfare (and the difficulty of relocating in this tight valley) is still outweighing the costs of placing the road back in a location where it has been repeatedly damaged. The

> "… chief engineer for the Vermont Agency of Transportation, noted that …. Some damage to highways like 107 was predictable…since many roads in mountainous areas follow river valleys.
>
> "We're not looking to move a highway up a mountain slope," he said. "If you look at an insurance policy, you weigh your premium against your risk. That's what society does with factors of safety on a whole host of infrastructure." (Schwartz 2011)

With similar dynamics in place for seven miles of stream in this area, the impacts of heightened stream power are likely to be passed and borne downstream for the foreseeable future. This vastly increases the importance of flood hazard mitigation and emergency operations planning downstream to the village of Bethel and beyond, making this the primary project prioritization in this area. Protecting existing undeveloped floodplains is one of the more important mitigation measures that can be taken in reaches R12 and R13, and retaining or establishing wooded buffers can help to mitigate and diffuse stream power in these type of situations as well.

Primary Stressors:

- Straightening (>50% of segment length) primarily by virtue of extensive encroachments, both development and roads, and channelization - amplified by extensive bank armoring
- Loss of access to historic floodplains (incision ratio 2.3)
- Highly erodible banks (sand and fine sand loams), buffers lacking
- Subwatershed road density and urbanization

Table 28. R13 Projects and Practices Table – White River mainstem

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
R13	Watershed Strategies	Very High	Medium	Y	Municipal corridor protection to limit development, include development encroachments in hazard mitigation planning and emergency operations plan; evaluate hazards indicated by river corridor zones in comparison with mapped FEMA floodplain. Consider hazard mitigation options for development downstream of Lilliesville Brook mouth: explore possibilities for active restoration of floodplain on LB (former Peavine RR location) if opportunities ever arise

6.1 Reach R12-S02.01 – Cleveland Brook from confluence with the White mainstem upstream for 1.34 miles to confluence with a tributary

Reach R12-S02.01 is approximately 1.34 miles in length, beginning, at the upstream end, at the confluence of two streams halfway between North Road and Abbott Road on the east-west axis, and halfway between David Road and Sewall Brook Road (off of North Road) on the north-south axis. It flows roughly northwest between North Road and Abbott Road, parallel to but at some distance from them, crossing from Royalton into Bethel at about the midpoint of the reach. From this point downstream it swings closer to Abbott Road and crosses Cleveland Brook Road approximately 250 ft. northeast of the intersection between these two roads. From there it continues northwesterly, crossing Route 107 (River Road) approximately one mile from the downtown area of Bethel, and enters the mainstem of the White River (Fig. 102).

This reach was broken into three segments based on differences in planform and depositional features. Segment R12S2.01A (978 ft. in length) has a significantly different planform from the other two segments, cascading through a steep valley with extremely steep walls. The valley widens and slopes moderate in the two upstream segments, with the primary difference (and reason for segmentation) being much heavier impacts from Irene (especially erosion and mass failures) and heavier deposition in mid-reach segment R12S2.01B than in upstream segment C.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
R12-S02.01	7,084	C	A	Cobble	Step-pool	Narrowly confined

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
R12-S02.01A	978	A	None	Cobble	Cascade	Narrowly confined
R12-S02.01B	3,953	B	a	Gravel	Step- pool	Narrow
R12-S02.01C	2,153	B	a	Gravel	Step- pool	Narrow
	Geomorphic condition	**Stream sensitivity**	**Incision ratio**	**Channel evolution stage**	**Channel evolution model**	**Stream Type Departure**
R12-S02.01A	Fair	Very High	1.0	IIc	D	None
R12-S02.01B	Poor	Extreme	2.4	III	F	C to B
R12-S02.01C	Fair	Very High	2.0	III	F	C to B

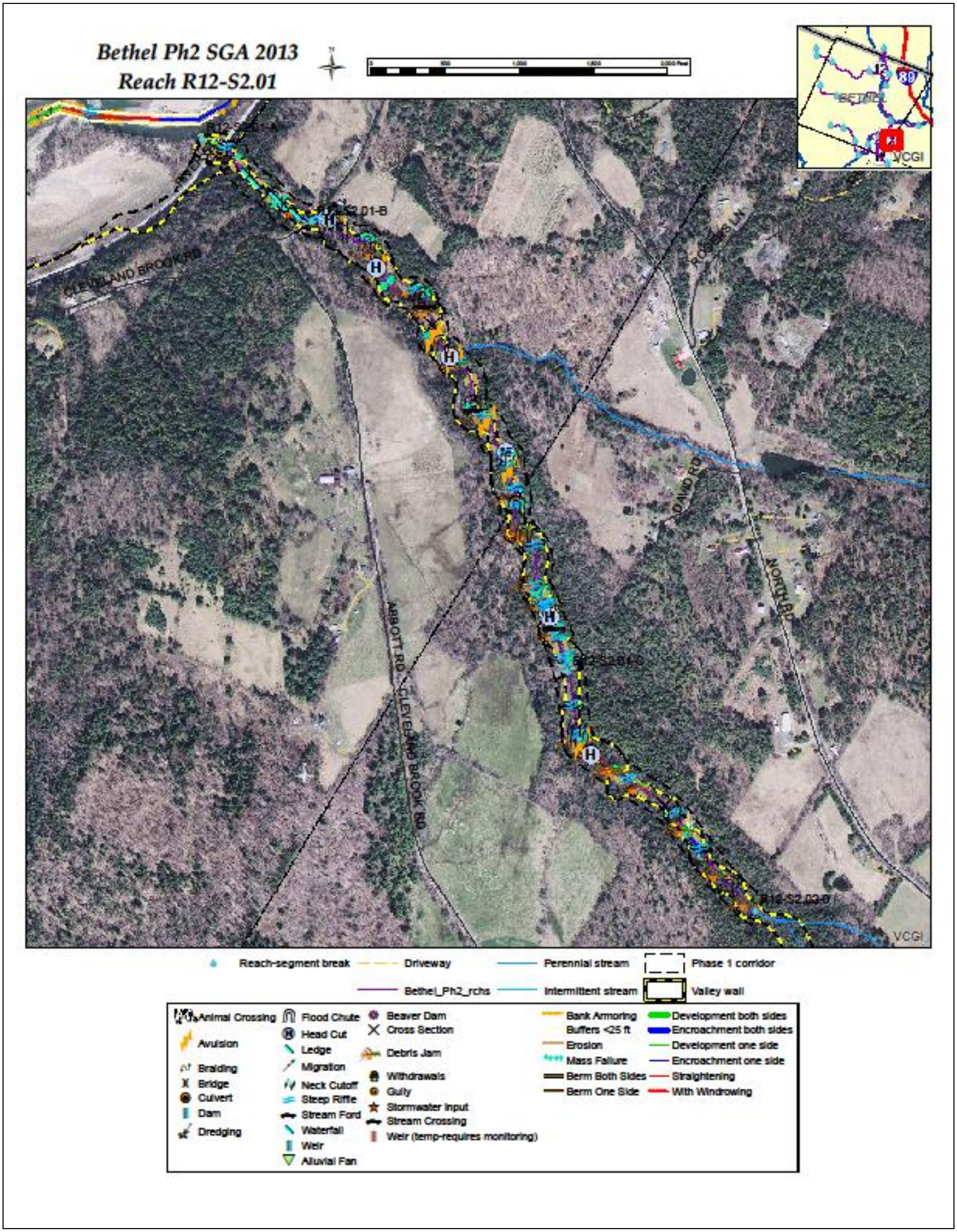


Figure 102. Bethel R12S2.01 reach map – Cleveland Brook.

Bedrock is abundant both on the sides and in the channel of segment R12S2.01A (Fig. 103). There are four channel constrictions in this short segment: the bridge at Cleveland Brook Rd.; the culvert at Rte. 107; and two bedrock constrictions in between (Fig. 103). All of these considerably constrict the channel.

Figure 103. Left: Bedrock cascade is common in R12S2.01A. Right: The bridge at Cleveland Brook Road constricts this 34 foot channel to 7 ft..

Alluvial fan sediments are found at the base of Cleveland Brook segment R12-S2.01A as the tributary enters the greater valley of the White River mainstem. As the stream reaches this valley floor, velocity decreases drastically and sediment tends to accumulate in this location, potentially blocking the culvert (Fig. 104). The stream has been channelized here to help it pass through the culvert under Route 107. Upstream, the channel bed is mostly stabilized by bedrock. In low to moderate flows this section of stream is likely very stable, but in higher flows like Irene the combination of water being forced through multiple constrictions, the steepness of the channel slope and valley walls, and the friability of the bedrock in some areas has led to multiple mass failures, bank erosion, flood chute development, and tipped-over trees (Fig. 104). Surface water inputs from Cleveland Brook Rd. increase water volume and velocity in this segment.

Figure 104. Left: the downstream side of the culvert under Rte. 107 shows sediment build up in the culvert as well as sediments that washed over the road during Hurricane Irene. Right: Mass failures are fairly common in R12-S2.01A, where valley walls are extremely steep.

Segment R12-S2.01B is the longest segment (3,953 ft.). It was separated from Segments A and C primarily based on depositional features. Valley confinement type widens from Narrowly Confined to Narrow in segment B, and channel slope is considerably reduced. Valley walls are extremely steep but are less steep than those in Segment A. This segment appears to be located on alluvial sediments in a small unmapped wetland area just upstream of the Cleveland Brook Rd. bridge (Fig. 105). Erosion and mass failures are very common (15 mass failures and 440 ft. of erosion) as the stream swings back and forth across the narrow valley (Fig. 105).

Figure 105. Left: Alluvial sediments upstream of the Cleveland Brook Rd. bridge in R12-S2.01B show signs of downcutting. As this area fills and then erodes, flushes of sediments can plug undersized downstream road crossings. Right: Mass failures typical of Segment B.

There is very little encroachment in segment R12-S2.01B, and no development. There is a history of timber harvesting, with old stumps right at the stream bank and old stream fords still visible. Storm impacts were primarily a function of soil erodibility and the steepness of the valley walls. Abundant depositional features included unstable side and mid-channel bars associated with steep riffles and braiding. Nick points and small head cuts were eroding through the steep riffles as the stream works to regain slope equilibrium and sort unstable sediments (Fig. 106). Abundant woody material falling into the stream after mass failures and bank erosion has led to numerous debris jams, flood chutes, and several channel avulsions (Fig. 106). Multiple terrace levels along the stream attest to past incision and successive floodplain abandonment.

Figure 106. Left: Headcut forming in head of a steep riffle as the stream works to find channel slope equilibrium and sort recently deposited sediments. Right: Channel avulsion, to the right side of the photo, caused by debris and sediment accumulation that blocked the original channel, to the left.

R12-S2.01C (2,153 ft. in length) is quite similar to Segment B. Valley type continues to be Narrow with extremely steep walls. Channel slope is similar and encroachments are minimal. Generally, the difference lies in more moderate recent storm impacts. Valley walls are still extremely steep, but less steep than for the downstream segments. Erosion is as common, but larger mass failures are more infrequent. Debris jams and unsorted, unstable sediment deposits are much less abundant. As in segment B multiple terrace levels suggest a history of incision, and old stumps and fords indicate periodic timber harvesting (Fig. 107). There is a small abandoned cabin on the stream's right bank (Fig. 107).

Figure 107. Left: Signs of periodic timber harvesting are common in segment R12-S2.01C. Right: A small cabin in the upstream part of segment C appears little used but has a small canopy opening maintained next to the stream.

Primary Stressors:

- Road crossings with severely undersized culverts/bridges (Segment A).
- Historic and recent incision has reduced access to floodplain (incision ratios: Segment B, 2.4; Segment C, 2.0).
- Alluvial sediments create potential for rapid incision and significant downstream sediment loading (Segments A and B)
- Steep and extremely steep valley walls prone to erosion and mass failures (all segments).
- Eroded stream banks and exposed valley wall slopes are likely to continue to add sediment to the stream in future high flows.
- Stormwater inputs (3 road ditches in Segment A).

