Leach Stream Phase 1 Geomorphic Assessment

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For
Essex County Natural Resources Conservation District

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Summary

Leach Stream is a small 14.5 mile long tributary of the Connecticut River, located in that river's headwaters region; with a watershed that straddles the international border between Canada's Province of Quebec and the state of Vermont. The watershed occupies a remote area largely dominated by mixed conifer/hardwood forest, though agricultural fields and development associated with the village of Canaan are prevalent along Leach Stream's lower reaches. This northeast corner of Vermont is renowned for its outdoor recreational resources; attracting summer vacationers, hunters, fisherman, and sightseers hoping to glimpse moose or other wildlife. As a headwater tributary, Leach Stream also influences the water quality of the Connecticut River - New England's longest river and provider of many benefits to the people and natural communities of the four states that it crosses.

In December 2009, the NorthWoods Stewardship Center was contracted by the Essex County Natural Resources Conservation District to perform a preliminary assessment of Leach Stream to determine whether a full geomorphic assessment would be necessary. In December 2012, NorthWoods was recontracted to do the complete Phase 1 Stream Geomorphic Assessments of the portions of Leach Stream and its major tributaries lying within Essex County, Vermont. The broad goals of this assessment were to evaluate the ability of these waterways to adjust in response to changes in flow and sediment supply and to understand how humans have impacted their in-stream and riparian habitats. A specific goal was to provide recommendations of reaches where Phase 2 assessments should be conducted, ultimately leading to the most effective use of resources for future restoration efforts and to intact stream habitats and functions throughout the watershed.

Results of the Phase I assessment indicate that most streams in the Leach Stream Watershed are already healthy, naturally functioning systems. The relative health of these streams is mainly due to the abundance of natural land cover, which covers approximately 93% of the total watershed area. However, Phase 1 assessments also identified a number of degraded reaches that have been negatively impacted by human activities - primarily in the lower portion of the watershed near the confluence with the Connecticut River, where pressures from agricultural land use and residential development are greatest. Urban and residential development, which increases runoff and reduces a stream's ability to filter out excess sediments and nutrients, occurs along approximately 1 river-mile of the assessed reaches. About 8% of the assessed reaches are suffering from reduced floodplain access due to road and berm encroachments. Approximately 50% of assessed reaches have reduced bank stability and increased sediment loads due to inadequate dominant buffer widths of <25 feet along one or both banks. Channel straightening, which can lead to increased stream power and sediment transport was found along 3.7 river-miles, or about 15.5% of the total length of assessed reaches.

Based on these results, we were able to identify 7 reaches that are in fair or poor geomorphic condition and should be prioritized for future Phase 2 field assessments - to determine the feasibility of implementing restoration activities. We also identified 8 reference condition reaches that were in natural or near-natural states. Maintaining these reaches in a healthy, natural condition and implementing restoration projects on the other, degraded reaches will be essential to improving water quality in the Leach Stream Watershed.

Study Area

Watershed Description

The Leach Stream sub watershed lies within the Connecticut River watershed and is located in northern Vermont and southern Quebec (Figure 1). Leach Stream drains a total area of approximately 60 square miles, with 17 square miles of its watershed located in the United States and 43 square miles located in Canada. Leach Stream originates in a small wetland in the town of Averill, VT, approximately 0.5 miles east of Dale Potter Road. From this wetland, the river flows northwest for approximately 2.2 miles before entering Forest Lake (63 acres). After exiting the lake, the river continues northeast for about 4 miles to Wallace Pond (532 acres). From Wallace Pond, the river flows east along the Canadian border for about 0.9 miles before turning north into Canada, where it remains for approximately 4 miles. After reentering Vermont, the river meanders south for approximately 3 miles before reaching its confluence with the Connecticut River. Leach Stream is fed by Morrill Brook, Black Brook, and several small unnamed tributaries in Vermont.

