



**Foote Brook  
Johnson, Vermont**

**Phase I & II Geomorphic Assessment**

**Prepared by Bear Creek Environmental and  
the Lamoille County Planning Commission**

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## **Executive Summary**

The River Corridor Planning effort is sponsored by the Lamoille County Planning Commission (LCPC) with funding provided through a grant from the State of Vermont Department of Public Safety and the Agency of Commerce and Community Development. The Vermont Department of Environmental Conservation (DEC) River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with Bear Creek Environmental, LLC (BCE). Information for the combined Phase I & II Geomorphic Assessment came from the DEC, the Vermont Center for Geographic Information (VCGI), and field data collected by BCE and LCPC.

The primary objective of the Phase I & II report is to use stream geomorphic assessment data to identify and prioritize river corridor protection and restoration projects within the Foote Brook of the Lamoille River watershed, primarily in the Town of Johnson. The stream geomorphic assessment data can be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use alter the physical processes and habitat of rivers. The Vermont Stream Geomorphic Assessment Protocol includes three phases:

1. Phase 1 – Remote sensing and cursory field assessment
2. Phase 2 – Rapid habitat and rapid geomorphic assessment to provide field data to characterize the current physical condition of a river
3. Phase 3 – Detailed survey information for designing “active” channel management

A Phase I Stream Geomorphic Assessment following Agency of Natural Resources Protocols was completed for the Foote Brook by the Lamoille County Planning Commission (LCPC) during the summer of 2006. During Phase I, 17 reaches out of 23 were assessed and the first 4 reaches were assessed for the phase 2 portion of the report. Overall, the Foote Brook is in fair condition with a few sections that had significant bedrock grade control and much of the stream had an adequate riparian buffer. As part of this assessment, land use, encroachments, and buffer condition are analyzed within 150 feet on each side of the river. Residential and

agricultural land use within the river corridor accounted for the majority of high impact score ratings on the Foote Brook.

Bear Creek Environmental, LLC was retained by the LCPC to conduct a Phase 2 Stream Geomorphic Assessment of Foote Brook during fall 2007. The Phase 2 study followed the protocols developed by the Agency of Natural Resources. The four lowest reaches on Foote Brook were assessed for a total of 1.3 river miles. All four of the reaches are located in Johnson, Vermont. Descriptions of each reach and recommendations for restoration and protection are provided in the Phase 2 section of this report.

As the river works toward a more stable equilibrium, the community of Johnson has the opportunity to provide long-term protection to the river corridor and encourage the reestablishment of floodplain vegetation and healthy instream habitat. At the reach and site level, potential restoration and protection projects that would be compatible with geomorphic adjustments and managing the stream toward equilibrium conditions were identified. A list of potential restoration and conservation projects were developed during project identification. Types of projects include: river corridor protection through corridor easements and conservation efforts, replacing an undersized structure causing localized channel instability, and further analysis to arrest a headcut.

## **Goals and Objectives of the Project**

The primary objective of the Phase I & II report is to use the Stream Geomorphic Assessment data to identify and prioritize river corridor protection and restoration projects within the Foote Brook watershed. The State of Vermont's River Management Program has set out several goals and objectives that are supportive of the local initiative in the watershed. The state management goal is to, "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner" (Vermont Agency of Natural Resources, 2007b). The objectives of the Program include fluvial erosion hazard mitigation and sediment and nutrient load reduction, as well as aquatic and riparian habitat

protection and restoration. The Program seeks to conduct river corridor planning in an effort to remediate the geomorphic instability that is largely responsible for problems in a majority of Vermont's rivers. Additionally, the Vermont River Management Program has set out to provide funding and technical assistance to facilitate an understanding of river instability and the establishment of well developed and appropriately scaled strategies to protect and restore river equilibrium.

## **Foote Brook Background**

The Foote Brook is located in the Town of Johnson, Vermont, and flows into the Lamoille River which in turn, flows into Lake Champlain. Most of the river flows through forested land, with small portions running through residential development. The main stem of the river is approximately 6.5 miles long and the combined length of the tributaries that were included in the study was also about 6.5 miles. The river drains a watershed of about ten square miles. Twenty three reaches, or segments, were assessed on the main stem of the river, with 18 additional reaches assessed on four tributaries (see attached map).

The Town of Johnson is situated in the central part of Lamoille County, under the shadow of Sterling Mountain (elevation 3,715 feet). Johnson Village is at the junction of the Gihon and Lamoille Rivers with an elevation of 531 feet. The average annual precipitation is 40 inches.

The water in the Foote Brook appeared to be very clear. One possibility for the water clarity is the lack of agricultural land use near the majority of the river upstream, and the largely undeveloped headwaters. However, a chemical analysis of water quality was not part of the Phase I geomorphic assessment, and this was just a visual observation.

## **Flood History**

According to the Vermont Agency of Natural Resources document "Municipal Guide to Fluvial Erosion Hazard Mitigation" (2006a), "Of all the natural hazards experienced in Vermont, flooding is the most frequent, damaging, and costly." The guide documents that over the last

50 years, flood recovery has cost the state an average of \$14 million a year and that during the period of 1995-1998 alone, flood losses in Vermont totaled almost \$57 million. Of particular concern for towns and properties near streams, it notes that,

“While some flood losses are caused by inundation (i.e. waters rise, fill, and damage low-lying structures), most flood losses in Vermont are caused by “fluvial erosion”. Fluvial erosion is erosion caused by rivers and streams, and can range from gradual bank erosion to catastrophic changes in river channel location and dimension during flood events.”

The Municipal Guide further documents that, “Closer study of our rivers and streams reveals that Vermont’s erosion hazard problems are largely due to pervasive, human-caused alteration during the past 150 to 200 years of our waterways and landscapes they drain. By end of the nineteenth century, forests had been cleared from many watersheds, resulting in major changes in watershed hydrology and sediment production. Towns and villages, the centers of commerce, grew on the banks of rivers, whose role in power generation and transportation at first outweighed flood risks. In addition, many watersheds were changed by development, agriculture, log drives, roads and railways.” The legacy of this landscape manipulation is rivers and streams, which are unstable and prone to fluvial erosion (Vermont Agency of Natural Resources 2006a).

In order to better understand the flood history of Foote Brook, long term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS) gauge on the Lamoille River in Johnson, VT were obtained (USGS 2007). Ninety-three years of records are available for the Lamoille gauge at Johnson, VT which provides a continuous record of flow from 1912 through the present.

The long term record on the Lamoille gauge shows major flood events also occurred in the years 1912, 1936, 1973, 1984, 1995 and 1997. The graph below (Figure 1) provides a flood frequency analysis for the Lamoille River gauge.