Table 29. R12-S2.01 Projects and Practices Table – Cleveland Brook.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
R12-S2.01A	Protect River Corridors	Medium	Low	Y	Low development potential but include development encroachment (mass failure below 569 Cleveland Brook Rd) in hazard mitigation planning (HMPG for relocation?)
R12-S2.01A	Remove/ Replace Structures	Very High	Medium	Y	Rte. 107 culvert undersized and at break in slope on alluvial fan - bound to fail again, should be sized significantly larger than bankfull (bkf 23 ft. by curve, 34 ft. field-measured) - but may just outflank with minimal damage; crapshoot. Cleveland Brook Rd bridge also extremely undersized; Venturi effect ramps up mass failures
R12-S2.01A	Restore Aggraded Reach	Very High	Next Highest	N	Replace undersized structures and protect corridor to minimize conflicts with recurrent aggradation and widening cycles
R12-S2.01A	Watershed Strategies	Low	Medium	Y	Municipal corridor protection to limit development, include development encroachments in hazard mitigation planning; evaluate hazards indicated by river corridor zones in comparison with mapped FEMA floodplain - but also recognize propensity to mass failures will extend beyond river corridor zone
R12-S2.01B	Protect River Corridors	Next Highest	Next Highest	Y	Municipal corridor protection to limit development; priority for further protections only decreased by limited amount of accessible floodplain and low threat of development, but segment is playing extremely valuable role in watershed dynamics and is high hazard area
R12-S2.01B	Watershed Strategies	Very High	Low	Y	Municipal corridor protection to limit development; Drainage and stormwater management - storage within upstream watershed features

Table 29 (cont'd). R12-S2.01 Projects and Practices Table – Cleveland Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
R12-S2.01C	Protect River Corridors	Next Highest	Medium	Y	Municipal corridor protection to limit development; priority for further protections decreased by limited amount of accessible floodplain and low threat of development, with fewer mass failures (Than segment B) contributing to sediment loading
R12-S2.01C	Watershed Strategies	Very High	Low	Y	Municipal corridor protection to limit development; Drainage and stormwater management - storage within US watershed features

6.1 Reach T3.01 – Locust Creek from confluence with White mainstem upstream 2.73 miles to 600 ft. upstream of Rte. 12 intersection with Rhoades Hill Rd.

Reach T3.01 flows through a deeply incised valley that roughly parallels Rte. 12 (and Old Rte. 12) for its entire length (Fig. 108). It was broken into four segments based primarily on differences in valley width, with differences in valley slope, corridor encroachments, and banks and buffers all providing secondary reasons for segmentation. Segment T3.01A is situated in a portion of the valley with the lowest channel slope and a Narrow valley confinement type. The valley further constricts in Segment B (Semi-confined), widens for Segment C (Very Broad), and narrows again in Segment D, which is a subreach in a naturally narrower portion of the valley (Narrowly confined).

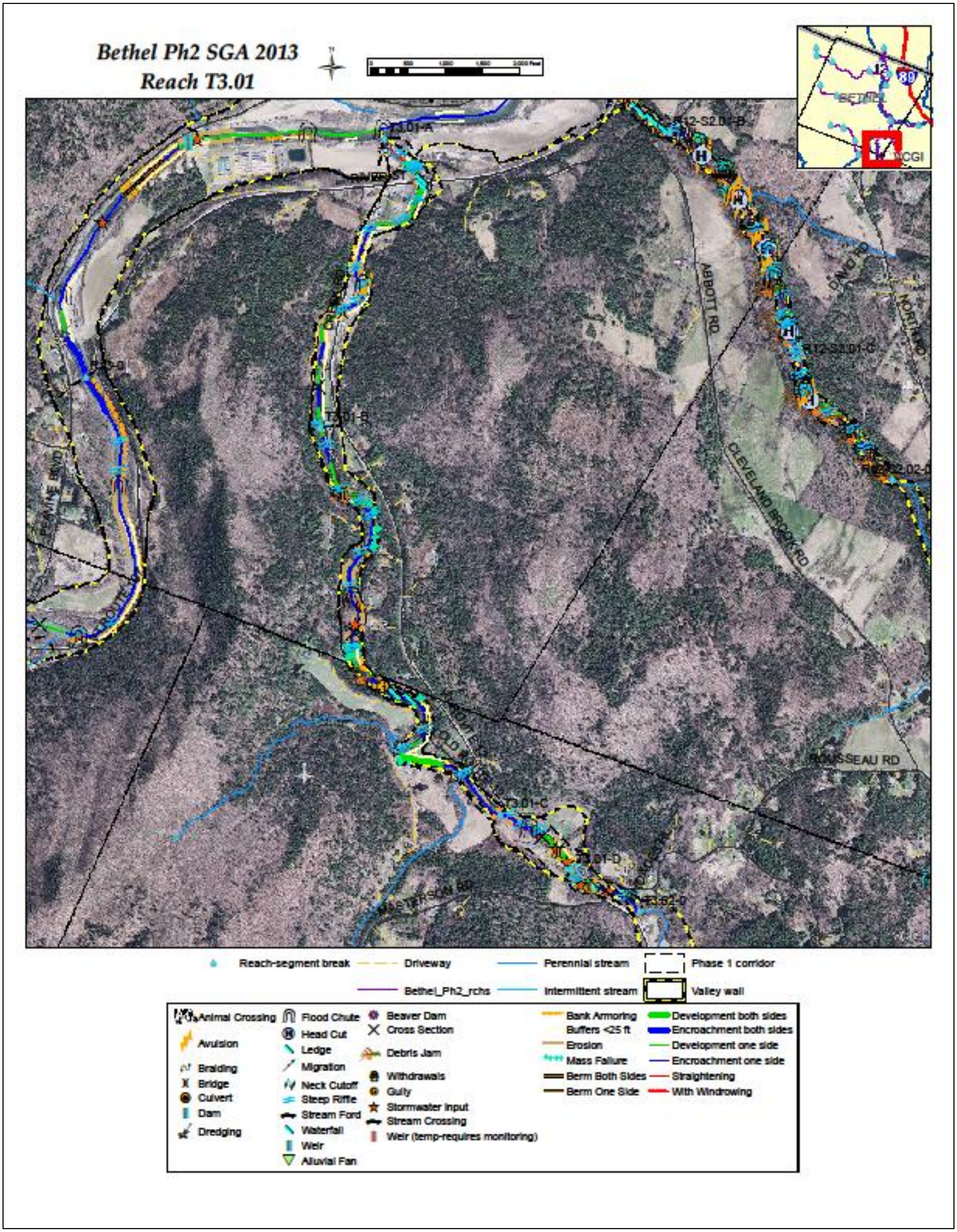


Figure 108. Bethel T3.01 reach map – Locust Creek.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T3.01	14,437	C	None	Gravel	Riffle- pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T3.01-A	4,895	F	None	Gravel	Plane bed	Narrow
T3.01-B	7,141	B	c	Gravel	Plane bed	Semi-confined
T3.01-C	1,266	B	c	Gravel	Plane bed	Very Broad
T3.01-D	1,135	B	None	Gravel	Plane bed	Narrowly confined
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T3.01-A	Poor	Extreme	3.5	III	F	C to F
T3.01-B	Poor	Very High	2.3	III	F	C to B
T3.01-C	Poor	High	3.5	III	F	C to B
T3.01-D	Fair	High	1.0	V	F	none

T3.01A comprises approximately 1/3 of the reach length. This section is a Narrow valley with extensive encroachment in the form of roads, bridges, and other development (Fig. 109). Almost the entire segment has been straightened, woody buffers are lacking in many locations, and invasive plants are abundant along the stream banks and in the buffer area. A large bedrock grade control is located at the site of the Route 107 bridge, at the downstream end of the segment (Fig. 109).

Figure 109. Left: encroachment on the right bank of segment T3.01A. House was rebuilt following Irene and is likely to be at risk again in future high flows. Right: Large bedrock grade control at the Rte. 107 bridge.

T3.01A experienced significant storm impacts during Irene. In the upstream portion of the segment a large bridge on Route 12 washed out and needed replacing (Fig. 110). Just downstream from this a major avulsion re-routed the stream toward the right valley wall and appeared to have damaged or swept away outbuildings off the right bank (present in Google Earth aerial imagery previous to 2011 but not afterward). There is very little woody debris in this segment of stream, indicating that it either was cleaned out following Irene, or that the volume of water moving through the segment was enough to move woody stems through; it appears likely that a combination of these represents a more complete story. Steep riffles and mid-channel bars, representing sediment accumulations that are too much for the stream to carry further or that have backed up at channel constrictions, are common in the segment. These depositional features indicate current instability and ongoing re-adjustments after high flow events. Multiple terrace levels are found alongside the stream in this valley, an indication of historic incision, and the stream shows signs of current widening that is mitigated somewhat by bedrock at the stream edges.

Figure 110. New bridge replacement after Irene damaged the former Rte. 12 bridge in segment T3.01A. Note the large diagonal bar in the foreground, typically a sign of stream instability and likely an indication of sediments from upstream mass failures dropping out as the high flows of Irene slowed when they were squeezed through the bridge.

T3.01B (7,141 ft. in length) is the longest segment in the reach and is characterized by a Semi-confined valley with steep and extremely steep valley walls. Multiple terraces in the valley are an indication of historic incision leading to successive floodplain abandonment, likely due in part to post-glacial downcutting through the highly erodible deposits of a kame terrace on a "finger" of glacial Lake Hitchcock as well as the effects of extensive straightening related to location along two roads that have been major thoroughfares historically. In parts of the segment abandoned floodplain terraces are high enough to form an effective valley wall. The segment alternates between this condition and a “truly” semi-confined valley with natural valley walls; in terms of stream processes, the net effect is a semi-confined valley throughout the length of the segment. This section of stream crosses back and forth across Old Route 12, and each of the three bridges on this road constrict stream flow and sustained damage in Irene. The Bethel selectboard voted to permanently close one town bridge on this road after post-Irene repairs began to deteriorate and the Federal Emergency Management Agency specified that the bridge either needed to be replaced or closed (Cassidy 2012; Fig. 111). Road and and/or development encroachments are present along the entire segment and there is over 1,000 ft. of riprap along the stream banks. Most of the rip rap appears to be of insufficient size to prevent damage in future storm events (Fig. 111).

Figure 111. Left: Bridge failure during Irene has led to closing of Old Rte. 12 at this bridge. Right: Riprap common along segment T3.01B appears insufficiently sized to withstand damage in large storms.

Erosion and mass failures are common throughout T3.01B (Fig. 112). Given the dominance of forest cover in these areas, there is surprisingly little woody debris in the stream channel. As with Segment A, it is possible that the water power and velocity was sufficient to carry material downstream out of this segment, but more likely that much of the wood was cleaned out of the channel following Irene. Large woody debris is an important feature for stream stability, sediment retention and diffusion of stream power in these types of settings. Heavy sedimentation is visible in numerous mid-channel and side bars as well as steep riffles found in Segment B. The stream is still in the process of sorting the material that was moved during Irene and subsequent high flows. Occasional bedrock grade controls lend some channel stability to the segment (Fig. 112).

Figure 112. Left: Mass failures are a common feature in segment T3.01B, as is the absence of woody debris that would have been found in the stream following these mass failures. Right: This bridge is located on a section of bedrock grade control.

T3.01C is much shorter in length (1,266 ft.) than the two downstream reaches and was segmented to account for a much wider natural valley. The valley here is dominated by open farm land that is mostly not in active use (Fig. 113). Similar to the downstream segments, this segment is affected by road and development encroachments contributing to straightening along its entire length. Like Segments A and B, as well, multiple terrace levels alongside the stream indicate a history of incision that has contributed to a loss of flood plain access. Two ponds have been constructed in the last twenty years in the historic floodplain on one of these terraces off the left bank of segment C (Fig. 113).

Figure 113. Left: Road encroachment along one side of the stream is typical of segment T3.01C. The road in this location is on an old terrace and gives a good indication of the level of incision and loss of flood plain access typical of this segment. Right: View of the wider natural valley and old farm fields in this area. The pond, constructed in the last 10 years, is only 100 ft. from the stream and is one of two ponds constructed in the last 20 years in this historic floodplain.