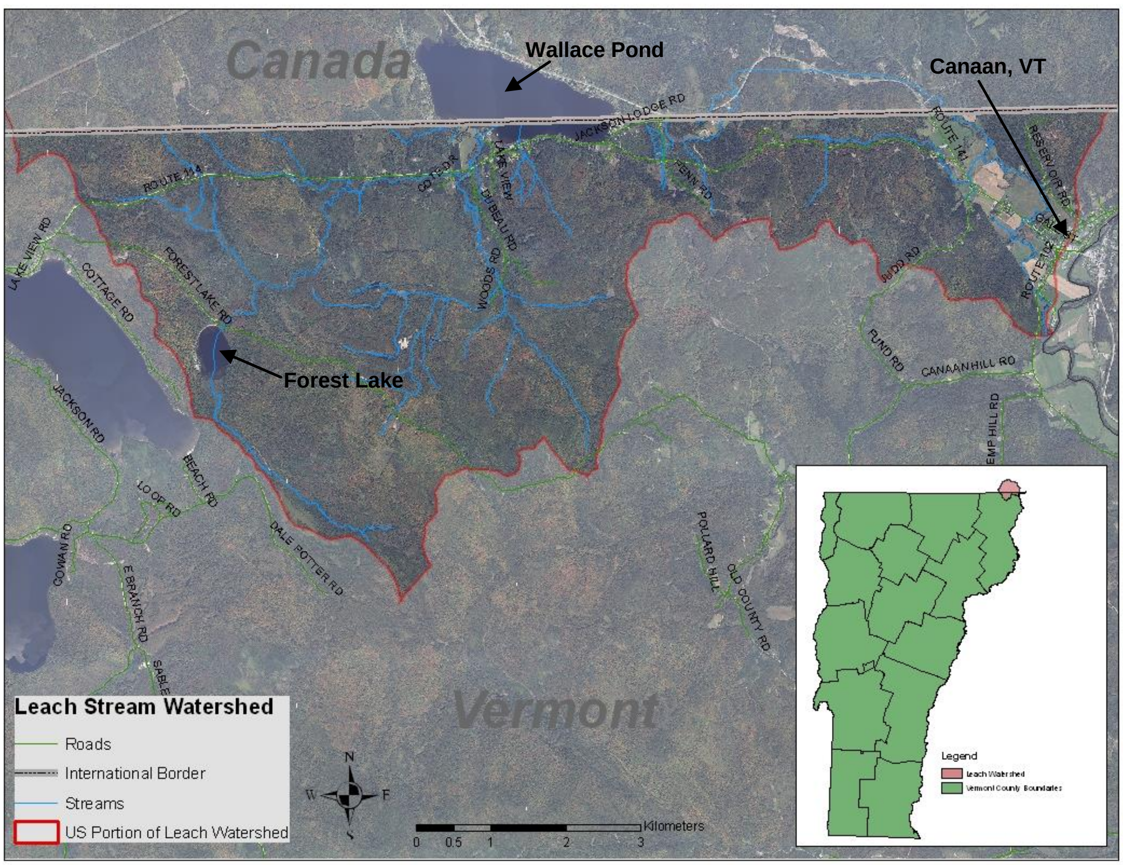

Figure 1. *Location of the Leach Stream Watershed.*

Methods

The Stream Geomorphic Assessment was completed using protocols established by the Vermont Agency of Natural Resources (State of Vermont 2007). The Phase 1 assessment is a preliminary evaluation of selected reaches and sub-watersheds that employs three sources of information; remote sensing, other existing survey datasets, and brief "windshield" field surveys. Most of the Phase 1 Assessment was completed using the following data layers (additional details about the data collected and their sources are in Appendix A):

1:24,000 USGS topographic maps (1988)
1:62,500 USGS topographic maps (1928, 1953)
1:5,000 Aerial orthophotographs (1944, 1955, 1960, 1962, 1964, 1999, 2003, 2008)
1:5,000 Vermont Hydrography Data Set
Land use – land cover maps (1990s)
Vermont Significant Wetland Inventory maps (2006)
National Wetlands Inventory maps (1975-1978)

Significant streams (generally >0.25 miles in length) within the Leach Stream Watershed represented in the Vermont Hydrography Data Set (VHD) were divided into individual reaches and sub-watersheds. The Stream Geomorphic Assessment Tool (SGAT), a GIS extension developed by the Vermont ANR, was then used to automatically associate all existing survey data with each individual sub-watershed. The data associated with each reach and sub-watershed included the following:

Reach number and length	Sub-watershed area
Valley length and width	Sub-watershed land cover / land use
Stream corridor land cover / land use	Channel slope and valley slope
Predicted channel width	

Through the examination of new and old topographic maps and aerial photographs, as well as field visits, the following features were evaluated:

Stream type / stream bed material	Presence of alluvial fans
Valley side slopes	Ground water inputs
Stream migration	Depositional features
Meander belt width and wavelength	Grade controls

In addition, data were collected describing anthropogenic modifications to the streams and their corridors:

Land use / land cover	Historic land use / land cover
Channel straightening	Riparian buffer width
Bridges and culverts	Floodplain encroachments
Dredging / gravel mining history	Development

All data were entered into a Microsoft Excel spreadsheet modeled after the Vermont ANR Data Management System (DMS) database. Similar to the DMS, the spreadsheet was used to integrate all of the data and assign impact ratings to each reach based on the degree of channel and floodplain modifications, and the degree to which the streams appeared to be responding to these modifications. These ratings were summed to calculate the overall reach condition rating, predicted adjustment scores, and reach sensitivities.