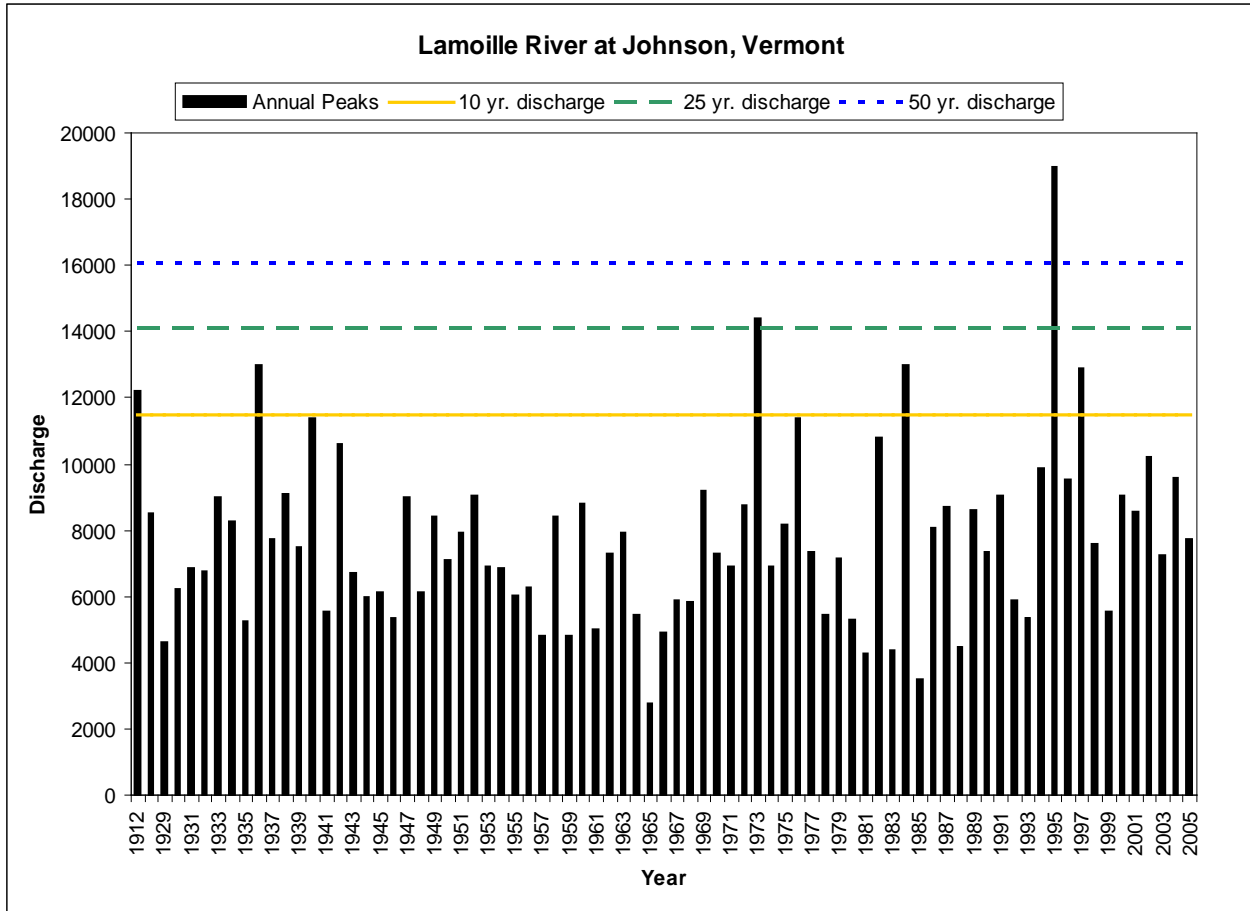


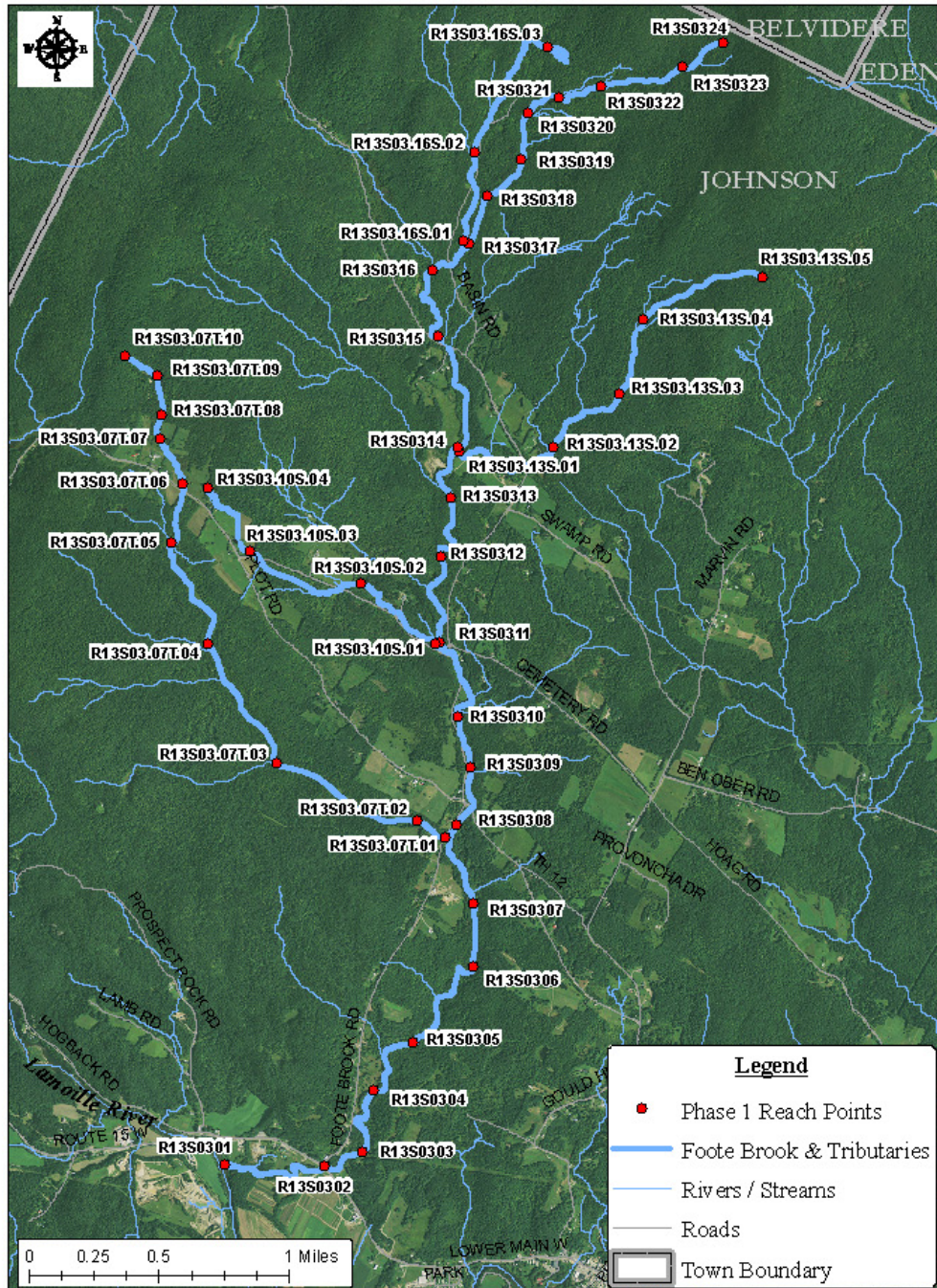
Figure 1. Lamoille River Gauge

## Phase I Watershed Assessment Methodology and Results

### Phase I Watershed Assessment Methodology

Stream reaches were defined by creating reach breaks using valley width and slope, geologic materials, and tributary influence. Twenty-three reaches were delineated on the Foote Brook main stem within Lamoille County. Reaches were numbered to efficiently organize, track, and communicate reach-related data. After stream reaches were defined, watershed, sub-watershed, and reach watershed areas were delineated and calculated. A stream reach identification map can be found in Figure 2.

# Foote Brook, Johnson, VT



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Traverse Mercator, VT State Plane, Meters, NAD83.  
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Figure 2. Phase I Reach Location Map

## Stream Geomorphic Assessment Tool (SGAT)

Using the Stream Geomorphic Assessment Tool (SGAT), numerous parameters were calculated including: valley width, length, and slope; channel length and slope; stream confinement; sinuosity; and reference channel width. Based on this data, reference stream types were classified according to characteristics of the valley, geology, and climate of the stream. The reference stream type describes the natural channel tendency of channel form and process in the absence of human-related changes to the channel.

## SGAT, Remote Sensing, Local Knowledge, and Field Verification

Using a combination of SGAT, remote sensing, and windshield surveys (field verification) the following parameters and their respective impacts were inventoried and/or calculated, and assessed:

- Valley side slopes
- River corridor delineation
- River corridor and reach land use and land cover
- Riparian buffer condition
- Hydrologic groups
- Soils and geology influences
- Alluvial fans
- Grade controls
- River corridor development
- Bank armoring
- Bridge and culverts
- Flow regulation and water withdrawal
- Channel modifications
- Floodplain encroachments
- Dredging and channel mining history
- Depositional features
- Meander migration
- Meander width ratio
- Stream wavelength
- Debris jam potential
- Dominant bed form and materials

## Impact Rating Methodology and Reach Results Summary

The following parameters are assigned impact ratings of “Not Significant” to “High Significance”, based on certain criteria for each impact type. After all impacts are determined, a reach can be further evaluated for the degree to which cumulative impacts are affecting the reach.