A bridge in T3.01C constricts the channel, and two surface water inputs provide some additional stress on the channel in this location. There are several steep riffles and a diagonal bar in this short section, an indication of heavy sedimentation from storm-related erosion in upstream reaches.

T3.01D is the shortest in length (1,135 ft.) and was segmented due to a distinct narrowing of the valley. Road and development encroachments are still present but they tend to be higher up on the valley wall and out of the effective stream valley corridor. This section of valley has steep to extremely steep walls. A bridge constriction and two surface water inputs provide some potential stressors for this section of stream, and several steep riffles indicate recent sediment inputs that the stream has yet to be able to sort. Bank erosion is present but is not as prevalent as in downstream segments. Bedrock grade controls and some bedrock at the stream edges appear to stabilize the bed and incision was not noted in this segment.

Primary Stressors:

- Loss of floodplain access related to historic incision and exacerbated by dredging/windrowing (incision ratios: Segment A: 3.5, Segment B: 2.5, Segment C: 3.5)
- Extensive straightening (approximately 100% for Segments A and C, and 25% for Segment B), primarily due to road encroachments, but also near buildings and by road crossings
- Multiple stormwater inputs (Segment B: 3 road ditches; Segment C: 2 road ditches; Segment D: 2 road ditches)
- Undersized riprap along road edges that abut the stream channel (Segments A, B, and C)
- Road crossings with undersized culverts/bridges (all segments)
- Steep and extremely steep valley walls prone to erosion and mass failures (all segments)

Table 30. T3.01 Projects and Practices Table – Locust Creek.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3.01A	Stream Buffers	Very High	Very High	Y	Create/protect buffer; passive or low-cost due to lateral instability; some seed sources but augment - may need knotweed control to get trees established in some areas; should be part of reach-scale passive restoration of incised reach. Better Back Roads BMPs along road embankments
T3.01A	Remove/ Replace Structures	Very High	Low	Y	Remove undersized old bridge abutment at TH78 (Poplar Manor Rd. - downstream of Rte. 107 bridge) - would greatly reduce hazards to nearby encroachments and increase floodplain access (but limited extent)

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3.01A	Watershed Strategies	Very High	Next Highest	Y	Corridor protection to limit development; hazard mitigation (ensure landowners are aware of buyout and elevation options, possible HMPG funding or other options) and emergency operations planning; although deeply incised, value as attenuation asset is increased by likelihood that upstream development dependent on Old Rte. 12 may make conflicts with stream processes ongoing for some time to come if not indefinitely

T3.01B	Stream Buffers	Medium	Medium	Y	Would benefit from Better Back Roads BMPs as most areas lacking buffers are road embankments or other encroachments with planting constraints
T3.01B	Watershed Strategies	Next Highest	Medium	N	Corridor protection to limit development; hazard mitigation (buyout and elevation options, possible HMPG funding, etc.) and emergency operations planning. STRUCTURES - 3 undersized bridges, 1 discontinued. Although disc'd bridge is constriction, sediment deposition is consistent with stream evolution - but presents risk to house downstream; alternatives analysis for costs-benefits of bridge removal vs. house (484) buyout/relocation. Alternatives analysis also desirable for replacement of Barnard TH68 bridge (15 ft. span temp bridge in this setting should likely be 120 pct bkf ; curve bkf is 54 ft., field measured 61 ft.) vs buyouts; factor in likely future repeat emergency operations costs and potential for surge from pond overflow (2 new ponds upstream in last 20 years). Ultimately hazard mitigation planning should at least look at feasibility of throwing up Old Rte. 12 - wouldn't be popular, several driveways and side roads, but long-term maintenance problematic.
T3.01C	Stream Buffers	Low	Low	Y	Would benefit from shrubs and Better Back Roads BMPs as area lacking buffers is surrounding bridge

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T3.01C	Remove/ Replace Structures	Very High	Next Highest	Y	Our field-measured span was 32 - channel curve width 51, field measured 59 ft.; amplifies erosive force on banks (road embankments)
T3.01C	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development; Drainage and stormwater management - storage within US watershed features; Buffer establishment and augmentation on US reaches; structures - as opportunities arise, bring into compliance with sizing requirements of new General Permit and 2013 Bridge and Culvert Standards

T3.01D	Stream Buffers	Low	Low	Y	Create-protect buffer US of TH8 bridge (seed sources already nearby) - riprapped after Irene, hard bank now likely to amplify Venturi effect and erosion DS of bridge
T3.01D	Remove/ Replace Structures	Very High	Very High	Y	TH8 bridge significantly undersized - likely contributed to upstream mass failure in Irene and now likely to amplify further erosion downstream of bridge
T3.01D	Watershed Strategies	Next Highest	Medium	N	Municipal corridor protection to limit development; Drainage and stormwater management - storage within US watershed features; Buffer establishment and augmentation on US reaches; structures - as opportunities arise, bring into compliance with sizing requirements of new General Permit and 2013 Bridge and Culvert Standards

6.1 Reach T4.01 – Lilliesville Brook from confluence with the White River, near intersection of Lilliesville Brook Rd. and Peavine Blvd./River Rd., upstream 1.05 miles to Lilliesville Brook Rd. bridge upstream of Whittier Rd.

Reach T4.01 straddles the Bethel-Stockbridge town line (upstream in Bethel, downstream in Stockbridge) and runs roughly parallel with Lilliesville Brook Rd. for its entire length, passing under that road once and under River Road once near the base of the reach. This reach was divided into two segments based primarily on differences in degree of stream alterations, but also on differences in valley width, corridor encroachments, and banks and buffers (Fig. 115). An alluvial fan in the downstream portion of this reach has been a particularly heavy sediment contributor to mainstem reach R13 in repeat flood events (see Figs. 100-101 in reach R13 description above in sec 6.1 of this report) and a number of structures along the stream have seen repeat flood damages (Fig. 114). The reach was heavily impacted in storm events in 1973, 1998, 2007, 2008 and again in 2011 (Tropical Storm Irene).

Figure 114. Flood damage following July 2007 flash flooding on Lilliesville Brook.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T4.01	6,387	C	b	Cobble	Riffle-pool	Very Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T4.01-A	3,490	B	None	Gravel	Plane bed	Narrow
T4.01-B	2,896	C	b	Gravel	Plane bed	Semi-Confined

Segment ID	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T4.01-A	Poor	Very High	2.9	III	F	C to B
T4.01-B	Poor	Very High	2.7	III	F	None

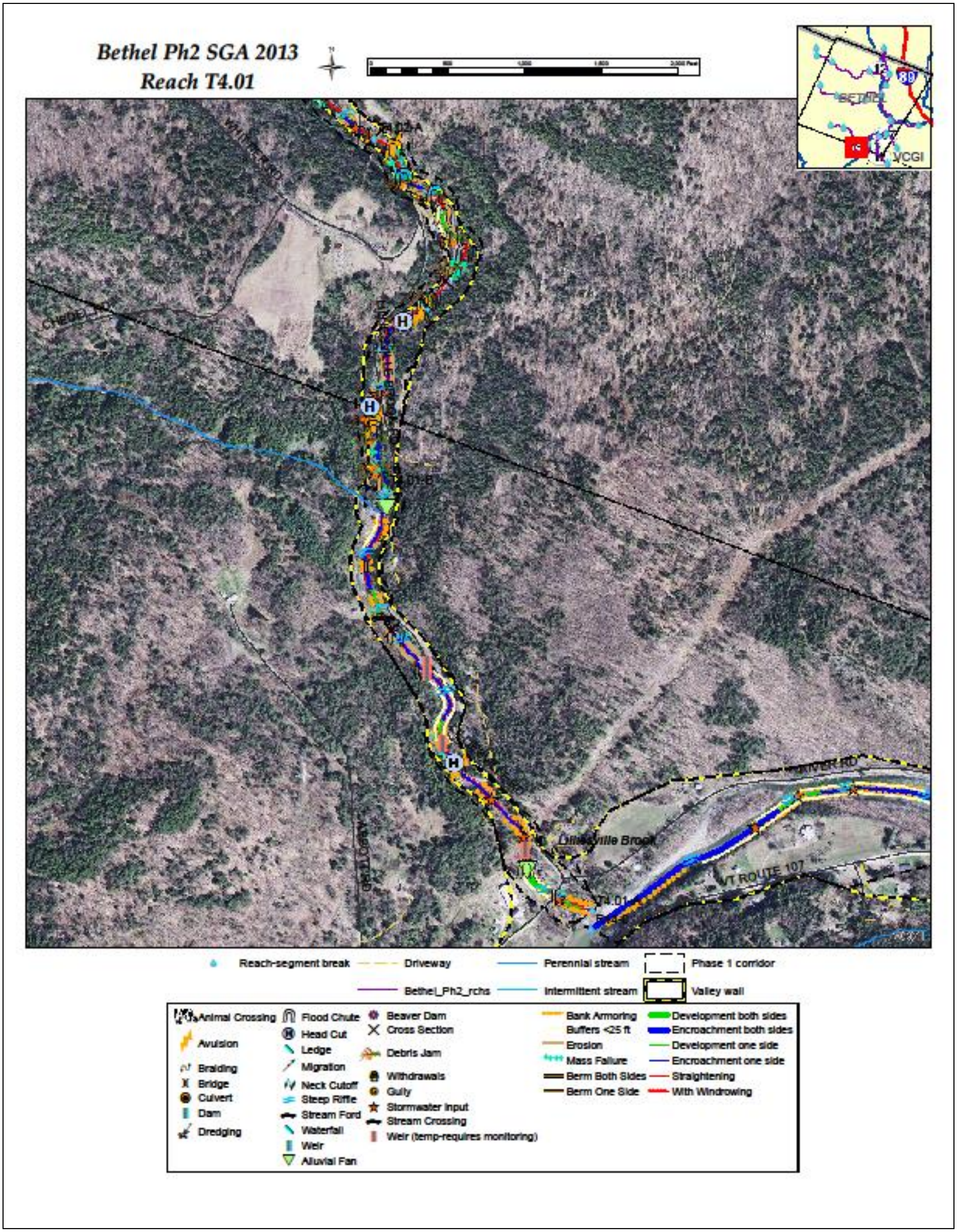


Figure 115. Bethel T4.01 reach map – Lilliesville Brook.

T4.01A is the slightly longer of the two segments (3,490 ft. in length) and approximates the extent of soils formed within the limits of glacial Lake Hitchcock (Fig. 9 in Sec. 3). It is in a Narrow valley with steep valley walls dominated by a complex of loams and sands deposited along the edges of the Lake. This stretch of stream has been very heavily impacted by human encroachment and activities. The entire segment is effectively straightened by virtue of constraint by road encroachment along one side for more than 80% of its length, repeat dredging in several areas, and the effects of multiple bridges. Past storm damages and human responses have been extensive in this segment. Local landowners have many tales to tell about bridge failures and damage to structures during these past storms, including a house and two-car garage that were never re-constructed. Most recently Irene washed out three bridges, which have since been rebuilt, although two private bridges were combined into one in a slightly different location (Fig. 116). Erosion and mass failures are common in this segment with approximately 30% of the segment affected (Fig. 116). Unsorted sediments from upstream mass failures and stream bank erosion are common here, creating mid channel bars and steep riffles.

Figure 116.Left: One private bridge replaces two that washed out in T4.01A during Irene. Right: Large mass failure in T4.01A.

Segment T4.01A was entirely snagged (removal of wood) and dredged (removal of sediments) following Irene (Fig. 117). As part of a project to mitigate some of the effects of this straightening, rock weirs/steps were constructed to arrest further incision (and consequent loss of floodplain access leading to even greater stream power impacts in future flood events), and trees with root balls were buried in the stream bank to help stabilize the bank and create some habitat features as well as channel roughness to aid in diffusing stream power. Old terraces provide evidence of historic incision in this valley.

Figure 117. Upstream view from River Rd. bridge in T4.01A. The building on the right was rebuilt following Irene and a berm stretches along the river bank to protect that area. Channelization is distinct here and several constructed steps were placed to arrest further resulting incision.