Results and Discussion

Leach Stream and its tributaries were divided into 31 reaches located within Essex County, Vermont. Each reach represents a section of river or stream with physical attributes that distinguish it from reaches immediately upstream and downstream. These attributes include valley width, valley slope, channel width, and channel sinuosity. Phase 1 assessments were conducted on 19 of these reaches, shown in Figure 2. The remaining reaches were not included in Phase 1 assessments because they were impounded or were low order streams located in forested areas that appeared to receive minimal human impact.

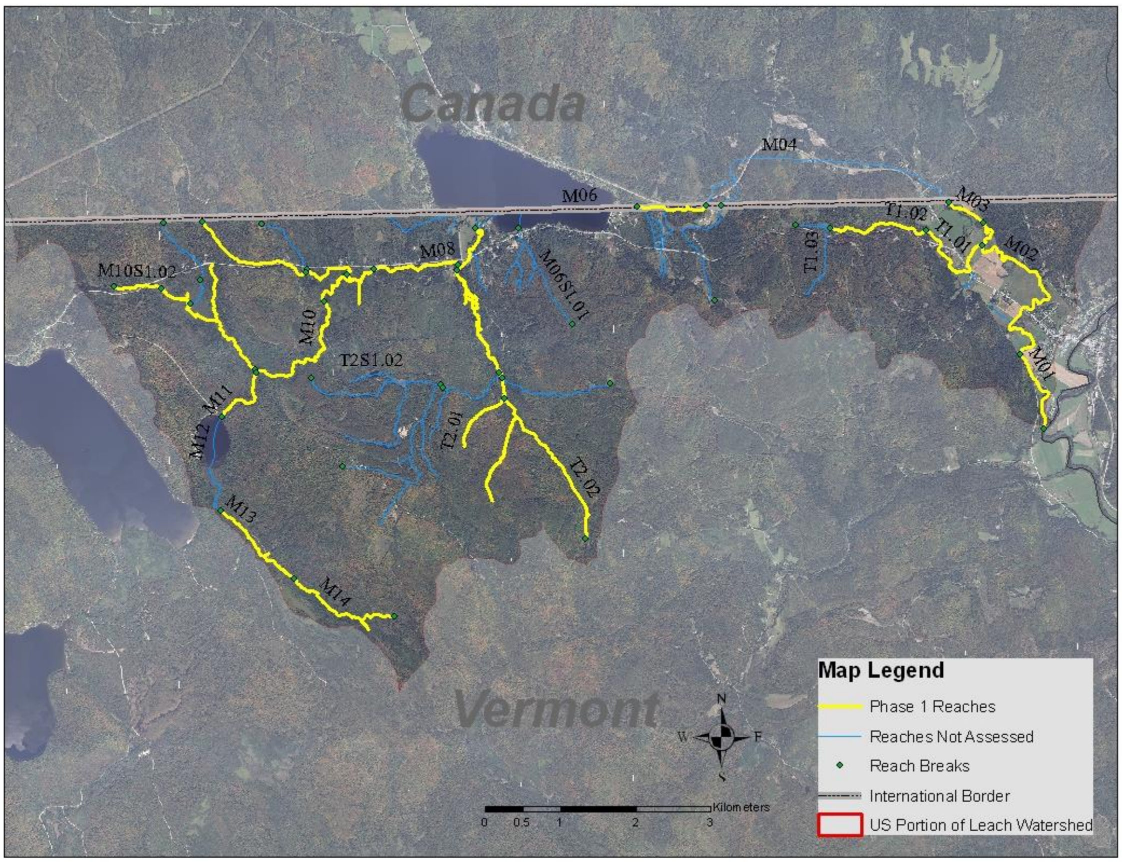

__Figure 2:__ Map of reach locations along Leach Stream and its major tributaries in Vermont.

Reference Stream Types (Step 2)

Using topographic maps and windshield surveys, data were collected to describe the valley setting and slope for each assessed reach (Table 1).