Comparing the results against other reaches in the watershed determines which reaches will have a Phase 2 assessment.

Phase I Parameters highlighted for data interpretation:

- Watershed Land Cover/Land Use
- Corridor Land Cover/Land Use
- Riparian Buffer Width
- Channel Modification
- Depositional Features
- Meander Migration
- Bridge and Culvert Survey-Using the VANR Appendix A datasheet

#### Watershed Land Cover/Land Use

Lakes, wetlands, and perennial vegetation play an important role in a watershed by storing water and trapping sediment, which helps reduce flood peaks and maintain summer base flows in rivers and streams. Urban development and cropland typically increase the peak and change the duration of stormwater and sediment runoff events. Recent orthophotos were used to evaluate this parameter.

High impact rating scores indicate 10% or more of the reach watershed is crop and/or urban. Reaches R13S0301, R13S0302, R13S0303, R13S0306, R13S03.07T.04, R13S03.07T.05, R13S03.10S.01, R13S03.10S.02, and R13S03.10S.03 received high impact ratings for watershed land use land cover.

#### Corridor Land Cover/Land Use

Land use/land cover within the stream corridor is particularly important with respect to sediment deposition and erosion during annual flood events. Wetlands, ponds, and perennial vegetation moderate storm water and sediment runoff, while impervious surfaces within urban areas and the exposed soils found in cropland have the potential to increase watershed inputs.

High impact rating scores indicate 10% or more of the reach corridor cover is crop and/or developed. Reaches R13S0301, R13S0302, R13S0308, R13S0309, R13S0310, R13S0313, R13S0314, R13S03.07T.05, R13S03.07T.06, R13S03.07T.08, R13S03.07T.09, R13S03.10S.01 - R13S03.10S.03, and R13S03.16S.01 received high impact rating scores. Many of these high

impact scores are due to crops being grown within the river corridor with percentages as high as 34% (R13S03.07T.06).

### Riparian Buffer Width

The riparian buffer is the area of land directly adjacent to the channel along the channel's banks and floodplain that is covered with woody, largely unmanaged, vegetation. Riparian buffers protect and enhance water quality, fish and wildlife habitats, aesthetics, and recreational values associated with streams. Streams without riparian vegetation often experience high rates of lateral erosion and may see such large increases in sediment that they undergo major adjustment of channel dimension, pattern, and profile. Orthophotos were used to estimate the percent of each buffer width category along the right and left banks.

Foote Brook's riparian buffer widths on the reach areas studied do not seem to have a significant impact on the channel's banks. Most of the reaches had widths greater than 100 ft on both the left and right sides with the exception of subdominant widths on the right bank that ranged from 51-100 ft. The forested upstream areas of the reach had large, intact riparian buffers. Downstream, towards agricultural areas, the buffer measured less than 100 ft on reaches R13S0301, R13S0302, R13S0304, R13S0307, and R13S0308.

### Channel Modifications

Channelization is the process of changing the natural path of a river through activities such as windrowing and straightening. A channelized stream may degrade, or cut down vertically into its bed and cause the channel to lose access to its floodplain. The sediment resulting from the degradation process is re-deposited downstream of the channelized area. This results in aggradation, or building up, of the channel bed in this downstream area. Aggradation can result in channel widening, bank instability, and other channel responses, most of which are detrimental to both riverside land and aquatic habitat. Interviews with natural resource professionals, and a review of orthophotos and topographic maps, were used to examine this parameter.

High impact rating scores indicate that greater than 20% of the reach had been channelized. No reaches along the Foote Brook received high impact scores. No known channel straightening has occurred.

#### Dredging and Gravel Mining History

Dredging and mining gravel bars from a channel may initiate a channel evolution process. Such activities straighten and steepen the channel and cause the river to cut down and erode its bed. The stream channel eventually aggrades with sediment supplied from upstream reaches as head cuts in the streambed move up-valley. Information and records from DEC's Stream Alteration Engineer were used to determine the relative frequency and volume of gravel extraction.

High impact rating scores indicate that the reach was historically used for commercial gravel mining and/or dredged for flood remediation. None of the reaches studied along Foote Brook had any significant dredging or gravel mining.

#### Depositional Features

An unvegetated bar is sign that the bar was recently formed and is growing. Mid-channel bars, large unvegetated point bars, and delta bars may indicate an increased sediment load (from upstream) and a high likelihood that the streambed is actively aggrading and/or undergoing rapid lateral movement. The sediment sources for these bars may be from bank failures or the degradation of the channel upstream. It may also be from upland watershed sources. Orthophoto interpretation and windshield surveys were used to evaluate this parameter.

High impact rating scores indicate numerous, large, unvegetated, mid-channel, point and/or delta bars present. There were no reaches on Foote Brook that received high impact scores during this Phase I assessment.

#### Meander Migration/ Channel Avulsions

Some amount of lateral migration is natural in most alluvial stream systems, but the rate of migration may be increased in streams due to changes in the sediment supply and/or sediment transport capacity of the channel. Comparisons of paths of the channel from similarly scaled

orthophotos of different years were used to identify channel migration, bifurcation, and/or avulsions. Channel migration occurs as the channel erodes its outer banks on meander bends. Bifurcation describes when the stream has split into two or more active channels. An avulsion describes a channel plan form change due to meander cutoffs.

High impact rating scores indicate frequent occurrences of channel migration, bifurcation, and/or channel avulsions along the reach. R13S0301 was the only reach on the Foote Brook that received a high impact score for this parameter. An avulsion was created in an area on the right bank downstream from RT. 15 near a nursery. The channel avulsed away from the nursery bank after the work, which included rip rap, was done.

#### Meander Width Ratio

The meander belt width is the horizontal distance between the opposite banks of fully developed meanders. Unconfined, gravel-based streams in shallow-sloped valleys that are in regime have belt widths generally in the range of 5 to 8 times the width of the channel. Higher values may indicate that the stream, possibly due to an increase in fine sediment, has started to aggrade and become more sinuous, decreasing its channel slope as it migrates laterally. Lower values may indicate that the stream has become straighter and steeper, possibly degrading its bed and losing access to its floodplain. Orthophotos and topographic maps were used to determine the reach's average belt width.

High impact rating scores indicate the meander width ratio is less than 3 or greater than 10, well outside the 5-8 range of reaches within regime. Reaches R13S1.01 and R13S1.04 received high impact ratings.

#### Bridge and Culvert- Field Verified Data

A watershed-wide bridge and culvert inventory and assessment was conducted to determine if stream crossings were contributing to localized stream bank erosion, sedimentation, and impaired fish passage. The Agency of Natural Resources Bridge and Culvert Phase I protocols were used (ANR, 2003). Bridge spans and culvert diameter measurements were compared to calculated bankfull width measurements. The bankfull width, also known as the channel forming

flow, is directly related to watershed drainage area. The bankfull flow is the discharge at which the majority of erosion and deposition takes place. Undersized bridges and culverts are not designed to accommodate both flow and sediment. During flood events large point bars can consequently deposit upstream of undersized bridges and culverts. During catastrophic flood events crossings can become outflanked, taking out large sections of roads and driveways. Significant sediment discharges to waterways can result. Sedimentation of the river poses water quality and aquatic habitat concerns.

Seven bridges and culverts were assessed on the Foote Brook main stem. There were no bridges or culverts along the Foote Brook that received high impact rating scores. However, six of the structures were undersized and the widths ranged from 44% to 78% of the bankfull width.

### **Current Stream Geomorphic Conditions**

The Phase I assessment of the Foote Brook and four of its tributaries was conducted by the Lamoille County Planning Commission (LCPC) during July 2006. Rather than the “windshield survey” described in the Agency of Natural Resources geomorphic assessment protocols, LCPC walked most of the river. Reaches 1-17 were walked in their entirety and the upper six reaches were assessed with a windshield survey. A bridge and culvert assessment was also conducted on the Foote Brook.