T4.01B (2,896 ft. in length) is found in a Semi-confined valley with extremely steep walls dominated by sandy, stony soils just upstream of the extent of glacial Lake Hitchcock. Approximately 50% of the segment has road or development encroachment along one bank, and like Segment A appears straightened along much of its length by virtue of this encroachment, effects of an undersized bridge, and historic incision (which is likely related to both human channel alterations and post-glacial downcutting through highly erodible sediments). Erosion and mass failures are extremely common in this stretch of stream, with approximately 40% of the segment exhibiting these on at least one side. Flood chutes are numerous, an indication that the stream adjusts to high flows by creating additional stream channels in the flood plain area. Forested buffers are found along both banks of this entire segment. Erosion has contributed to considerable buildup of woody debris in the channel, and during Irene this debris diffused stream power through 3 major avulsions into what appeared to be previously existing flood chute channels. Roughly 30% of the segment was snagged and dredged post-Irene.

Primary Stressors:

- Loss of floodplain access related to historic incision and exacerbated by dredging/windrowing (incision ratios: T4.01A: 2.9, T4.01B: 2.7)
- Extensive historic and recent straightening (T4.01A: 100%, T4.01B: 65%) primarily by virtue of significant downcutting, road and development encroachments with attendant channel alterations, and effects of undersized road crossings
- Road crossings with undersized culverts/bridges (T4.01A: 2, T4.01B: 1; at least one other in segment A previous to being damaged by flooding)
- Exposed banks and valley walls due to erosion and mass failures
- Removal of large woody debris that would normally serve to moderate flow and sediment movement (T4.01A: extreme, T4.01B: moderate)
- Stormwater inputs from road (T4.01A: 3, T4.01B: 3)

Table 31. T4.01 Projects and Practices Table – Lilliesville Brook.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.01A	Stream Buffers	Very High	Very High	Y	Create/protect buffer; passive or low-cost due to instability; some seed sources but likely to need augmentation; should be part of reach-scale restoration of incised reach. Assess plantings already installed in DS portion of segment before augmenting
T4.01A	Arrest head cuts and nick points	Very High	Medium	Y	Monitor (and maintain if necessary) post-Irene weirs in DS portion of reach; other headcuts washing out but stream is deeply incised - evaluate as part of reach-scale restoration of incised reach; though high importance for reach, DS reaches need sediment recruitment - but lack of floodplain access is sending fines as well as coarse sediments
T4.01A	Remove Berms	Low	Low	N	US berm (DS of 441 Lilliesville Brook; A-frame was not rebuilt DS at 342) top priority currently but is more limited in amount of floodplain to be gained; DS berms (US of 7 Lilliesville Rd.) would be highest priority if house had not been rebuilt following Irene; deep incision (IR 2.9) means berm removal itself of less value unless part of larger restoration - likely higher priority to address watershed strategies
T4.01A	Remove/ Replace Structures	Very High	Very High	Y	Though one bridge recently replaced at 36 ft width following damage in Irene, recommend bridges in this valley (due to topography, geology and hydrology) be sized at least 120 pct bkf (curve bkf 34, field-measured 53 ft); ability to pass wood and sediment critical in this setting - alluvial fan

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.01A	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development, channel management easements if/when opportunities arise (buyouts or relocations) - importance increased by value of attenuation at DS end of stream that is likely to take a good bit of time to equilibrate due to multiple structures needing replacement; hazard mitigation and emergency operations planning - inform owners of buyout and elevation options and funding sources (houses at 7 Lilliesville Brook Rd and 1550 River Rd especially; possibly 230 as well); STRUCTURES - adequate sizing - though 2013 bridge & culvert standards spec 100 pct bankfull, recommend 120 pct bkf in this setting; drainage and stormwater management upstream
T4.01B	Stream Buffers	Very High	Very High	Y	Protect existing buffers - critical in this setting
T4.01B	Remove/ Replace Structures	Medium	Medium	Y	Though already sized at 33 ft (roughly 110 pct bkf), angle of alignment reduces effective width; recommend bridges in this valley (due to topography, geology and hydrology) be sized at least 120 pct bkf; (curve bkf 31, field-measured 30 ft); ability to pass wood and sediment critical in this setting
T4.01B	Watershed Strategies	Medium	Next Highest	Y	Municipal corridor protection to limit development, channel management easements if/when opportunities arise (buyouts or relocations); hazard mitigation and emergency operations planning - inform owners of buyout and elevation options and funding sources (house at 2525 Lilliesville Brook Rd at moderate risk); STRUCTURES - adequate sizing - although 2013 B&C standards spec 100 pct bankfull, recommend 120 pct bkf in this setting

6.1 Reach T4.02 – Lilliesville Brook from 1.05 mi. up Lilliesville Brook Rd. (near bridge upstream of Whittier Rd.) to ~ 0.3 miles upstream of the Brink Hill Rd. bridge

While Lilliesville Brook Rd. is still located parallel to the stream in reach T4.02, this reach generally has a bit more room between the road and stream than reaches up and downstream (Fig. 118).

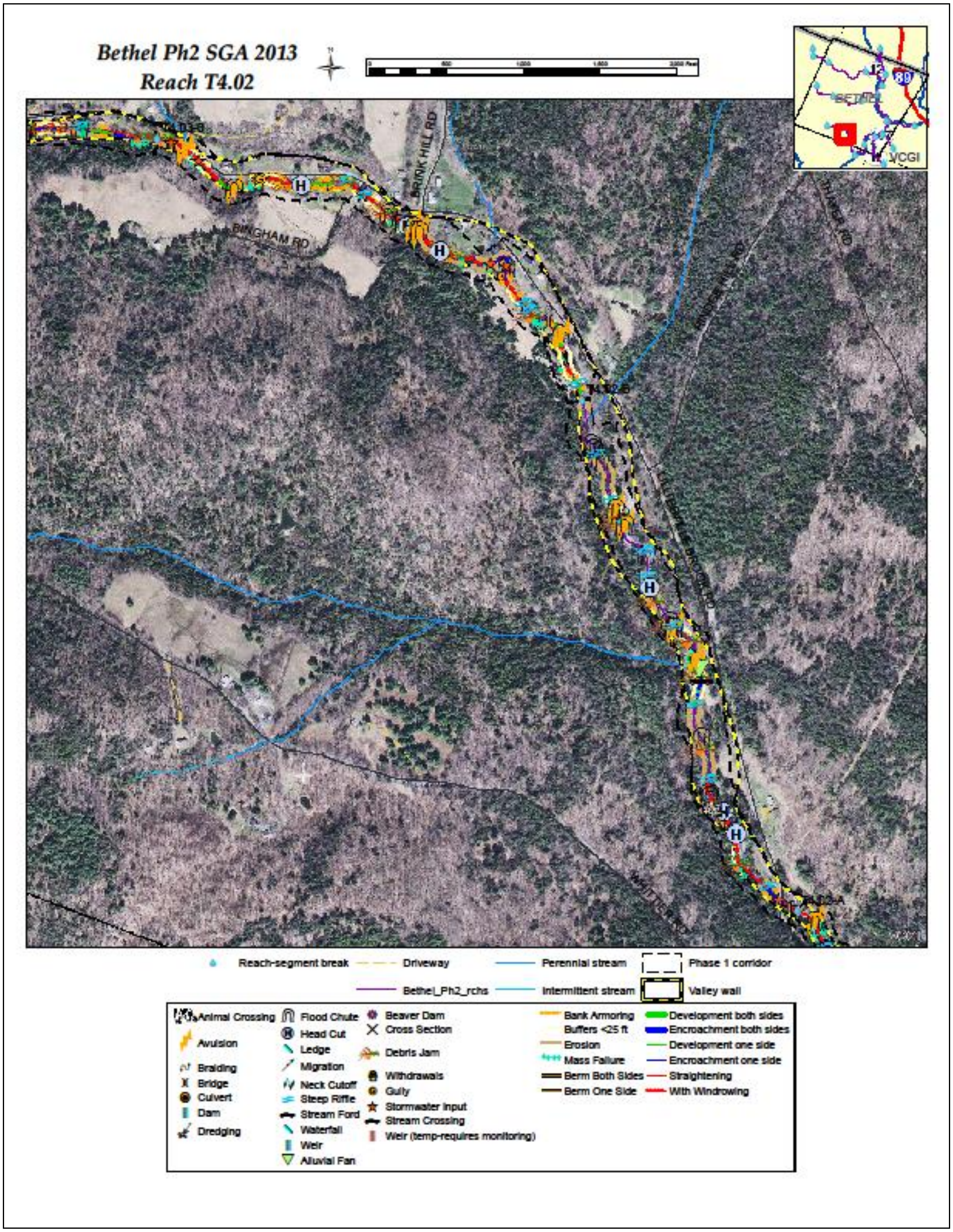


Figure 118. Bethel T4.02 reach map – Lilliesville Brook.

Reach T4.02 was divided into two segments for Phase 2 assessment based primarily on differences in corridor encroachment, and, secondarily, on differences in banks and buffers. The valley is similar for both segments, though valley wall slopes tend to be steep to very steep in the downstream segment and extremely steep upstream.

Phase 1 (reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T4.02	7,709	C	b	Gravel	Riffle-pool	Broad

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T4.02-A	3,394	B	None	Gravel	Plane bed	Broad
T4.02-B	3,774	B	None	Gravel	Plane bed	Broad
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T4.02-A	Poor	Extreme	4.0	III	F	C to B
T4.02-B	Poor	Extreme	3.4	III	F	C to B

T4.02A, the slightly shorter of the two segments (3,394 ft.), is relatively undisturbed by human activities for most of its length. Approximately one-third of the segment is straightened by windrowing and the effects of a bridge at the bottom of the segment that constricts the channel (Fig. 119), with approximately 450 ft. of recently channelized stream in the middle of the segment (post-Irene clean up). The stream is well buffered in this segment and there were numerous debris jams, flood chutes, avulsions, and abundant mid-channel and diagonal sediment bars, steep riffles, and braiding indicative of channel instability and adjustments (Fig. 119).


Figure 119. Left: Bridge constriction at the bottom of T4.02A. Right: Channel avulsions, where the stream jumps its banks and moves to a new location, were typical of this segment.

Erosion, gullies, and mass failures are common in T4.02A, with ~85% of the segment affected. Bank erosion has tipped many trees over, often into the channel (Fig. 120). Considering that this section of stream is not very disturbed by encroachment, there was a somewhat surprising amount of storm damage that occurred during Irene. This is likely due to a combination of highly erodible soils within this segment's right corridor, the presence of alluvial sediments in the stream valley, and extensive human encroachment and channel alterations immediately upstream on Lilliesville Brook. Multiple terrace levels indicate a history of incision, with the most recent incision occurring during Irene. There is one bedrock grade control in this segment that serves to arrest incision in the area immediately upstream. This area appeared considerably eroded and scoured out in recent storm events (Fig. 120). A tributary entering from the southwest in the lower third of this segment, just below this bedrock grade control, also showed significant erosion at its base. This tributary receives water from a large area that includes a section of Whittier Rd., and may have been affected by road runoff, damage to culverts, or a possible beaver pond blow-out or wetland saturation and overflow (near a hard corner of Whittier Rd. on its upstream end) in that area.


Figure 120. Left: Bank erosion is extensive in T4.02A, leading to abundant woody debris tipped into the stream channel. Right: scour and bank erosion in the area of a large bedrock grade control.

T4.02B (3,774 ft. in length), in contrast to downstream segment A, has been extensively encroached upon and manipulated. There is road encroachment for approximately 60%, and development along 20%, of the length of the segment, and the entire length is effectively straightened by these impacts and the effects of undersized bridges. Riprap is present along more than 40% of the stream bank (Fig. 121). Forested buffer is present along one bank, while the other is dominated by residential development with a woody buffer absent or minimal (Fig. 121).


Figure 121. Left: Riprap is common in areas where the road comes close to the stream bank in segment T4.02B. Right: encroachment from buildings is not uncommon in the segment. Signs of dredging with windrowing, post-Irene, are evident in this photo.

Tropical Storm Irene severely impacted many parts of segment T4.02B. Erosion and mass failures were common, with approximately 50% of the segment affected (Fig. 122). Impacts from Irene and other storms have been spread unevenly and affected by the distribution of riprap, encroachments and straightening effects, causing the stream to frequently alternate between narrow/incised and over-widened/aggraded. Unsorted sediment bars are common. Steep riffles were frequently associated with large mid-channel bars, with head-cutting beginning to occur at the downstream edge of the steep riffles. Flood chutes, debris jams, and large avulsions were also common (Fig. 122).