Table 1. *Valley and channel characteristics of Phase 1 assessed reaches on Leach Stream and its major tributaries.*

Reach	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type	Reference Stream Type*	Bedform	Streambed Substrate
M01	46.5	0.08	1.08	Broad	C	Riffle-Pool	Gravel
M02	46.3	0.06	1.68	Very Broad	E	Riffle-Pool	Gravel
M03	42.5	0.00	1.00	Broad	C	Riffle-Pool	Gravel
M05	40.2	2.15	1.05	Narrowly Confined	B	Riffle-Pool	Cobble
M07	37.5	0.38	1.15	Broad	C	Riffle-Pool	Gravel
M08	28.8	2.40	1.08	Narrowly Confined	B	Plane Bed	Cobble
M09	28.1	1.54	1.29	Narrowly Confined	C	Riffle-Pool	Gravel
M09S1.01	11.1	1.89	1.14	Very Broad	B	Plane Bed	Cobble
M09S1.02	7.5	4.2	1.05	Semi-confined	A	Step-Pool	Cobble
M10	26.7	2.61	1.14	Broad	B	Plane Bed	Cobble
M10S1.01	16.6	0.07	1.23	Very Broad	E	Dune-Ripple	Silt
M10S1.02	10.1	2.14	1.09	Semi-confined	B	Plane Bed	Gravel
M11	18.2	0.95	1.07	Broad	C	Riffle-Pool	Gravel
M13	11.7	5.48	1.07	Narrowly Confined	A	Step-Pool	Cobble
M14	10.0	1.96	1.17	Very Broad	C	Plane Bed	Sand
T1.01	17.0	1.48	1.23	Very Broad	C	Riffle-Pool	Gravel
T1.02	12.6	5.22	1.15	Narrowly Confined	A	Step-Pool	Cobble
T2.01	26.1	0.91	1.23	Broad	E	Riffle-Pool	Gravel
T2.02	13.8	5.17	1.07	Narrowly Confined	A	Step-Pool	Cobble

*** See Appendix B for stream type descriptions**

Stream types were assigned based on the Rosgen stream classification system (Appendix B), where variables such as channel slope, valley slope, valley width, and sinuosity were evaluated, as these variables determine the type of stream found in a given location. Each reach was assigned a letter classification ranging from A through G. Approximately 53% of the Phase 1 assessed reaches in the Leach Stream watershed are C and E stream types, which are characterized by broad valleys with well developed floodplains and gentle slopes (<2%). The second most abundant stream type among Phase 1 reaches is the B stream type, which is exhibited by approximately 26% of the reaches. These reaches generally have lower sinuosity and are located in narrower valleys with slightly steeper slopes (2-4%) than C and E stream types. The remaining 21% of the assessed reaches are A-type streams, with extremely narrow (<2 times the channel width) or confined valleys and very steep slopes (>4%).

Basin Characteristics (Step 3)

<u>Alluvial Fans (Step 3.1)</u>

Alluvial fans are fan shaped sediment deposits that occur at sudden changes in valley slope where steep confined streams enter wide, flat valleys. No alluvial fans were found during Phase 1 assessments of the Leach Stream watershed.

<u>Grade Controls (Step 3.2)</u>

Figure 3. *Natural grade control- as viewed from Jackson Lodge Road Bridge.*

Grade controls are features that span the width of a stream channel and maintain the elevation of the channel at a given height. Both natural grade controls (e.g. rock ledges) and manmade grade controls such as dams and weirs can impact fluvial geomorphology by altering stream velocity and/or sediment load. These changes can affect both stream depositional patterns and in-stream and riparian habitat quality. One natural grade control was observed among the Phase 1 assessed reaches, on reach M05. This natural grade control was a rock ledge located approximately 25 feet downstream of Jackson Lodge Road. This location was visited during windshield surveys and no adverse impacts from the grade control were observed (Figure 3). Additionally, the aerial photos indicated that there may have been a dam, also on M05. The aerial photos suggest that this dam impounds a very short section of river - approximately 400 feet long - and is inaccessible from the road. As a result, it was not assessed during the windshield survey. Aerial photography indicates that some sediment deposition has occurred upstream of this dam. A second dam is located at the Wallace Pond outlet, just over the international border in Canada. This dam was also not accessible for a windshield survey and is difficult to assess using recent aerial photography, due to tree canopy cover.

Geologic Materials (Step 3.3)

The geologic materials that comprise the substrate within a watershed can strongly influence many above-ground characteristics, from forest tree species to water chemistry to stream type. These materials fall into two general categories: bedrock and surficial (glacial or post glacial) deposits.