The results of the assessment concluded that overall, the river is in fair condition. There were sections with significant bedrock grade controls (see Figure 3), and much of the stream had an adequate riparian buffer. As part of this assessment, land use, encroachments, and buffer condition are analyzed within 150 feet on each side of the river. Residential and agricultural land use within the river corridor accounted for the majority of these high impact scores on Foote Brook. Of the reaches assessed on the main stem of Foote Brook, reach R13S0301 received the highest total impact score of 10 (out of a possible score of 32). Reach R13S0304 received the second highest impact score of 7 with reach R13S0302 and reach R1S0308 received an impact score of 6. These relatively high scores are due to land use within the river

corridor: reach R13S0301 had 12% crop land and 7% residential land, and reach R13S0302 had 20% crop land, 5% residential land, and 2% commercial land use. Of all the reaches assessed on the tributaries, only four reaches had impact scores over 4; all other reaches scored lower.



Figure 3. Bedrock waterfall at “Journey’s End” swimming hole.

### **Predicted Stream Channel Adjustment Processes**

The Foote Brook is undergoing a variety of geomorphic processes, specifically in the lower reaches where historically the channel has been adjusted by human activity. Reaches R13S0301, R13S0302 and to a small extent R13S0303, are undergoing the most active adjustments including degradation, aggradation, planform adjustment, and widening. The river is slightly incised, and the beginning stages of reestablishment of a new floodplain are evident.

Aggradation is the major adjustment process on most of these reaches as multiple channel bars indicate. Planform adjustment is the major adjustment process for reach R13S0301. This process changes the shape and size of meander bands and the overall path the river follows. If further development and modifications within the floodplain are avoided, the river will establish

a stable condition on its own. The upper reaches are in good reach condition with healthy riparian buffer widths as well as having the potential to be conservation areas for the river corridor.

## **Phase 2 Watershed Assessment Methodology and Results**

### Reach-Level Opportunities

A phase 2 assessment was completed for the lower four reaches of Foote Brook by Bear Creek Environmental, LLC in 2007. A description of each reach/segment is provided in this section along with general recommendations for restoration and protection strategies. The reaches are listed from downstream to upstream. Further details about project types for each reach will be discussed on pages 31 and 32.

### **Reach R13S3.01**

#### **River Corridor Protection**

#### **Arrest headcut**

#### **Bridge Replacement**

Foote Brook reach R13S03.01 is 2,630 feet in length, and begins at the confluence of the Lamoille River and ends about 40 feet upstream of the Route 15 crossing. This lowest reach on Foote Brook has a very broad valley and a gentle slope. Reach R13S03.01 was broken into three segments to account for differences in channel dimensions, banks and buffers, substrate size, and valley width. The segment lengths are 850 feet (A), 584 feet (B) and 1,196 feet (C).

As shown in Figure 4, segment R13S03.01-A (the most downstream segment) generally has a wide buffer. The south bank has a riparian buffer that is greater than 100 feet in width, and the north bank has a dominant buffer width of 51 to 100 feet with a subdominant buffer width of greater than 100 feet. No areas of buffers less than 25 feet were mapped within this segment. Japanese knotweed is common along both banks. Wetlands are present on both sides of the channel in the middle of the segment. Forest is the dominant land use in the riparian corridor on the south bank, while residential is dominant on the north bank. Wetland is the subdominant land use on both sides of Foote Brook in the riparian corridor.

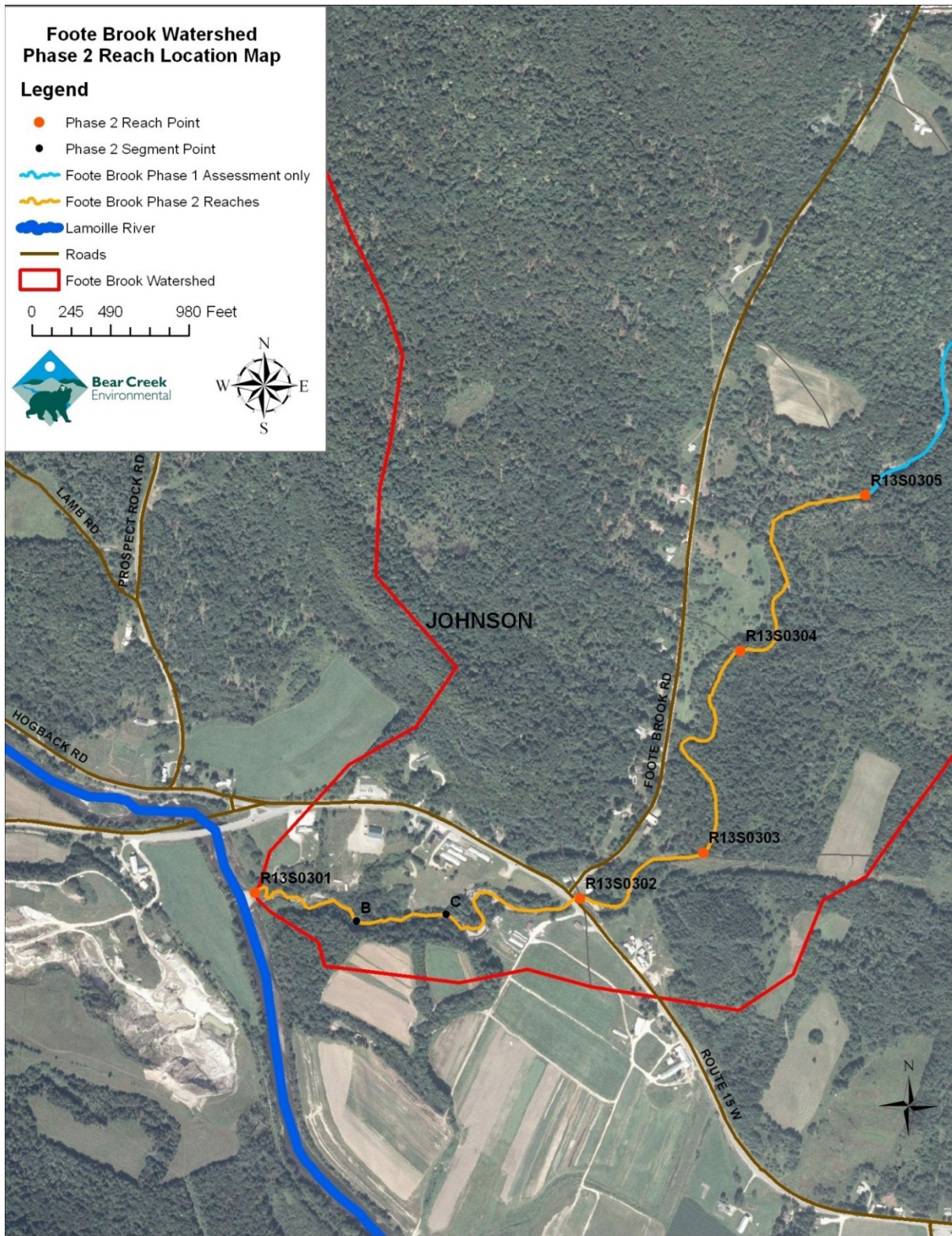


Figure 4. Reach location map for Phase 2 Stream Geomorphic Assessment



Figure 5. Typical channel in segment R13S03.01-A

The rapid geomorphic assessment (RGA) scored in the “fair” category due to major historic degradation, major aggradation and planform adjustment and minor widening. This is a “C” gravel dominated segment with a juvenile floodplain that has formed on the inside of meander bends. Riffles were classified as sedimented. Signs of planform adjustment include a channel avulsion and flood chute. The channel width is beginning to narrow through aggradation and development of bar features. The channel may continue to shift back and forth and erode terrace side slopes as the juvenile floodplain widens. It is important to allow the channel room to continue to adjust.