Figure 122. Left: bank erosion as shown here is typical in segment T4.02B where the stream has incised below the level of tree roots. Right: Large avulsions such as this are common in the segment.

Two bridge constrictions and five stormwater inputs provide additional stress on segment T4.02B during periods of high flow. At least one of these bridges, and possibly both, washed out during Irene (Fig. 123). A landowner in the top part of this segment says the stream has flooded over Lilliesville Brook Rd., near her house, five times since 1974. Multiple terrace levels are an indication of historic incision and successive floodplain abandonment in the valley. A historic ford provides a good visual indication of how deeply this stream has cut below the grade of the original crossing (Fig. 123).

Figure 123. Left: Private bridge in T4.02B that may have washed out during Irene. There were definite signs that the stream crested the banks in this location. Right: Historic ford showing depth of incision since it was used.

Primary Stressors:

- Loss of access to historic floodplains (incision ratios: T4.02A, 4.0; T4.02B, 3.4)
- Straightening (all of segment T4.02B) primarily due to road encroachments, but also near buildings and road crossings as well as through impacts of repeat dredging and snagging
- Bridges with major constrictions (T4.02A: 1, T4.02B: 2)
- Abundant mass failures, erosion, and tributary rejuvenation contributing to heavy sediment loads
- Significant additional storm water inputs (T4.02A: 1 road ditch, 1 overland flow; T4.02B: 2 road ditches, 1 field ditch, 2 overland flow)
- Lost/impacted wetlands in subwatersheds

Table 32. T4.02 Projects and Practices Table – Lilliesville Brook

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.02A	Protect River Corridors	Very High	Very High	Y	Municipal corridor protection to limit development; although relatively limited in accessible floodplain extent, this corridor is least developed along Lilliesville Brook and plays an important attenuation role, has potential for rebuilding floodplain access
T4.02A	Stream Buffers	Medium	Very High	Y	Protect existing buffers - critical in this setting
T4.02A	Remove/ Replace Structures	Next Highest	Next Highest	Y	Though sized at 34 ft (roughly 110 pct bkf), abutment is cracked and angle of alignment reduces effective width - stream dynamics indicate hourglass/Venturi effect; recommend bridges in this valley (due to topography, geology and hydrology) be sized at least 120 pct bankfull width (curve bkf 31, field-measured 32 ft); ability to pass wood and sediment critical in this setting
T4.02A	Watershed Strategies	Very High	Very High	Y	Municipal corridor protection to limit development; drainage and stormwater management to reduce flashiness; STRUCTURES - adequate sizing - although 2013 bridge & culvert standards spec 100 pct bankfull, recommend 120 pct bkf in this setting

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.02B	Stream Buffers	Medium	Medium	Y	Low cost or passive: limited opportunities, high instability but important in this setting; encroachments tight on stream and road embankments extensive; explore Better Back Roads BMPs for embankments
T4.02B	Remove/ Replace Structures	Very High	Very High	Y	Undersized structures- roughly half bkf- are major contributors to overall reach (and entire stream) instability; may need evaluation of impacts to structure upstream of bridge across from 1565 Lilliesville Brook
T4.02B	Watershed Strategies	Very High	Very High	N	Municipal corridor protection to limit development, include development encroachments in hazard mitigation planning and emergency operations plan; evaluate hazards indicated by river corridor zones in comparison with mapped FEMA floodplain and include additional likely slope changes due to mass failures; drainage and stormwater management to reduce flashiness; STRUCTURES - adequate sizing - although 2013 B&C standards spec 100 pct bankfull, recommend at least 120 pct bkf in this setting

6.1 Reach T4.03 – Lilliesville Brook from ~0.3 miles upstream of the Brink Hill Road bridge to 250 ft. downstream of the 4-corners at Gay Hill, Dartt Hill, Campbell and Lilliesville Brook Roads

Reach T4.03 was not segmented for Phase 2 assessment. This section of stream gets progressively larger from top to bottom, as well as more impacted by recent storms and human activities, but there was no clear division to indicate segmentation. The stream here runs through a narrow valley with extremely steep walls in close proximity to Lilliesville Brook Rd. through most of its length (Fig. 124).

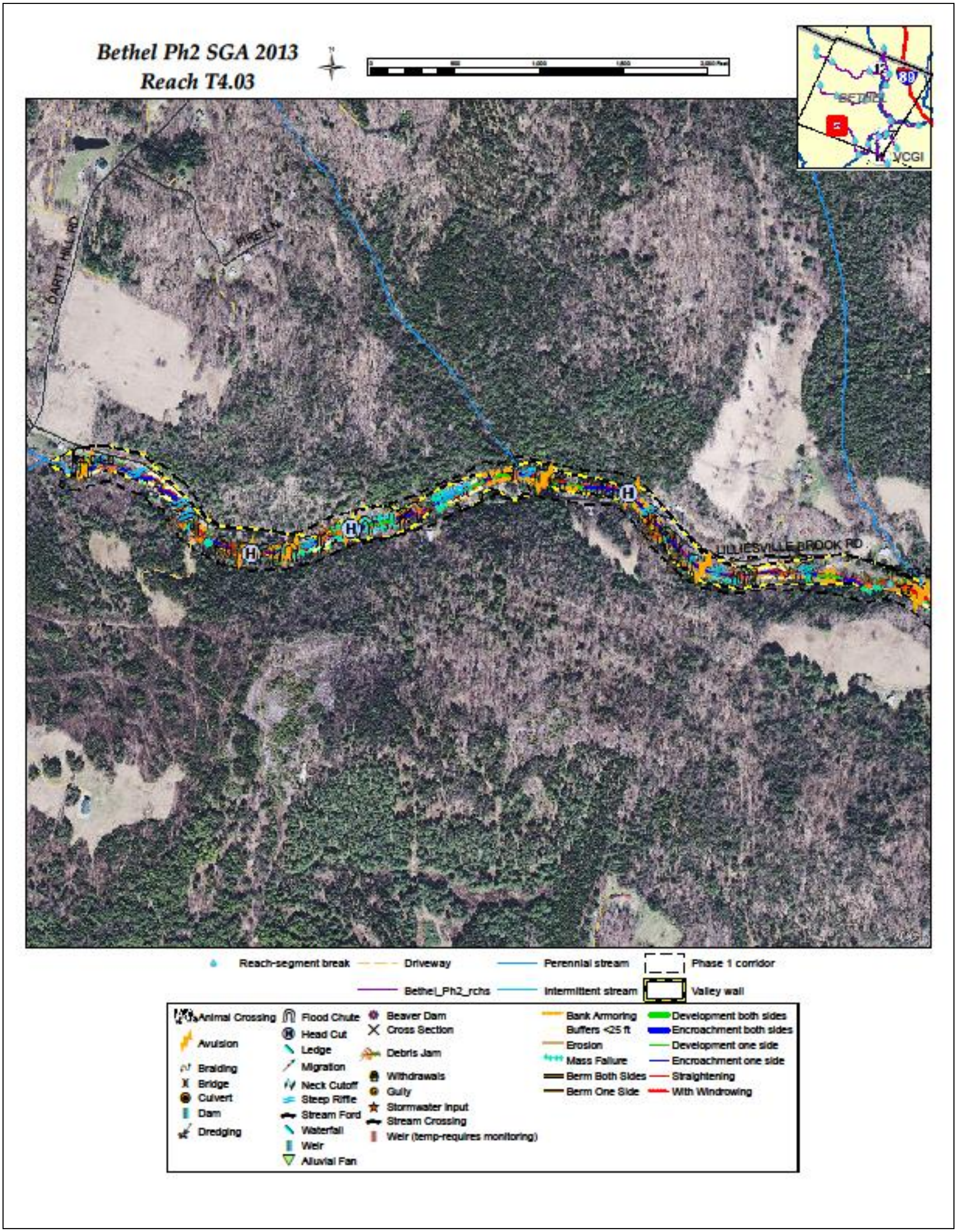


Figure 124. Bethel T4.03 reach map – Lilliesville Brook.

Lilliesville Brook Reach T4.03 is highly impacted by human activities. While the stream is naturally straighter than downstream reaches due to its steep slope, it is also effectively straightened further by virtue of corridor encroachments, channel alterations, and the effects of multiple stream crossings. Development and/or road encroachment is a constant on one side or the other of the stream.

Phase 1
(reference)

Reach ID	Channel length (ft)	Stream type (reference)	Sub-slope	Bed material	Bed-form	Valley type
T4.03	5,474	B	a	Cobble	Step-pool	Narrow

Phase 2

Segment ID	Channel length (ft)	Stream type (existing)	Sub-slope	Bed material	Bed-form	Valley type
T4.03-0	5,474	B	a	Cobble	Step-pool	Narrow
	Geomorphic condition	Stream sensitivity	Incision ratio	Channel evolution stage	Channel evolution model	Stream Type Departure
T4.03-0	Poor	High	2.7	III	F	none

Bridges are a major issue in reach T4.03, and 3 of the 5 bridges documented in the reach are private. One landowner noted two bridges held in Irene but the road washed out on either side; 3 of 4 landowners that discussed their situations during the course of the assessment wanted to remove large woody debris from the channel and saw that as a primary cause of damage - though large wood and sediment continuity are critical to the ability of the whole of Lilliesville Brook to establish greater long-term stream stability, reduce “flashiness” in heavy downpours, and lessen the impacts of elevated stream power.

All of the bridge crossings in T4.03 create channel constrictions (the largest ones, despite being sized adequately, create constrictions due to the angle of alignment to the stream reducing the effective width of the structure). Several of these bridges were over-topped and severely damaged during Irene (Fig. 125). Surface water inputs from road ditches (9 inputs) add additional flow to the stream. Development is frequently located close to the stream channel, and there have been recurrent conflicts with stream processes during periods of high flow (Fig. 125). Dredging and snagging were common activities post-Irene.

Based on predicted channel bankfull width (22 ft) from regional hydraulic curves (a function of drainage area), three of the bridges are sized at ~70 percent stream bankfull width (at typical 1.5-2 yr. peak flow levels), one at 95 percent and one at 135 percent (though the latter bridge effective opening is significantly reduced by the angle of alignment to the stream and the combined effects of riprap and sloped fill under the abutments). Based on field measurements taken at the Phase 2 “representative cross-section” for this reach (29 ft.), these figures drop to ~55-60 percent for three bridges, one at 70 percent, and one at 100 percent. Due to the topography and hydrography of this portion of Lilliesville Brook it is highly recommended that bridge replacements in this area be sized at least 120 percent of bankfull width to accommodate passage of wood and sediment as well as water. Failure to size bridges adequately continues to contribute to hourglass and Venturi effects at undersized structures.

Figure 125. Left: This bridge on Lilliesville Brook Rd. was damaged during Irene, but remained standing while the road washed out on both sides. According to landowner reports, this was a common occurrence with the bridges in this reach. Right: Bank encroachment and recent riprapping, with associated dredging, post-Irene.

Personnel from the Green Mountain Forest District of the USDA Forest Service documented a number of recently installed culverts, sized at 100 percent stream bankfull width or larger, that sustained no damage during Irene despite having had to pass significant amounts of large woody debris (Kirn 2014) Because these culverts were sized this large, they limited the “hourglass effect” associated with undersized structures (Fig. 126) that tends to funnel and accumulate sediment and woody debris just upstream of a structure, while downstream of the structure the heightened stream power of “tailwater” being accelerated after being forced through an undersized opening tends to cause amplified erosion that typically needs to be controlled with bank armoring.