Two distinct types of bedrock dominate the Leach Stream watershed. Metasedimentary rocks known collectively as the Gile Mountain Formation underlie the eastern two thirds of the area. These rocks weather relatively easily into fine sediments containing 15-45% carbonate minerals, including calcium and magnesium, which help to buffer acids in soil or water and which more readily support nutrient-demanding deciduous tree species such as sugar maple, white ash, and basswood. The western third of the watershed overlies granite-family bedrock of the New

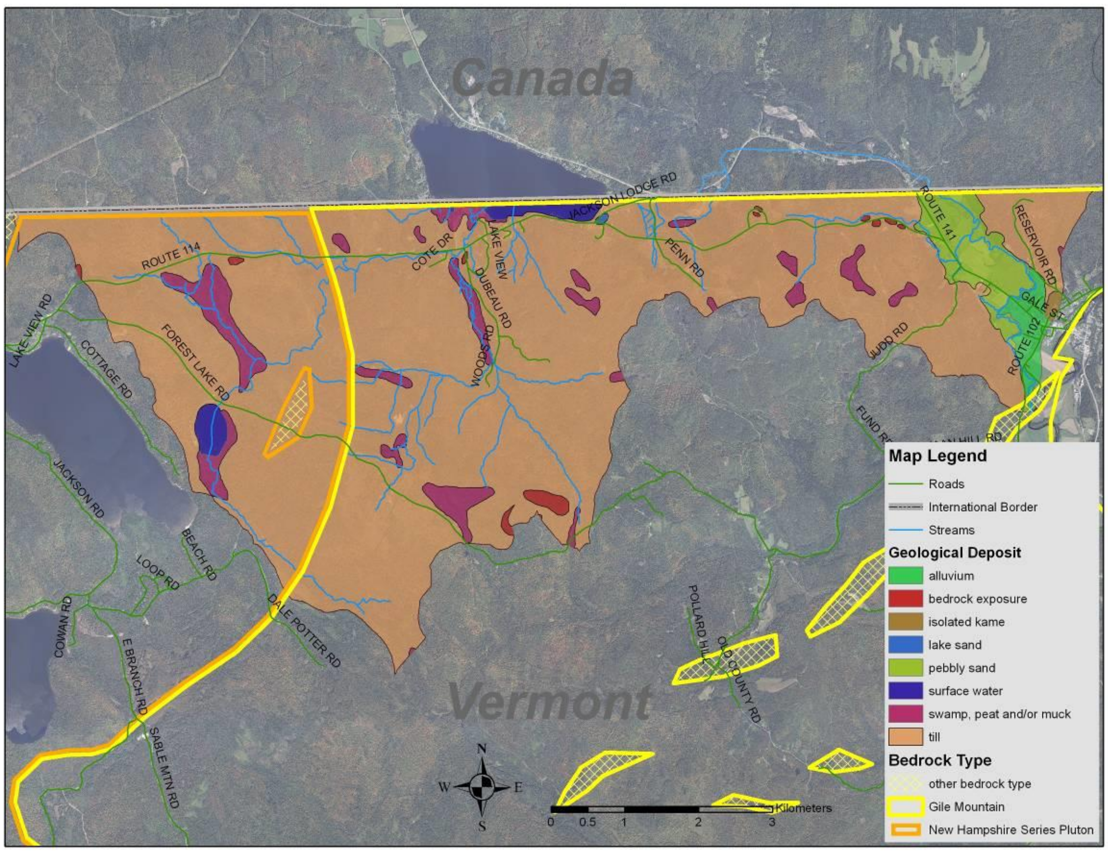

***Figure 4**. Map of bedrock and surficial geology in the Leach Stream Watershed.*

Hampshire Series pluton. These rocks contain large amounts of quartz, which resists weathering, and they tend to produce somewhat acidic coarse textured soils that support higher proportions of conifers such as red spruce and balsam fir.

Overlying the bedrock are materials that originated either during the most recent glacial retreat (approximately 13,000 years ago) or from subsequent deposition of water-borne sediments. Glacial till and swamp/peat/muck parent materials are relatively well distributed throughout the Vermont portion of the Leach Stream watershed, covering approximately 87.7% and 5.2% of the total area, respectively (Figure 4). Reaches flowing through areas dominated by till deposits tend to be A and B type streams, while reaches flowing through areas with swamp, peat, or muck deposits tend to be C type streams. Pebbly sand and alluvium deposits are confined to the eastern edge of the watershed near the confluence with the Connecticut River, covering approximately 3.4% and 1.3% of the total area, respectively (Figure 4). Reaches flowing through areas with these deposit types exhibit C and E stream types. Isolated kame deposits, lake sand, and bedrock exposure each cover less than 1% of the total Leach Stream watershed area in Vermont and are relatively minor influences.