The rapid habitat assessment (RHA) rated in the “good” category. The RHA parameters for sediment deposition and channel flow status were rated in the fair category reflecting the major aggradation that is occurring within the reach. Very little deep water was available for fish at the time of the assessment. A corridor easement or the adoption of FEH zones are recommended to project the high quality riparian corridor in this segment. The lower end of

Foote Brook is an important attenuation asset and limiting encroachments in the corridor would allow the river to continue to adjust and reach an equilibrium condition over time.

R13S03.01-B is the middle segment on the lowest reach of Foote Brook. Segment B has an existing stream type of “F” that is a departure from the reference type of “C”. The substrate is larger in segments B and C than in A, accounting for the aggradational processes that are taking place at the downstream end of the reach. A mass failure at the lower end of segment B is contributing sediment to Foote Brook (Figure 6). Similar to segment A, the dominant buffer width is greater than 100 feet on both sides on Foote Brook in segment B. There are some areas on the north bank where the buffer width is between 51 and 100 feet. Mixed trees are generally found along both banks, and there are some short sections where herbaceous vegetation is growing on the south bank in residential areas.



Figure 6. Mass Failure in segment R13S03.01-B

A well defined terrace about 4 feet higher than the bankfull elevation is the recently abandoned floodplain. On the cross section that was measured, this terrace extended from the north stream bank out to Route 15 (about 650 feet). The channel within segment B is incised (ratio

of 2.4), indicating there is poor floodplain access (Figure 7). This has resulted in an increase in stream power within the channel, which will eventually erode the stream banks. Bank erosion was noted to be minor; however, the erosion may have been underestimated during the Phase 2 assessment due to leaf cover. The Phase 2 assessment took place during October 2007 at the height of the foliage season. High quality native vegetation on the banks is preventing planform adjustment and widening. The channel is in Stage F-II of the channel evolution model. Extreme historic degradation is leading to minor aggradation and widening. The geomorphic condition is “fair”.

The habitat condition scored in the “good” range. All of the habitat parameters scored in the good or reference category with the exception of fish cover and channel flow status. The log in Figure 8 is creating a nice pool for resident fish.

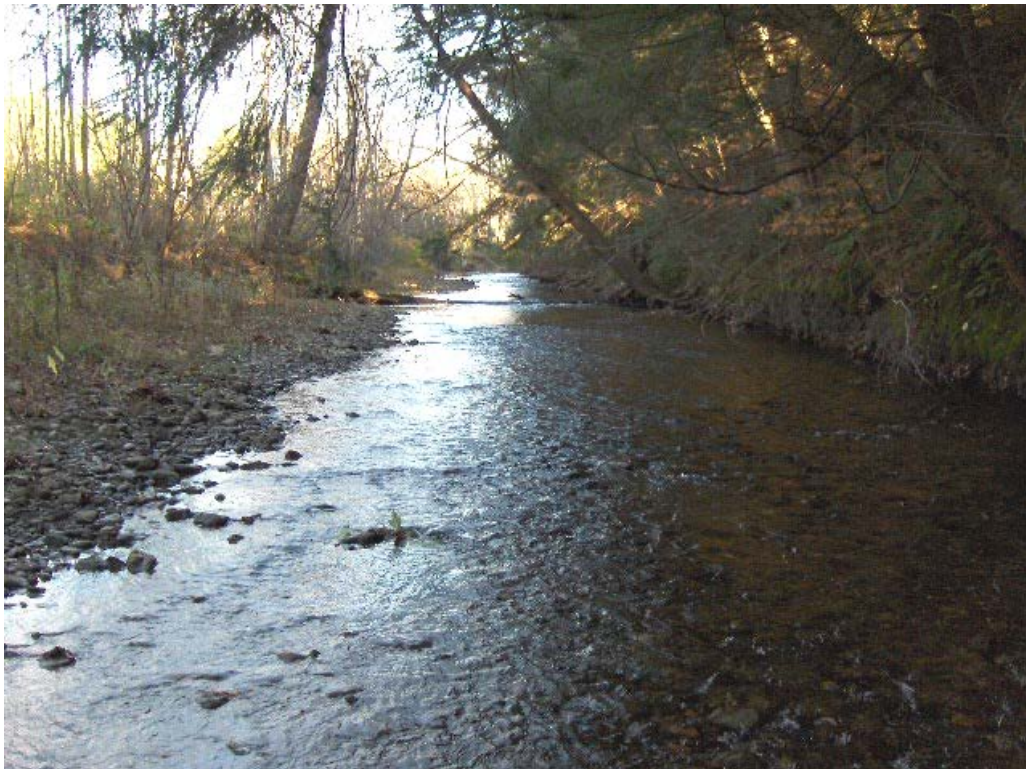


Figure 7. Incised and entrenched cross section in R13S3.01-B

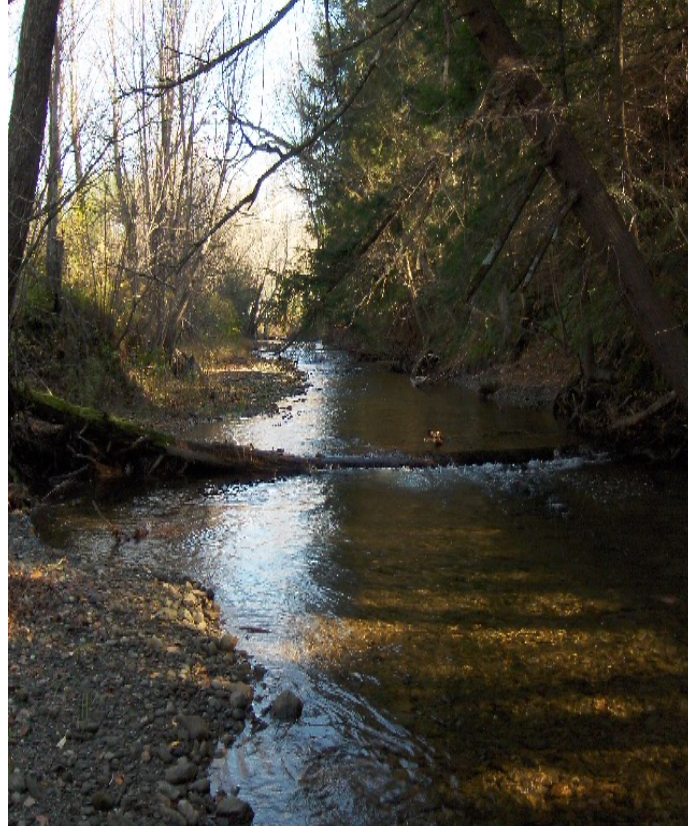


Figure 8. Log creating a pool in R13S3.01-B

The most upstream segment, R13S3.01-C, includes the Route 15 crossing at its upper end and is extremely dynamic. The upper 550 feet of the segment has been straightened and rock riprap lines the southern bank (see Figure 9). The slope steepens significantly below a channel avulsion in the middle of the segment. An active head cut (i.e., nick point or sharp change in slope) downstream of this straightened section may have developed in response to this recent channel avulsion. The channel likely steepened in the area as a result of the channel length being shortened, and the headcut is moving upstream causing widening. The existing channel elevation is two to three feet lower than the former channel. There is a considerable amount of deposition in this area, which is immediately downstream of where the channel has been straightened. It is difficult to separate out which adjustment process, degradation or aggradation, is dominant. There are a number of large depositional features in this area, and some of the changes in slope appear to be steep riffles. One of the flood chutes was noted to have an active headcut during a visit to the site on September 19, 2010. An alternatives analysis is recommended to determine if it makes sense to try to arrest this headcut.



Figure 9. Rock riprap along southern bank in R13S3.01-C

The buffers in segment C are narrow in comparison to the lower two segments of reach R13S3.01. The dominant buffer on the south bank and north bank is 26-50 feet and 51-100 feet, respectively. There are approximately 100 feet on both sides that have buffers less than 25 feet. Trees have been planted in the buffer on the south bank between a house and the mass failure near the lower end of segment C. The mass failure (see Figure 10) is 70 feet wide by 40 feet high.