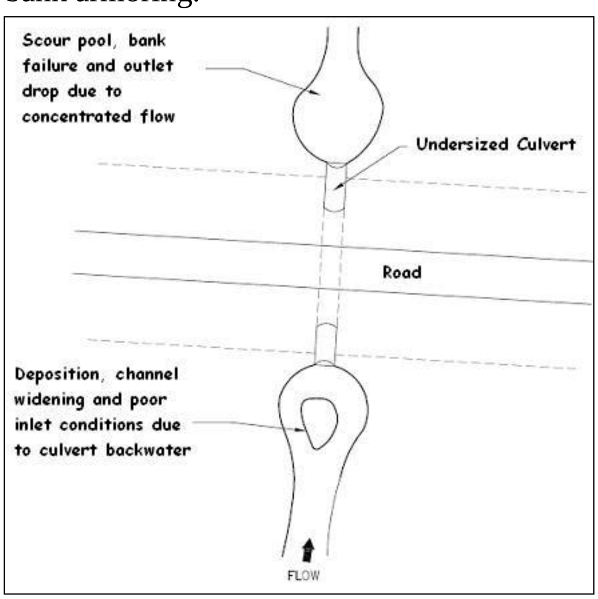


Figure 126. “Hourglass effect” at undersized stream crossing structures tends to accumulate sediment and woody debris in an over widened channel just upstream of the undersized opening, while scour due to heightened erosive power of “tailwater” forced through the structure over widens the channel just downstream (Kirn 2014; Bates and Kirn 2009).

Elevated erosive power of high flows constrained to the current channel can be expected to continue to widen the stream (and recruit more wood) in reach T4.03 since aggradation has not brought the stream bed up to a level that can regain historic flood plain access across which high flows can be diffused. Undersized bridges are likely to continue to be in recurrent conflict with inevitable stream processes on this brook, and continued dredging and snagging are likely to continue to increase the impacts of heightened stream power. Adequately sized structures and reduced levels of encroachment are likely to become increasingly cost-effective with the more frequent recurrence of intense downpours forecast for the northeast US in the decades ahead.

Forested buffers dominate the stream corridor of reach T4.03, with residential development secondary. Recent storm damage has eroded banks, caused mass failures and deposited abundant woody debris in the stream channel. Erosion and mass failures now affect approximately 35% of the reach (Fig. 127). Riprap placed to prevent further erosion is found in another 25% of the reach. During Irene and subsequent high flows, woody debris from tipped over trees left numerous debris jams, large un-sorted sediment deposits, and split channels and channel avulsions (Fig. 127). The stream is in the process of adjusting to all of these recent impacts.

Figure 127. Left: Mass failure in the downstream end of reach T4.03. Several of the mass failures in this reach were of this magnitude. Right: The debris jam in this photo retained sediments upstream, bringing the channel bed close to the flood plain level, as well as causing a channel split with erosion and headcutting downstream in the newly formed second channel.

Primary Stressors:

- Loss of access to historic floodplains (incision ratio: 2.7)
- Multiple road crossings with bridges that cause moderate to severe channel constrictions
- Development close to channel banks with associated dredging and riprapping
- Extensive straightening due to a combination of road encroachment, bridge construction, and housing development
- Multiple stormwater inputs from road ditches (7)
- Past erosion and mass failures have left exposed banks contributing to sediment loading.

Table 33. T4.03 Projects and Practices Table – Lilliesville Brook.

River Segment	*Project*	*Reach Priority*	*Watershed Priority*	*Completed Independent of Other Practices*	*Next Steps and Other Project Notes*
T4.03	Stream Buffers	Low	Low	N	Explore Better Back Roads BMPs for road embankments; primary areas of diminished buffers are along these embankments
T4.03	Remove Berms	Next Highest	Next Highest	Y	Several opportunities exist for cuffing out windrows, particularly at bridge "clean-out" areas, that would open access to a wider floodplain with relatively little risk to nearby structures or infrastructure; other opportunities will likely only open with buyouts or relocations
T4.03	Remove/ Replace Structures	Very High	Very High	Y	Likely highest priority on Lilliesville Brook overall, but several are substantial concrete structures that are likely to continue outflanking rather than the structure failing; adoption of 2013 Bridge and Culvert standards was huge step in right direction but other funding options may need to be explored due to outflanking dynamics
T4.03	Watershed Strategies	Very High	Very High	N	Municipal corridor protection to limit development, include development encroachments in hazard mitigation planning and emergency operations plan; until structures are resolved, and there are multiples upstream as well, stream equilibrium will be hard to attain and this remains a high hazard area; STRUCTURES - adequate sizing - although 2013 bridge & culvert standards spec 100 pct bankfull, recommend at least 120 pct bkf in this setting. Evaluate hazards indicated by river corridor zones and include additional likely slope changes due to mass failures; drainage and stormwater management to reduce flashiness

6.2 PROJECT PRIORITIZATION

Based on the foregoing analysis, project prioritization for this 2014 River Corridor Plan for Bethel features (in order of descending priority):

- Watershed (largely municipal) strategies
- Buffer establishment and protection
- Reach-scale corridor protection projects: Third Branch reach M03, Gilead Brook reach T1.01, White River mainstem reach R12
- Reach-scale restoration projects: Gilead Brook reaches T1.02, T1.01

Although buffer protection and/or establishment is an important part of any efforts in these basins and can certainly be recommended as a stand-alone project if opportunities arise (with adequate planning to account for widespread bank instability and its potential impacts on plantings), selecting areas for prioritization favors areas where reach-scale corridor protection or restoration activities will help move streams more quickly toward equilibrium conditions. Buffer prioritization is thus discussed further following the reach-scale projects below. Reach-scale projects with multiple coordinated strategies may require multiple partners or organizations to restore better floodplain function and meander geometry.

A river is considered stable, or in a state of "dynamic equilibrium," if it can adjust its channel geometry (width, depth, and slope) to efficiently discharge, transport, and store water, sediment, and debris (Leopold, 1994, Rosgen, 1996). Due primarily to deep and extensive channel incision (aka downcutting or bed degradation) throughout the majority of streams in the 2013 assessment area, a high degree of stream instability is likely to be ongoing for some time to come in Bethel (probably decades at least). Only 10 of 36 segments (in 6 of 18 reaches) were classed in Fair condition (undergoing Major adjustments); the remainder were deemed in Poor condition (undergoing Extreme adjustments).

These factors place a particularly high value on addressing flood preparedness (flash flooding as much as inundation flooding) in Emergency Operations and Hazard Mitigation Planning, as well as on protecting valuable attenuation assets capable of storing and/or diffusing high sediment and water discharges (Third Branch reach M03, Gilead Brook reach T1.01, White River mainstem reach R12) while upstream issues such as highly channelized reaches and multiple undersized bridges are being addressed.

Lilliesville Brook reach T4.01 and Locust Creek reach T3.01 are high priorities for reach-scale corridor protection from the perspective of overall stream stability but are severely constrained in possibilities for meaningful protection and/or restoration due to current levels of development along these streams and along other roads either primarily or solely accessed from the roads that run along these streams (Lilliesville Brook Rd. and Old Rte. 12). The intractable nature of this situation reinforces the recommendation of municipal corridor protection to limit further development in close proximity to streams as the top priority recommendation of this Corridor Plan. Realistically, greater long-term stream stability in these areas may only come about with a reduction in current levels of development along these streams.

Some of the efforts highlighted here have already been initiated in the Bethel area, and adaptive management should be used to periodically assess the feasibility and prioritization of future projects based on stability gained from cumulative efforts. Recent efforts by the White River Partnership to document and monitor past project implementation throughout the White River basin (pers. comms. 2012-2013, Mary Russ, Executive Director; Greg Russ, Project Manager; Emily Miller, Monitoring Coordinator) are an example of the kind of information needed for such adaptive management.

Watershed strategies

The highest priority project recommendations include the following watershed strategies (listed in order of descending priority but understood to be strongly interconnected and interdependent):

1) Floodplain and River Corridor Planning and Protection

- River Corridor overlay in conjunction with updated Flood Hazard Bylaws (the river corridor includes space for both the meander belt and a 50 ft. riparian buffer; VT DEC 2014, pp. 8-11). Draft model ordinances and regulations are available as a starting point (Kline 2010, pp. 66-67; VT WMD 2014).
- Local Emergency Operations and Local Hazard Mitigation Plans. All of the towns in the 2013 study area have up-to-date Emergency Operations Plans; Bethel and Barnard are currently in the process of updating Local Hazard Mitigation Plans (FloodReadyVT 2014). These plans are particularly important along the White mainstem, Locust Creek, and Camp, Gilead and Lilliesville Brooks due to current levels of stream encroachment and long-term challenges in mitigating the effects of heightened stream power in these narrow valleys. Addressing road encroachments will be especially important, and Hazard Mitigation Plans may benefit from incorporating guidance from the Vermont Standard River Management Principles and Practices (Schiff et al 2014).

It would be difficult to overemphasize the importance of the role that encroachments on small streams play in narrow valleys and restricted floodplains (which is the case in most of Bethel). Large costs associated with road repair are challenging for small towns to accommodate, and a number of houses or structures damaged in Irene and other flash flood events in Bethel and the surrounding area illustrate impacts that are being amplified by loss of floodplain access or heightened stream power transferred from upstream of the impacts (frequently due to road encroachments, undersized bridges and culverts, or protection of development). River Corridor overlays provide not only flood protection and /or hazard identification for land and structures adjacent to the stream, but accommodation of stream processes that will help break a cycle of impacts being amplified and passed to downstream reaches.

2) Road-Stream Crossing Retrofits and Replacements

- All of the towns in the 2013 study area (Bethel, Randolph, Stockbridge, Barnard and Royalton) have adopted Vermont Agency of Transportation 2013 Bridge and Culvert Standards (VTrans 2014), an important step that will help leverage funding for adequately sized structures damaged in flood events (Emergency Relief Assistance Fund). Although the 2013 standards recommend sizing structures at 100% bankfull width, Bethel, Stockbridge and Barnard may wish to explore incorporating standards (possibly in Local Hazard

Mitigation Plans) that require at least 120% bankfull widths for structure replacements on Lilliesville and Camp Brooks, plus Locust Creek, in particular; possibly Gilead Brook as well.

- Bethel and Randolph: develop comprehensive digital inventories through VTCulverts (formerly VOBCIT) and also utilize existing data (VT-ANR Atlas 2014; VT SGA-DMS 2014) collected with River Management/Fish & Wildlife data collection protocols (Milone & McBroom 2008; Milone & McBroom 2009) to permit use of the Culvert Screening Tools for prioritization and leverage a variety of funding mechanisms for retrofits and replacements (Kline 2010, p. 71; Kirn 2014).
- The importance of Locust Creek and Lilliesville and Gilead Brooks to trout habitat (see section 3.5.1 of this Corridor Plan) should figure prominently in addressing ongoing issues with undersized structures (leading to repeat post-flood "cleanouts" of sediments and large woody debris from the stream channel) as a major impediment to restoration and protection of aquatic habitat on these streams
- Vermont River Management: Expand Culvert Geomorphic Compatibility Screening Tool to permit prioritization of bridges on geomorphic compatibility basis
- All towns: Capital budget planning with geomorphic compatibility included in prioritization discussions with structure owners about replacement schedules

3) Buffer Protection and Establishment

- Predominant widening and meander re-establishment needed to achieve stability will entail frequent erosion and numerous mass failures, and will benefit from large woody debris for rebuilding access to abandoned floodplains, sediment retention, diffusion of stream power, and provision of habitat features.
- Although buffers are good in many areas, buffer zones should be protected; protection mechanisms could be included in municipal River Corridor overlay zones or similar mechanisms, and should be included in any channel management or river corridor easements negotiated with individual landowners. Due to widespread current instability and the likelihood of continued erosion and mass failures until streams gain greater stability, buffer widths need to accommodate continuing channel evolution and landowners need to be aware of the widths needed to permit buffer establishment that will not be eroded away in the short term (typically 50 ft. beyond the meander belt width; VT DEC 2014, pp. 8-12, p. 26)
- Intermittent stretches of missing buffers (particularly along the Third Branch) and buffers impacted by frequent roadside encroachment work in tandem with the highly erodible geologic legacy of the Bethel area to contribute large amounts of fine sediments to streams in the study area. Road crews are encouraged to leave roadside trees to the greatest extent of safe feasibility and utilize design guidelines for incorporating vegetation into road encroachments requiring bank armoring (Schiff et al 2014, esp. Appendix J). Bethel and surrounding communities are highly encouraged to stay abreast of technical assistance and funding opportunities through the Better Back Roads program in particular (VT Better Back Roads 2014).
- Buffer establishment is generally recommended for passive reseeding or low-cost plantings with shrubs and grasses closer to the stream and trees toward the rear edge of the Fluvial

Erosion Hazard zone (due to lateral and vertical instability and risk of losing plantings to widening and planform adjustments)

4) Drainage and Stormwater Management

- Develop stormwater master plans; recommendations for Bethel and surrounding communities can be found in the Appendix and planning templates in the Vermont Stormwater Master Planning Guidelines (VT ANR-ERP 2013); priority areas on Camp, Gilead and Lilliesville Brooks
- Management of overland flow and keeping entry points well vegetated currently more of an issue on assessed reaches than actual erosion at entry points
- U-shaped and stone-lined ditches desirable for fine sediment reduction; will likely need prioritization as the issue is prominent throughout the study area, with streams sharing narrow valleys with a relatively dense road network. Importance of Master Planning is increased by the fact that ditches will deliver water to streams more quickly in flood situations, contributing to "flashiness"

Reach-scale protection and restoration strategies

Four reaches were identified as priorities for reach-scale protection and/or restoration strategies, listed in order of priority in Table 19.