Land Cover and Reach Hydrology (Step 4)

Land Use and Land Cover Types (Steps 4.1 and 4.2)

Natural land cover types such as forests and wetlands play important roles in watersheds by storing and filtering run-off, trapping sediment, reducing peak flood levels, and maintaining base flows during summer. The loss of these natural land cover types can affect watersheds in several ways. Deforestation and urban and agricultural development increase rainwater and snowmelt runoff by decreasing the amount of natural vegetation available to filter water and sediment. Urban lands also contain impervious surfaces which quickly shed stormwater into adjacent drainages, rather than allowing the water to percolate gradually through the soil. The result is higher peak flood levels as well as high nutrient and sediment inputs. Consistently high stormwater runoff can cause a channel to enlarge, erode, and incise to accommodate high flows. Additionally, agricultural practices that rely on tilling increase the amount of bare soil - which is susceptible to eroding during precipitation events or during the annual spring melt.

The Leach Stream Watershed contains 93.33% natural land cover (Table 2; Figure 5). This category includes the land areas that are forested, those transitioning to forest, wetlands, and surface waters. Forested land is the most prevalent land cover type in the watershed, covering nearly 84% of the total area, followed by wetlands at 6.41%. Urban areas, which include transportation, communication, and utility infrastructure, as well as residential, urban, and commercial lands, occupy a small proportion of the watershed at 3.65% of the total area. Approximately 88% of this urban land cover is comprised of transportation and utilities infrastructure, which is somewhat concentrated around the village of Canaan, but is generally well distributed throughout the watershed. Residential lands occupy only about 0.41% of the