Figure 10. Mass failure on south bank of R13S3.01-C

The geomorphic condition and the habitat conditions both scored in the “fair” range. A terrace 3 feet higher than the bankfull elevation was identified as the recently abandoned floodplain in R13S3.01-C. An active headcut, associated with the recent channel avulsion, also contributed to a channel degradation score of poor. The channel is undergoing minor aggradation and widening and major planform adjustment.

The “fair” habitat score reflects the channel alteration (almost 50 percent straightened), the narrow buffers, and the presence of Japanese knotweed (an invasive). There were no areas of deep water in the straightened section, where the bedform was planebed rather than riffle pool. In addition to the rock riprap, the bridge at the top of the reach over Route 15 is adding to the channel alteration. The span of the bridge is 24 feet and the channel width based on reference channel width is 33.4 feet. This means the bridge is undersized and is approximately 70 percent of the bankfull channel width. Deposition above and below the bridge was noted (Figure 11), as well as scour above the bridge. The angle of stream flow approach the bridge is a mild bend, which is creating a minor alignment problem. The bridge is undersized and is causing minor

geomorphic incompatibility. For this reason, the bridge is a low to moderate priority for replacement.



Figure 11. Deposition below Route 15 Bridge in R13S3.01-C

### **Reach R13S3.02** **River Corridor Protection**

The second reach on Foote Brook is a transition between the higher valley slope (4.3%) and confined valley of R13S3.03 and the gentle valley slope (0.8%) and very broad valley of R13S3.01. Reach R13S3.02 has a valley slope of 2.6% and valley confinement ratio of 11.5 (very broad). There are high banks along R13S3.02 that are confining the channel and the defined valley wall especially on the south bank at the lower end of the reach is far from the channel. The channel contained ledge in places, but there was not clear evidence that the bedrock is channel spanning. The existing stream type is an entrenched “B” channel. Given the broad valley, the reference stream type is likely a “C” channel with a “B” subclass because of the

higher slope. The dominant bedform is step-pool (see Figure 12); however, there were some sections that were characterized as riffle-pool. The dominant substrate is cobble.



Figure 12. Step created by large boulders in R13S3.02

Notes taken in the field in October 2007 suggest reach 2 is stable with very little bank erosion. This appears to be contrary to the stream type departure that is noted from the cross section data. The terraces on both sides are about five feet higher than the bankfull elevation (Figure 13). It is not clear whether these adjacent terraces are a recently abandoned floodplain. There is a very narrow bankfull bench on both sides, suggesting the channel incised at one point. The combination of the large substrate, well vegetated banks, and high slope likely contribute to this being a stable section. Some minor planform adjustment was noted at the lower end of the reach where the valley widens and there is a flood chute. There is also a large side bar from aggradation that has occurred upstream of the Route 15 Bridge. The RGA scored at the lower end of the “good” range.

The rapid habitat assessment scored at the high end of the “good” range. Other than some minor historic channel alteration at the lower end of the reach associated with the Route 15

Bridge and a narrow buffer on the south bank adjacent to a private residence, the aquatic and riparian habitat was of high quality.



Figure 13. High banks on south side of channel at lower cross section (R13S3.02)

### **Reach R13S3.03** **Conservation**

The downstream end of reach R13S3.03 begins about 1000 feet upstream of the Route 15 crossing and extends upstream from the reach break 1615 feet. The valley width is narrow at 120 feet on average, making the overall confinement type semi-confined. The channel has an existing and reference stream type of “B” and a step-pool bedform (Figure 14). Riffle-pool was a subdominant bedform in the upper reach, where the valley wall was slightly wider than the lower half of the reach. The channel substrate material is dominated by cobble. There is a ledge outcrop in the middle of the reach that is acting as a grade control (see Figure 15). Immediately below the bedrock grade control and about 300 feet below the grade control

there was large material along the side of the channel. This material is likely associated with a remnant mill, but could also be old abutments.



Figure 14. Step-pool bedform in reach R13S3.03



Figure 15. Bedrock grade control in middle of reach R13S3.03

Reach R13S3.03 is reference in terms of geomorphic condition and habitat. No channel adjustment processes were identified. The reach scored in the reference category for all ten habitat parameters. The riparian corridor is entirely forested with the exception of a short section of Foote Brook Road, which lies within the west corridor near the middle of the reach. Conservation of this reach is recommended.

### **Reach R13S3.04**

The upper most reach on Foote Brook that received a Phase 2 assessment in 2007 is R13S3.04. This reach has a broad valley confinement. The reach is 1662 feet in length and the upstream extent of the reach is about 550 feet upstream of a tributary that enters Foote Brook from the north. The incision ratio is 1.39 indicating the channel has historically incised. The elevation of the recently abandoned floodplain is one to two feet higher than the bankfull elevation. An eight foot high bank was noted in the middle part of the reach on the east bank.

Knotweed was present on the near bank with mixed trees the dominant vegetation type on the bank and within the buffer. Buffer widths were greater than 100 feet in width on both sides. There were a number of signs of minor planform adjustment including three mid channel bars and two flood chutes. Some of this planform adjustment is attributed to large woody debris. Debris was in the channel on a bend and there is potential for planform change if the debris jam continues to build; this could result in the flood chute turning into an island (Figure 16). Overall the reach is stable and there is very little erosion. The RGA scored in the “good” range with minor historic degradation and minor aggradation and planform adjustment. The habitat scored at the low end of the “reference” range with all parameters being given a reference rating with the exception of channel flow status, sediment deposition and bank vegetative protection, which were given good ratings.



Figure 16. Flood chute and debris in reach RI3S03.04 causing minor planform adjustment

## Site Level Opportunities

Site specific projects were identified using the criteria outlined by the ANR in Chapter 6 – Preliminary Identification and Prioritization (Vermont Agency of Natural Resources 2007a). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium. The site level projects that were developed for Foote Brook are provided below in Table 1. High priority projects include river corridor protection to provide attenuation of sediment and floodwaters through conservation and corridor easements, the replacement or retrofitting of undersized stream crossing structures, and arresting active incision.

The project strategy, technical feasibility, and priority for each project are listed by project number and reach. A total of four projects were identified to promote the restoration or protection of channel stability and aquatic habitat in the Foote Brook watershed. Table 1 provides information for each project, including the project strategy, technical feasibility, and general cost. The project locations and categories identified for Foote Brook are depicted below in Figure 2. These projects identified include:

- **Passive Restoration** of river corridor in the section of river between the Lamoille River confluence to the Route 15 crossing through corridor easements or adoption of fluvial erosion hazard (FEH) zones (project #1).
- **Active Restoration** of channel by arresting the active head cut downstream of Route 15 near the channel avulsion (project #2).
- **Active Restoration** by replacing undersized Route 15 bridge that is causing minor localized geomorphic instability on the lowest reach of the main stem of Foote Brook (project #3).
- **Conservation** of river corridor in high gradient section (1000 feet to 2600 feet) upstream of Route 15 Bridge.

**Table I. Foote Brook Site Level Opportunities for Restoration and Protection**

<b>Project # Segment</b>	<b>Type of Project</b>	<b>Site Description Including Stressors and Constraints</b>	<b>Project or Strategy Description</b>	<b>Technical Feasibility and Priority</b>	<b>Other Social Benefits</b>	<b>Costs</b>	<b>Land Use Conversion</b>	<b>Potential Partners</b>
#1 Lamoille River confluence to upstream of Route 15 crossing  Johnson, VT  R13S03.01	Passive Restoration	This section is located at the lower end of the watershed and is acting as an important attenuation asset for floodwaters and sediment.	Protect River Corridor through corridor easement or adoption of FEH zones.	High priority for corridor easement (natural attenuation area)	Flood and sediment attenuation	Cost of corridor easements	No new structures within corridor	ANR, LCPC, Town of Johnson, landowners, land trust
#2 Downstream of Route 15 crossing  Johnson VT  <b>R13S03.01-C</b>	Active Restoration	A recent channel avulsion has resulted in a sharp change in channel slope.	Alternatives analysis to arrest headcut (active incision)	High priority	Improved geomorphic stability	Unknown	Unknown	ANR, LCPC, Town of Johnson, landowners
#3 Route 15 Crossing  Johnson VT  R13S03.01-C	Active Restoration	The Route 15 bridge is undersized (span is approximately 70 percent of the bankfull channel width). The bridge has poor alignment and is causing localized geomorphic instability.	Replace bridge	Low priority	Improved localize geomorphic stability	High costs for design and replacement	Unknown	VTRANS, Town of Johnson, ANR, LCPC
#4 1000 to 2600 feet above Route 15 crossing  Johnson VT  R13S03.03	Active Restoration	Channel scored reference for geomorphic condition and habitat. Bedrock grade control in middle of reach where old mill site may have been located. Riparian corridor is forested with the exception of short section that on west bank that is near Foote Brook Road.	Conservation	High priority	Protect forested riparian corridor and high quality aquatic habitat.	Cost of corridor easements	No new structures within corridor and preservation of forested riparian corridor	ANR, Town of Johnson, landowners, land trust, LCPC