Table 34. Priority reaches for integrated reach-scale corridor protection and/or restoration strategies

1	M03	Third Branch from east of Gilead Brook Rd. to Beanville (south Randolph)
2	T101	Gilead Brook from Third Branch to farm bridge downstream of Messier Rd.
3	T1.02	Gilead Brook from Mitchell Dr. to bridge at Schoolhouse Rd.
4	R12	White River from Third Branch at Peavine Park to Tozier's on Rte. 107

Buffer establishment and protection are thus preferentially recommended on these high-priority reaches, ideally as part of an integrated strategy aimed at restoring floodplain function and a more stable planform allowing greater meander development - but as a good starting point regardless of whether other pieces of an overall reach strategy can be implemented. Other portions of these integrated strategies are listed in the Priority Project Summary Table below.

Stand-alone buffer project priorities

Stream reaches including additional priority buffer establishment projects recommended for stand-alone implementation, roughly in order of recommended priority, are found in Table 20. Since there are buffers existing along many of the streams in Bethel and on the surrounding tributaries assessed in 2013, the starting point for most buffer "projects" is protecting existing buffers and allowing for passive regeneration. Road encroachment areas will greatly benefit from Better Back Roads designs and would do well to incorporate vegetation into bank armoring (Schiff et al 2014 Appendix J) when repairs are needed.

Table 35. Stream segments with priority buffer projects recommended for stand-alone implementation.

River Segment	*Next Steps and Other Project Notes*
M01	Passive regeneration or low-cost plantings due to lateral instability; be clear about meander belt-width and assume high instability near banks. Marsh Meadow buy-out site: plant full-width buffer to maximum amount acceptable to stakeholders (close buffers on this side), consider a ***wooded*** trail; will regenerate naturally but site invites public participation in planting choices. Augment buffers at Peavine Park and consider educational sign about importance of buffers. Seed and plant (shrubs and fast-growing trees) point bar upstream of Peavine Blvd. bridge. Athletic fields and just upstream. Several ag fields in upstream portions of reach.
M02	Passive or low-cost due to lateral instability; be clear about meander belt-width and assume high instability near banks. Wood critical to stream stability (fine sediments due to Lake Hitchcock legacy). Right bank US Findley Rd. bridge. Both banks upstream of Gilead Brook.
R11	Create/protect buffer; passive or low-cost due to lateral instability, may need Japanese knotweed control to allow trees to establish. Right bank downstream of River St. bridge.
T4.01A	Create/protect buffer; passive or low-cost due to instability; some seed sources but likely to need augmentation, particularly in downstream portion of reach. Assess plantings already installed in downstream portion of segment before augmenting.
T1.01D	Passive or low-cost due to lateral instability, seed sources exist but buffers need augmentation - especially base of tributary from Messier Rd.
T4.02A	Protect existing buffers - critical in this setting - augment buffer at upstream end of field between 2289 and 2387 Lilliesville Brook Rd.
M01-S3.02A	Opportunities limited as primary areas lacking buffers are road embankments; investigate Better Back Roads and VT River Management Practices (Schiff et al 2014) design guidelines. May be opportunity near 1523 Camp Brook Rd.
T3.01C	Would benefit from shrubs, Better Back Roads, VT River Management Practices (Schiff et al 2014) BMPs as area lacking buffers is surrounding Barnard TH-80 bridge

Top project priorities

Current geomorphic conditions on the streams assessed during 2013 in the Bethel area are largely related to two primary factors:

1) widespread loss of access to historic floodplains through glacial legacies and significant land and river use changes; and

2) extensive and pervasive channel straightening

In part due to the effects of the latter, the first factor was dramatically amplified by the impacts of Irene, leaving streams even more entrenched in what were already diminished floodplains and valley bottoms. Unless large woody debris and coarse sediment deposition can begin to contribute to rebuilding meanders and access to abandoned floodplains, flash flooding in increasingly common heavy downpours will continue to impact the area with elevated levels of erosion, mass failures and other flood damage.

These factors place the highest priority (in terms of project prioritization) on restoration of optimal floodplain functions (especially attenuation of high flows and storage of sediment and nutrients) and stable planform geometries (typically allowing establishment of meanders that help to reduce stream slope). This primarily translates to accommodating streams that are widening and/or migrating laterally at this point in time. Due to the type of geologic materials present throughout the study area, the streams of these basins will supply the raw materials needed (passive restoration); wide buffers are critical to supplying these materials (and limiting the amount of finer sediments and nutrients being exported). The most helpful projects will reduce or remove constraints to the unimpeded progress of these processes. Although the raw materials needed generally occur throughout the area, extensive channelization and dredging along portions of Gilead, Camp and Lilliesville Brooks have removed placed these materials far from the channel and more active restoration is recommended in these areas.

In addition to the projects noted above (watershed strategies primarily contingent upon municipal actions and buffer creation/establishment projects), the highest priority projects identified in the creation of this River Corridor Plan are listed below in a Project and Strategy Summary Table (Table 36) intended as a quick reference for those wishing to assess project status and/or plan further project activities.

It should be noted that existing floodplains in the study area included beaver-controlled areas that were not able to be fully assessed in Phase 2 as well other areas in and along the margins of assessed reaches (“river-adjacent wetlands”). These areas help provide flood resiliency and permit a break from transfer of impacts to downstream reaches. A number of these areas (notably segments T1.04B - Gilead Brook in Rochester Little Hollow, M01-S3.03C – Camp Brook below Charlie Wilson Rd., and several abandoned oxbows and floodchutes along Third Branch reach M03 from Gilead to Beanville) lack Class 2 wetland protections. Although these “projects” are not listed in the table below, River Corridor protections noted in the watershed strategies above are crucial to safeguarding the vital flood mitigation functions of these areas.

Table 36. Prioritized Project and Strategy Summary Table for top 11 projects identified in Bethel area Corridor Planning 2013-2014.

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
1	M03: Poor, FSTCD sediment regime, Extreme Sensitivity	Extremely active channel prone to neck cut-offs and frequent migrations, multiple 60-90 foot mass failures and extensive 6-8 foot eroding banks contributing large amounts of fine sediments to wash load but relatively few coarse sediments; relatively few corridor encroachments	Primarily passive restoration highlighting municipal corridor protection and channel management easements; high priority area for buffer plantings but highlight low cost and wide setbacks due to high bank instability	Very high feasibility and priority
2	T1.01A: Poor, FSTCD sediment regime, Extreme Sensitivity T1.01B: Fair, FSTCD sediment regime, Extreme Sensitivity	High value attenuation asset downstream of highly channelized reach that will take time to regain equilibrium; undersized Spring Hollow bridge and farm field berm restrict LB floodplain access, likely contributed to mass failure beneath WRV Ambulance, possibly Randall Drive-In as well	Reach-scale corridor protection and combined passive-active floodplain restoration (municipal Corridor protection, easements at berm); remove Spring Hollow bridge and left bank berm); trail access - possible educational sign location?	High feasibility and priority

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
1	Relatively low costs, high benefits; increased flood resilience for village area downstream; water quality (heavy sediment contributions) and habitat; conservation of Significant Natural Community with high biodiversity	Corridor easement purchase and transaction costs, buffer plantings	High value cropland/ hayfields to buffer plantings	Towns of Bethel and Randolph, esp. Planning and Conservation Commissions, Selectboards; White River Partnership; White River Natural Resource Conservation District; CT River Watershed Council; CT River Mitigation and Enhancement Fund; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust
2	Public access with ready-made trail; reduction of risk for further mass failures beneath WRV Ambulance in particular, restoration of High Quality trout stream, reduced road maintenance	Corridor easement purchases and transaction costs (farm field), bridge removal, buffer plantings	High value cropland/ hayfields to buffer plantings, likelihood of increased periodic flooding; change field access to Tyson Justin Rd (private?) as is already happening; downgrade Class 3 road (Spring Hollow)	Town of Bethel, especially Planning and Conservation Commissions, Selectboard, Town Manager; White River Partnership; White River Natural Resource Conservation District; Vermont Youth Conservation Corps; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust; Trout Unlimited

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
3	T1.01B: Fair, FSTCD sediment regime, Extreme Sensitivity T1.01C: Poor, FSTCD sediment regime, Extreme Sensitivity	Buffers upstream of Rte. 12 bridge 38 impacted after 1996 (1998 flood?), in vicinity of 379 Gilead in 2007 flood; flood chute near 379 Gilead Brook plugged in Irene, exacerbated by snagged wood	Reach-scale corridor protection (municipal Corridor protection, easements at flood chute); flood chute restoration: open flood chute, restore some of large wood to stream and/or floodplain for sediment retention and meander development	Municipal corridor protection and buffers very high feasibility and priority; flood chute restoration needs Alternatives analysis and investigation of permitting issues

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
3	Reduction of risk for further mass failures in downstream portions of reach, restoration of High Quality trout stream	Corridor easement purchases and transaction costs (379 Gilead), flood chute restoration design, permitting, equipment costs for large wood placement/ restoration	Garden space/ hayfields to buffer plantings, likelihood of increased periodic flooding in flood chute	Town of Bethel, especially Planning and Conservation Commissions, Selectboard; White River Partnership; US Forest Service (large wood design); US Fish & Wildlife Service; Trout Unlimited; US Army Corps of Engineers; Vermont Agency of Natural Resources; Vermont Youth Conservation Corps; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
4	T1.02C: Poor, FSTCD sediment regime, High Sensitivity	Heavily channelized/ windrowed downstream of bridge at Schoolhouse Rd.- Gilead Brook Rd.; windrows don't form continuous berm but do restrict floodplain access, esp. at moderate flood levels. Flood chute (former channel) plugged off LB just DS Schoolhouse Rd. bridge - combination of snagged wood and windrowed sediments; next house downstream was buyout location (structures now removed), mass failure on opposite bank will likely push stream toward former house location as stream adjusts	Reach-scale corridor protection and restoration: municipal Corridor protection; bridge replacements may be opportunistic, Bethel made key decision to adopt VTrans 2013 Bridge and Culvert Standards (see Prelim Project ID table for segment T1.02C structures priorities), but consider Gilead Brook for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements; flood chute restoration: open flood chute, restore some of large wood to stream and/or floodplain for sediment retention and meander development; cuff off windrows along left bank in particular, especially in vicinity of buyout location; re-establish buffers, low-cost or passive	Municipal corridor protection very high feasibility and priority; buffers very high feasibility but should follow restoration work; flood chute and channel/ floodplain dimension restorations need Alternatives analysis and investigation of permitting issues