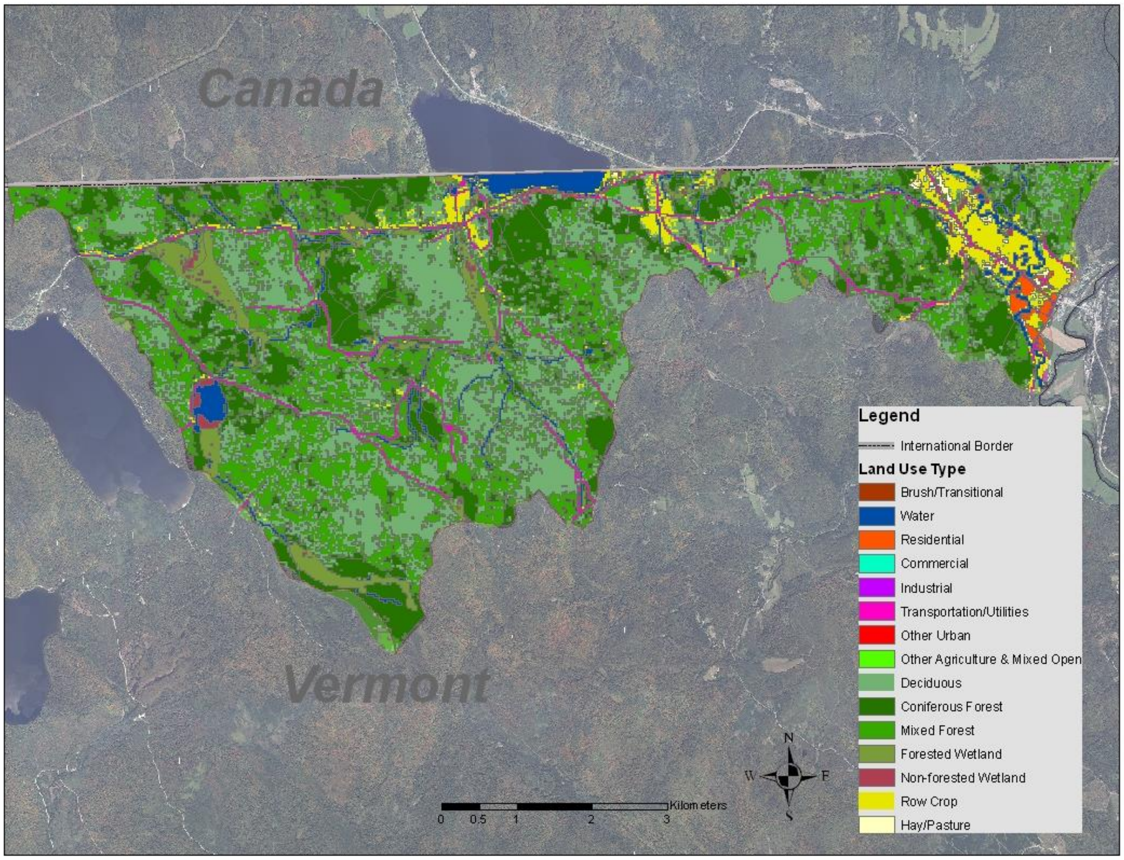

Figure 5. *Land Use and Cover Types in the Leach Stream Watershed.*

total land cover, and are concentrated near the lower reaches of Leach Stream. Agricultural land occupies approximately 3% of the total watershed, a relatively low proportion when compared to the statewide average of 20.9% (USDA 2007). Similar to residential areas, the majority of agricultural lands are concentrated near the lower reaches of Leach Stream, with other small patches located near Wallace Pond. Overall, the Leach Stream watershed in Vermont is relatively free of human development, allowing it to retain a mostly natural hydrologic regime.

Table 2. *Summary of Land Uses in the Leach Stream Watershed*

Land Use	Percentage of Watershed	
Deciduous forest	27.36%	
Mixed deciduous-coniferous forest	35.09%	Forested or brush: 83.94%
Coniferous forest	21.49%	
Brush or transitional between open and forested	0.01%	
Forested wetland	6.09%	Wetland: 6.41%
Non-forested wetland	0.32%	
Hay/rotation/permanent pasture	0.33%	
Row crops (not including orchards and berries)	2.68%	Agriculture: 3.02%
Other agricultural land	<0.01%	
Transportation, communication, and utilities	3.22%	
Residential	0.41%	
Industrial	<0.01%	Urban: 3.65%
Commercial, services, and institutional	<0.01%	
Outdoor and other urban and built-up land	<0.01%	
Water	2.98%	Other: 2.98%

Riparian Buffers (Step 4.3)

Riparian buffers are vegetated areas along stream banks that play a vital role in maintaining the health and integrity of aquatic ecosystems. Specific benefits provided by vegetated riparian buffers include stabilization of stream banks against erosion, shading to keep water temperatures cool, food and woody substrates for aquatic organisms, slowing the rate of runoff after a rainfall, and filtering of sediments, excess nutrients, and pollutants before they enter the stream.