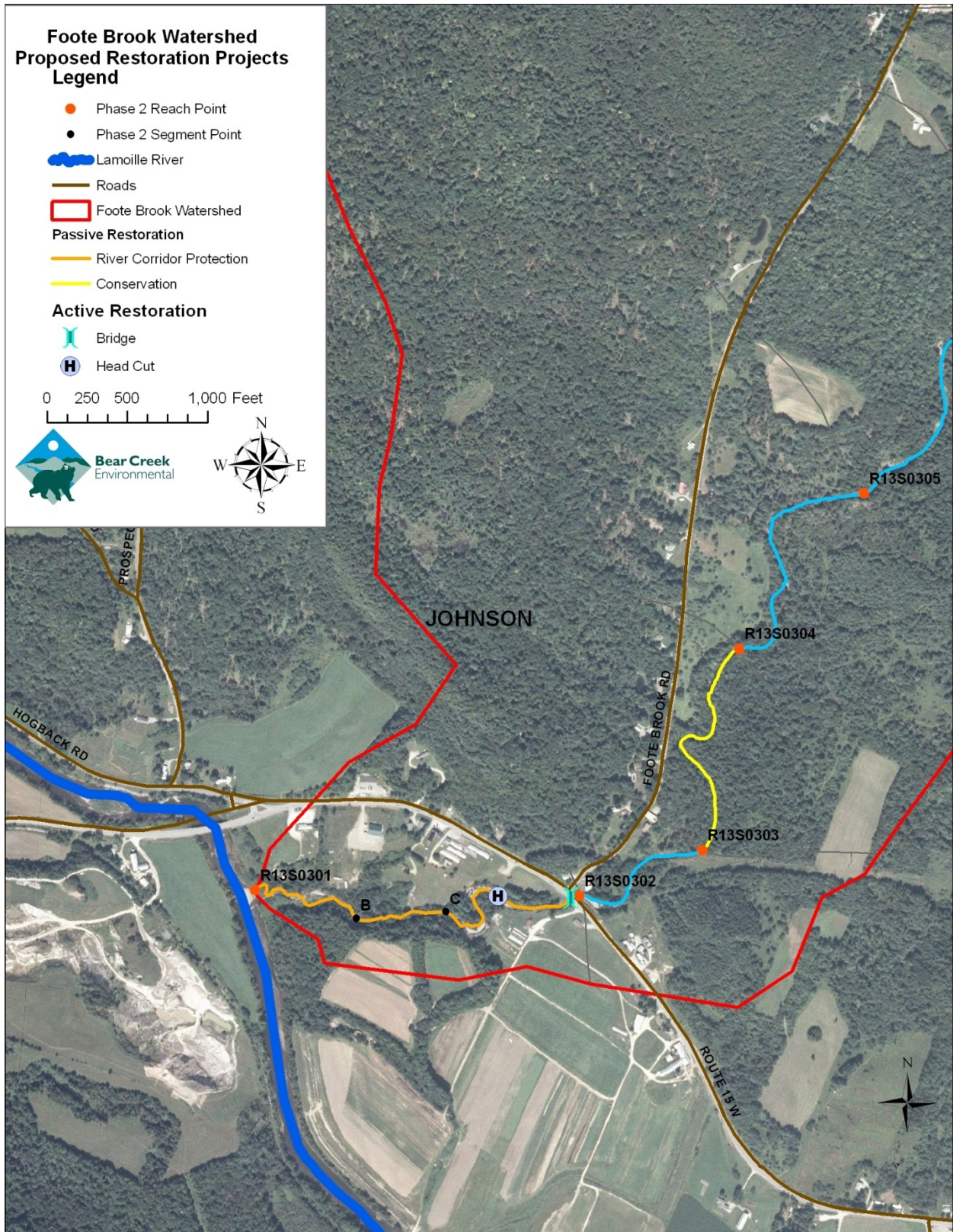


Figure 17. Proposed restoration and protection projects for Foote Brook in Johnson, Vermont

## Appendix A

### Phase 1 - Step 1. Reach Locations

Basin: **Lamoille** Watershed: **Lamoille River** Sub-watershed: **Lamoille River -- Gihon River to mouth**

SGAT Version: **4.56** Quality Assurance Status **Step 2 done**

Reach ID	Stream Name	Excluded?	Towns	Description
R13S03.07T.01	Joe Brook		Johnson	Begins about 350 feet downstream of the end of reach R13S0307. Continues for about 760 feet, about 625 feet upstream of the Foote Brook Road crossing.
R13S03.07T.02	Joe Brook		Johnson	Continues for about 3275 feet, about 100 feet upstream of a tributary entering from the west.
R13S03.07T.03	Joe Brook		Johnson	Continues for about 2900 feet, about 200 feet upstream of the second tributary entering from the west.
R13S03.07T.04	Joe Brook		Johnson	Continues for about 2515 feet, about 75 feet upstream of a tributary entering from the north.
R13S03.07T.05	Joe Brook		Johnson	Continues for about 1325 feet, about 150 feet upstream of the Plot Road crossing.
R13S03.07T.06	Joe Brook		Johnson	Continues for about 1100 feet, about 315 feet upstream of where the channel enters an open field behind a farmhouse.
R13S03.07T.07	Joe Brook		Johnson	Continues for about 560 feet. There are no significant reference points along this reach.
R13S03.07T.08	Joe Brook		Johnson	Continues for about 850 feet. There are no significant reference points along this reach.
R13S03.07T.09	Joe Brook		Johnson	Continues for about 800 feet. There are no significant reference points along this reach.
R13S03.10S.01	Tributary at S03.10S of Foote Brook		Johnson	Begins at about 100 feet downstream of the end of reach R13S0310, near the intersection of Foote Brook Road, Coddling Hollow Road, and Cemetery Road. Continues for about 2200 feet and ends about 1160 feet upstream of crossing Gilcris Road.
R13S03.10S.02	Tributary at S03.10S of Foote Brook		Johnson	Continues for about 2675 feet, about 235 feet upstream of crossing Foote Brook Rd.
R13S03.10S.03	Tributary at S03.10S of Foote Brook		Johnson	Continues for about 1800 feet. Ends about 400 feet upstream of a small pond to the west of the channel.
R13S03.13S.01	Tributary at S03.13S of Foote Brook		Johnson	Begins about 200 feet downstream of the end of reach R13S0313. Continues for about 2500 feet, about 130 feet upstream of a tributary entering from the north.
R13S03.13S.02	Tributary at S03.13S of Foote Brook		Johnson	Continues for about 1960 feet, about 1200 feet upstream of a tributary entering from the northeast.
R13S03.13S.03	Tributary at S03.13S of Foote Brook		Johnson	Continues for about 1725 feet, about 180 feet upstream of a tributary entering from the northeast.
R13S03.13S.04	Tributary at S03.13S of Foote Brook		Johnson	Continues for about 2825 feet. There are no significant reference points along this reach.
R13S03.16S.01	Tributary at S03.16S of Foote Brook		Johnson	Begins about 165 feet downstream of the end of reach R13S0316. Continues for about 20920 feet, about 675 feet upstream of Basin Road.