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
4	Increased attenuation here may offer reduction of risk for road encroachments downstream; restoration of High Quality trout stream	Flood chute and channel dimension-floodplain access restoration designs, permitting (cuffing off windrows, bridge replacement reconfigurations), equipment costs for cuffing windrows/ restoring channel dimensions and floodplain access; large wood placement/ restoration; bridge replacements	Open land to buffer conversion and potential for increased periodic flooding if Alternatives analysis and design work indicate floodplain reconnection potential in conjunction with bridge replacements	Town of Bethel, especially Planning and Conservation Commissions, Selectboard; White River Partnership; US Forest Service (large wood design); US Fish & Wildlife Service; Trout Unlimited; US Army Corps of Engineers; Vermont Agency of Natural Resources; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
5	T1.02B: Poor, FSTCD sediment regime, High Sensitivity	Heavily channelized reach post-Irene, primarily in vicinity of undersized bridges that mostly held up due to substantial concrete construction. Weirs installed to arrest headcuts in areas near bridges will need monitoring to evaluate functionality, but significant portions of segment did not have weirs installed: highest priority for evaluation near 1745 Gilead Brook Rd and 2577 Gilead Brook Rd. Reach is less incised than other portions of Gilead Brook, increasing priority for reach-scale restoration.	Reach-scale corridor protection (municipal KEY), possible channel management easement US of Winterberry Ln. and combined active-passive restoration of incised reach; high priority to monitor (install?) and maintain weirs if necessary; pursue removal of encroachments; explore BMPs for roadside bank armoring (Schiff et al 2014) upstream Winterberry Ln.; cuff off windrows; replacement of undersized bridges likely to be more expensive but is high priority. Consider Gilead Brook for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements. Create and protect buffer area, but actual plantings or passive buffer restoration should follow any active restoration work.	Municipal corridor protection and easement very high feasibility and priority; buffer very high feasibility but should follow restoration work; flood chute and channel/ floodplain dimension restorations and bank armoring need Alternatives analysis and investigation of permitting issues

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
5	Increased attenuation here may offer reduction of risk for road encroachments downstream (T1.02A where development has occupied former left bank floodplain); bank armoring BMPs may offer better resilience for infrastructure and reduce long-term maintenance costs; restoration of High Quality trout stream	Corridor easement purchase and transaction costs (upstream Winterberry Ln.), alternatives analysis for weir installation and/or monitoring, equipment costs for cuffing windrows/ restoring channel dimensions and floodplain access; buffer planting across from Winterberry Ln.; bridge replacements	High likelihood of further channel migration in vicinity of Winterberry Ln. may affect property boundaries; hayfield to buffer off right bank in same area; access for evaluating, installing, monitoring weirs	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard; White River Partnership; US Forest Service (large wood design); US Fish & Wildlife Service; Trout Unlimited; US Army Corps of Engineers; Vermont Agency of Natural Resources; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
6	R12: Poor, FSTCD sediment regime, Extreme Sensitivity	Entrenched reach (incision ratio 2.1) with significant development encroachments, but still high value attenuation asset downstream of highly straightened area; diminished buffers in Bethel village likely amplified Irene impacts in vicinity of Miller Dr./ River St. bridge	Municipal corridor protection to limit development; channel management easements on key areas (visibly sedimented in 2011 aerial imagery) - priority to attenuation assets in Bethel village (Washburn Farm) and downstream/across from National Fish hatchery; buffer establishment in numerous areas, but especially in vicinity of Miller Dr./ River St. bridge - wide buffers to anticipate lateral instability	Very high feasibility and priority
7	M01: Poor, FSTCD sediment regime, Very High Sensitivity	Incised reach (IR 2.1), but value as attenuation asset increased by intractable nature of stream conflicts with railroad embankments that cut much of valley and floodplain in half. Development encroachments limit current opportunities, increasing importance of municipal corridor protection and hazard mitigation planning. Wood is critical to stream stability due to geology (fine sediments due to glacial Lake Hitchcock legacy)	Municipal corridor protection, channel management easements on key areas (visibly sedimented in 2011 imagery) with buffers; hazard mitigation and emergency operations planning. Consider relocation of two riverside baseball fields to allow buffers, or relocation of pump station; bank armoring elevates risks to pump station - consider large wood design (WRP 2012-13 if armoring unavoidable). Consider reorienting athletic fields to place parking on outside banks, minimize infrastructure investments, combine with boat take-out. Buffers: passive regeneration or low-cost plantings due to lateral instability; be clear about belt-width and assume high instability near banks. Marsh Meadow buy-out site: full-width buffer (ideally close buffers on this side), consider ***wooded*** trail if any; will regenerate naturally but site invites public participation in planting choices	Municipal corridor protection very high feasibility but limited impact due to pre-existing development; other opportunities technically feasible but large wood bank armoring design lacks wood on-site; need Alternatives Analysis.

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
6	High priority reach due to both benefits for geomorphic equilibrium and high incidence of rare-threatened-endangered element occurrences; importance increased by high degree of straightening upstream	corridor easement purchase and transaction costs, buffer plantings	High value cropland/hayfields to buffer plantings, open yard areas as well	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard; White River Partnership; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust
7	Increased public river access; decreased risks to pump station; reduced long-term maintenance and repair costs at ball fields	Corridor easements upstream of village. Alternatives Analysis for changes at athletic fields in relation to elevated risks for pump station damage	High-value cropland and hayfields, other open land to buffers. Significant changes in configuration of athletic fields, difficult-but important-to achieve buffer accommodation.	Town of Bethel, esp. Planning, Recreation and Conservation Commissions, Selectboard, Town Manager; Whitcomb Jr./Sr. High School, Bethel Elementary School, Verdana Ventures; White River Partnership; White River Natural Resource Conservation District; Clean Water Future; Vermont River Conservancy; Vermont Land Trust; Upper Valley Land Trust

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
8	T4.01A: Poor, FSTCD sediment regime, Very High Sensitivity	Highly channelized segment, repeatedly snagged and dredged, on alluvial fan at base of Lilliesville Brook; repeat damages to bridges and structures in Narrow valley. Weirs installed to limit headcuts in response to channelization post-Irene; some small trees with root wads placed along banks. Bridges and development encroachments have been replaced in similar locations to those damaged	Municipal corridor protection to limit development, channel management easements if/when opportunities arise (buyouts or relocations; houses at 7 Lilliesville Brook Rd and 1550 River Rd esp. at risk; possibly 230 as well); STRUCTURES - adequate sizing - although 2013 B&C standards spec 100 pct. bankfull (per VT Stream Alteration Permits and Schiff et al 2014), consider Lilliesville Brook for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements; drainage and stormwater management upstream (develop plan; Pease and Archer 2013). Restore more wood to stream for habitat diversity and stream power mitigation	Municipal corridor protection very high feasibility but limited impact due to pre-existing development; easement opportunities only likely to arise as result of future damage. Ability of town to spec higher size for structure replacements needs research

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
8	Reduce both infrastructure/ structure replacement and ecosystem impact costs due to repeat channelization. Importance increased by value as attenuation asset at DS end of stream that is likely to take a good bit of time to equilibrate due to multiple structures needing replacement. Begin restoration of Very High Quality Wild Trout Spawning and Nursery Tributary	Monitoring/ maintenance of weirs; corridor easement purchases and transaction costs if opportunities arise; buffer plantings	Development out of corridor, or at least elevate structures to allow channel adjustments and floodplain reconnection; reduce structural controls on channel	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard; White River Partnership; US Forest Service (large wood design); US Fish & Wildlife Service; Trout Unlimited; US Army Corps of Engineers; Vermont Agency of Natural Resources; Vermont Youth Conservation Corps; Clean Water Future; Vermont River Conservancy

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
9	T4.03: Poor, FSTCD sediment regime, High Sensitivity	5 bridges in this reach, 4 significantly undersized and 3 privately owned. Incised reach with development encroachments on at least one side of the stream throughout.	Undersized bridges may be highest priority on Lilliesville Brook overall, but numerous are substantial concrete structures that appear likely to continue outflanking rather than the structure failing; adoption of 2013 Bridge and Culvert standards was step in right direction but other funding options may need to be explored due to outflanking dynamic. Consider Lilliesville Brook for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements. Municipal corridor protection to limit further development; hazard mitigation (ensure landowners are aware of buyout and elevation options, possible HMPG funding or other options) and emergency operations planning.	Municipal corridor protection very high feasibility but limited impact due to pre-existing development; easement opportunities only likely to arise as result of future damage

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
9	Reduce both infrastructure/ structure replacement and ecosystem impact costs due to repeat channelization. Restoration of Very High Quality Wild Trout Spawning and Nursery Tributary.	Bridge replacements. Channel management easements if opportunities arise.	Development out of corridor, or at least elevate structures to allow channel adjustments and floodplain reconnection; reduce structural controls on channel	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard, Town Manager; VTrans; White River Partnership; Two Rivers-Ottauquechee Regional Commission; Clean Water Future

Project #	Reach/ Segment Condition	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority
10	T3.01A: Poor, FSTCD sediment regime, Extreme Sensitivity	Deeply incised (IR 3.5), but value as attenuation asset increased by likelihood that upstream development dependent on Old Rte. 12 may make conflicts with stream processes ongoing for some time to come. Development encroachments limit current opportunities, increasing importance of municipal corridor protection and hazard mitigation planning. Corridor easement area downstream of new Rte. 12 bridge is partly road ROW	Primarily passive restoration of incised reach. Corridor protection to limit further development, channel management easement downstream of new Rte. 12 bridge; hazard mitigation (ensure landowners are aware of buyout and elevation options, possible HMPG funding or other options) and emergency operations planning. Remove undersized old bridge abutment at TH78 (Poplar Manor Rd - DS of Rte. 107 bridge). Buffer plantings should highlight low cost and wide setbacks due to high bank instability; high priority near new Rte. 12 bridge. Consider Locust Creek for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements	Municipal corridor protection very high feasibility but limited impact due to pre-existing development; easement opportunities only likely to arise as result of future damage. Removal of old abutment very high feasibility but limited spatial extent of benefits
11	M01-S3.02B: Poor, FSTCD sediment regime, Extreme Sensitivity	1 bridge and 2 culverts in segment undersized - Pond Rd culvert especially; temporary footbridge in place near Birch Hill Rd. after former bridge destroyed in Irene - appeared headed for replacement; this segment is least incised attenuation asset on Camp Brook but development encroachments limit current opportunities	Structures replacements - sediment continuity and ability to pass large wood important to channel evolution and flood hazard mitigation-permit process should require bankfull sizing but consider Camp Brook for inclusion in Town Plan as area needing 120 pct. bankfull structure replacements; municipal corridor protection to limit development; hazard mitigation plan is in process - highlight funding options for buyouts and relocations; emergency operations planning	Municipal corridor protection very high feasibility but limited impact due to pre-existing development; easement opportunities only likely to arise as result of future damage

Project #	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitments	Potential Partner Commitments
10	Removal of old abutments at TH 78 would greatly reduce hazards to nearby encroachments and increase floodplain access (but limited extent), reduce need for channel "clean-outs". Aid restoration of Very High Quality Wild Trout Spawning and Nursery Tributary	Corridor easements, abutment removal, buffer plantings.	Open land to buffer conversion, potential for increased periodic flooding	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard, Town Manager; White River Partnership; Two Rivers-Ottauquechee Regional Commission; US Fish & Wildlife Service; Trout Unlimited; Clean Water Future
11	Reduce both infrastructure/structure replacement and ecosystem impact costs due to repeat channelization.	Bridge and culvert replacements. Channel management easements if opportunities arise.	Development out of corridor, or at least elevate structures to allow channel adjustments and floodplain reconnection; reduce structural controls on channel	Town of Bethel, esp. Planning and Conservation Commissions, Selectboard, Town Manager; White River Partnership; Two Rivers-Ottauquechee Regional Commission

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Appendices

Bethel area Corridor Plan 2013-2014

Appendix 1. Reach/Segment Rapid Geomorphic Assessment Scores, Channel Geometry Data, Rapid Habitat Assessment Scores

Appendix 2. Phase I Reach Summary Reports

Appendix 3. Phase II Reach/Segment Summary Reports

Appendix 4. Plots of Channel Cross Sections

Appendix 5. QA/QC Reports and documentation

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

Appendix 7. Large Format (11x17) Maps

Appendix 8. Bridge and Culvert Survey Reports

Failure modes: Geomorphic incompatibility

Failure modes: Problem causes

Aquatic organism passage ratings: Passage, geomorphic compatibility, retrofit potential

Wildlife passage