R13S03.16S.02	Tributary at S03.16S of Foote Brook	Johnson	Continues for about 3200 feet, about 2100 feet upstream of a tributary entering from the north.
R13S0301	Foote Brook	Johnson	Begins at the confluence with the Lamoille River just south of Route 15. Continues for about 2575 feet and ends at the upstream side of the bridge over Route 15.
R13S0302	Foote Brook	Johnson	Continues for about 960 feet. There are no significant reference points along this reach.
R13S0303	Foote Brook	Johnson	Continues for about 1580 feet. There are no significant reference points along this reach.
R13S0304	Foote Brook	Johnson	Continues for about 1660 feet, about 730 feet upstream of a tributary entering from the north.
R13S0305	Foote Brook	Johnson	Continues for about 2490 feet, about 1300 feet upstream of a tributary entering from the northwest.
R13S0306	Foote Brook	Johnson	Continues for about 1320 feet, about 220 feet downstream of a tributary entering from the northeast.
R13S0307	Foote Brook	Johnson	Continues for about 1860 feet, to about 350 feet upstream of a tributary entering from the west.
R13S0308	Foote Brook	Johnson	Continues for about 1330, about 75 feet upstream of a tributary entering from the east.
R13S0309	Foote Brook	Johnson	Continues for about 1080 feet, ending about 180 feet downstream of a tributary entering from the east.
R13S0310	Foote Brook	Johnson	Continues for about 1980 feet, about 120 feet upstream of crossing Cemetery Rd.
R13S0311	Foote Brook	Johnson	Continues for about 2080 feet, about 870 feet upstream of a tributary entering from the northwest.
R13S0312	Foote Brook	Johnson	Continues for about 1530 feet, about 75 feet upstream of a tributary entering from the northwest.
R13S0313	Foote Brook	Johnson	Continues for about 1360 feet, about 230 feet upstream of a tributary entering from the east.
R13S0314	Foote Brook	Johnson	Continues for about 2600, about 60 feet upstream of a tributary entering from the northeast, and about 300 feet after crossing Coddington Hollow Road.
R13S0315	Foote Brook	Johnson	Continues for about 1825 feet, and about 45 feet upstream of a tributary entering from the north.
R13S0316	Foote Brook	Johnson	Continues for about 1100 feet, about 650 feet upstream of the Basin Road crossing.
R13S0317	Foote Brook	Johnson	Continues for about 1090 feet, about 200 feet upstream of a pond to the west of the channel
R13S0318	Foote Brook	Johnson	Continues for about 1095. There are no significant reference points along this reach.
R13S0319	Foote Brook	Johnson	Continues for about 995 feet, about 100 feet upstream of the second tributary entering from the east.
R13S0320	Foote Brook	Johnson	Continues for about 800 feet, about 50 feet upstream of a tributary entering from the northeast.
R13S0321	Foote Brook	Johnson	Continues for about 1000, about 530 feet upstream of a tributary entering from the northeast.
R13S0322	Foote Brook	Johnson	Continues for about 1830 feet. There are no significant reference points along this reach.
R13S0323	Foote Brook	Johnson	Continues for about 940 feet, about 690 feet upstream of a tributary entering from the east.

## Glossary of Terms

Adapted from:

*Restoration Terms*, by Craig Fischenich, February, 2000, USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180 and Vermont Stream Geomorphic Assessment Handbook, Appendix Q, 2004, VT Agency of Natural Resources, Waterbury, VT.

[http://www.vtwaterquality.org/rivers/docs/assessmenthandbooks/rv\\_apxqglossary.pdf](http://www.vtwaterquality.org/rivers/docs/assessmenthandbooks/rv_apxqglossary.pdf)

**Adjustment process** – type of change that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes).

**Aggradation** - A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that the stream discharge and/or bed load characteristics are changing. Opposite of degradation.

**Alluvial fan** – A fan-shaped accumulation of alluvium (alluvial soils) deposited at the mouth of a ravine or at the juncture of a tributary stream with the main stem where there is an abrupt change in slope.

**Alluvial soils** – Soil deposits from rivers.

**Alluvium** – A general term for detrital deposits made by streams on riverbeds, floodplains, and alluvial fans.

**Avulsion** – A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.

**Bank Stability** – The ability of a streambank to counteract erosion or gravity forces.

**Bankfull channel depth** - The maximum depth of a channel within a riffle segment when flowing at a bankfull discharge.

**Bankfull channel width** - The top surface width of a stream channel when flowing at a bankfull discharge.

**Bankfull discharge** - The stream discharge corresponding to the water stage that overtops the natural banks.

This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.

**Bar** – An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an over wide channel.

**Berms** – Mounds of dirt, earth, gravel or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.

**Cascade** – River bed form where the channel is very steep with narrow confinement. There are often large boulders and bedrock with waterfalls.

**Channelization** – The process of changing (usually straightening) the natural path of a waterway.

**Culvert** – A buried pipe that allows flows to pass under a road.

**Degradation** – (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation.

**Delta bar** – A deposit of sediment where a tributary enters the main stem of a river.

**Depositional features** – Types of sediment deposition and storage areas in a channel (e.g. mid-channel bars, point bars, side bars, diagonal bars, delta bars, and islands).

**Drainage Basin** – The total area of land from which water drains into a specific river.

**Dredging** – Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.

**Erosion** – Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

**Floodplain** – Land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.

**Gaging Station** – A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

**Grade control** - A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams or culverts.

**Gradient** – Vertical drop per unit of horizontal distance.

**Habitat** – The local environment in which organisms normally grow and live.

**Headwater** – Referring to the source of a stream or river.

**Incised River** – A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

**Islands** – Mid-channel bars that are above the average water level and have established woody vegetation.

**Lacustrine soils**- Soil deposits from lakes.

**Meander** - The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

**Meander migration** – The change of course or movement of a channel. The movement of a channel over time is natural in most alluvial systems. The rate of movement may be increased if the stream is out of balance with its watershed inputs.

**Meander belt width** – The horizontal distance between the opposite outside banks of fully developed meanders determined by extending two lines (one on each side of the channel) parallel to the valley from the lateral extent of each meander bend along both sides of the channel.

**Meander wavelength** - The lineal distance downvalley between two corresponding points of successive meanders of the same phase.

**Meander wavelength ratio** – The meander wavelength divided by the bankfull channel width.

**Meander width ratio** – The meander belt width divided by the bankfull channel width.

**Mid-channel bar** – Sediment deposits (bar) located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.

**Planform** - The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel.

**Plane bed** – Channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed.

**Point bar** –The convex side of a meander bend that is built up due to sediment deposition.

**Pool** -- A habitat feature (section of stream) that is characterized by deep, low-velocity water and a smooth surface.

**Reach** - Section of river with similar characteristics such as slope, confinement (valley width), and tributary influence.

**Restoration** – The return of an ecosystem to a close approximation of its condition prior to disturbance.

**Riffle** - A habitat feature (section of stream) that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

**Riffle-pool** - Channel has undulating bed that defines a sequence of riffles, runs, pools, and point bars. Occurs in moderate to low gradient and moderately sinuous channels, generally in unconfined valleys with well-established floodplains.

**Riparian Buffer** – The width of naturally vegetated land adjacent to the stream between the top of the bank and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface.

**Riparian Corridor** – Lands defined by the lateral extent of a stream’s meanders necessary to maintain a stable stream dimension, pattern, profile and sediment regime.

**Segment** – A relatively homogeneous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach.

**Sensitivity** – The valley, floodplain and/or channel condition’s likelihood to change due to natural causes and/or anticipated human activity.

**Side bar** – Unvegetated sediment deposits located along the margins or the channel in locations other than the inside of channel meander bends.

**Step-pool** – Characterized by longitudinal steps formed by large particles (boulder/cobbles) organized into discrete channel-spanning accumulations that separate pools, which contain smaller sized materials. Often associated with steep channels in confined valleys.

**Surficial sediment/geology** – Sediment that lies on top of bedrock.

**Tributary** – A stream that flows into another stream, river, or lake.

**Urban runoff** – Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the receiving waters.