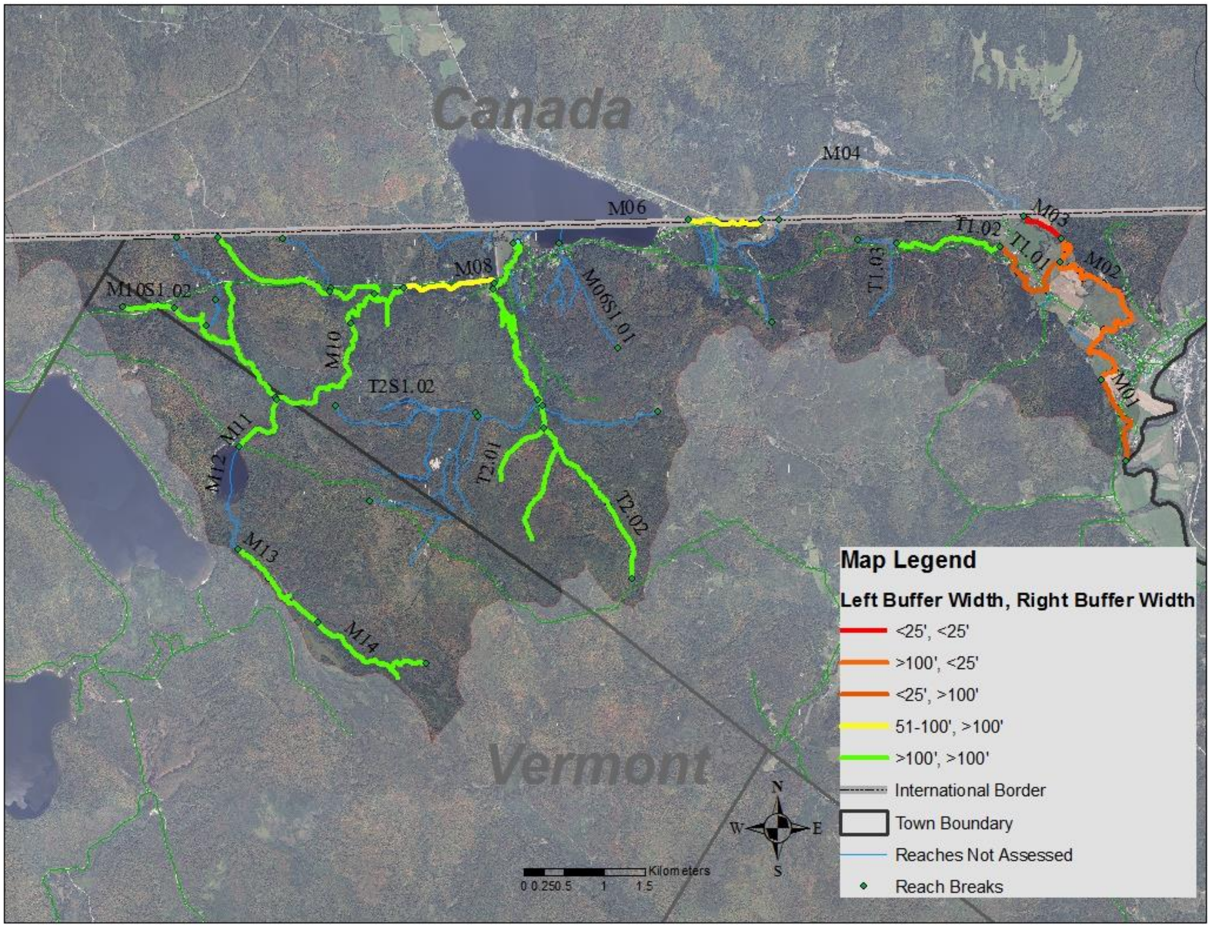

Figure 6 *Map of dominant buffer widths for assessed Leach Stream reaches.*

Approximately 68% of Phase 1 reaches were well-buffered, with dominant buffer widths of at least 100 feet along both banks. Two reaches, M05 and M08, were well-buffered along their right banks, but suffered reduced buffers of 51-100 feet along their left banks due to their close proximity to roads (Figure 6). The remaining four reaches, all located in the lower portion of the watershed near the confluence with the Connecticut River, had severely reduced buffers of less than 25 feet along one or both banks (Figure 6).

Channel Modifications (Step 5)

Flow Regulations and Water Withdrawals (Step 5.1)

Artificial flow modifications resulting from dam operation can impact stream ecosystems through the stresses of sudden reductions or increases in flow, habitat alteration, changes in water temperature, and loss of river connectivity. Water withdrawals, in particular, can negatively impact aquatic biota by removing usable habitat and changing water temperature - if excessive water is removed when flows are already naturally low.

The only flow regulation structure suspected of being in the Vermont portion of the Leach Stream watershed was a small dam on reach M05, though the dam at Wallace Pond in Quebec likely also impacts downstream reaches. Little information was available about the design or operation of these dams, making it difficult to predict their possible impacts on the stream.

Bridges and Culverts (Step 5.2)

Figure 7. *Perched and undersized culverts along reach M10S1.02 (left) and M09S1.02 (below).*

Bridges and culverts are frequently undersized and can act as channel and floodplain constrictions that have many negative impacts on streams and their surrounding areas. Undersized stream crossing structures act like dams during high flows, causing unwanted flooding and sediment deposition upstream. Sediment deposition may alter channel morphology and, in severe cases, can lead to major channel adjustments that result in loss or damage of property. By straightening and concentrating the flow of streams, culverts can also become perched, creating barriers to passage of fish and other aquatic organisms.

A total of thirteen bridges, eight culverts, and two unknown structures with negative impacts were found on Phase 1 assessed reaches in the Leach Stream watershed (Figures 7 and 8). Together these stream crossings appear to affect about 0.4 river miles, or approximately 2% of the total length of assessed reaches. Several new culverts in the upper headwater tributaries were notably undersized, and will likely be undermined and result in flooding, sediment deposition, and channel migration in the future. In addition, the majority of the culverts observed were already perched, disrupting the upstream migration of fish and causing pooling downstream. Similarly, bridges in reaches M02, M08, M09, and T2.01 are currently constricting their floodplains. Upstream and/or downstream scour pools and sediment deposition are currently found at many of these sites, indicating the impacts of the structures on the stream condition.

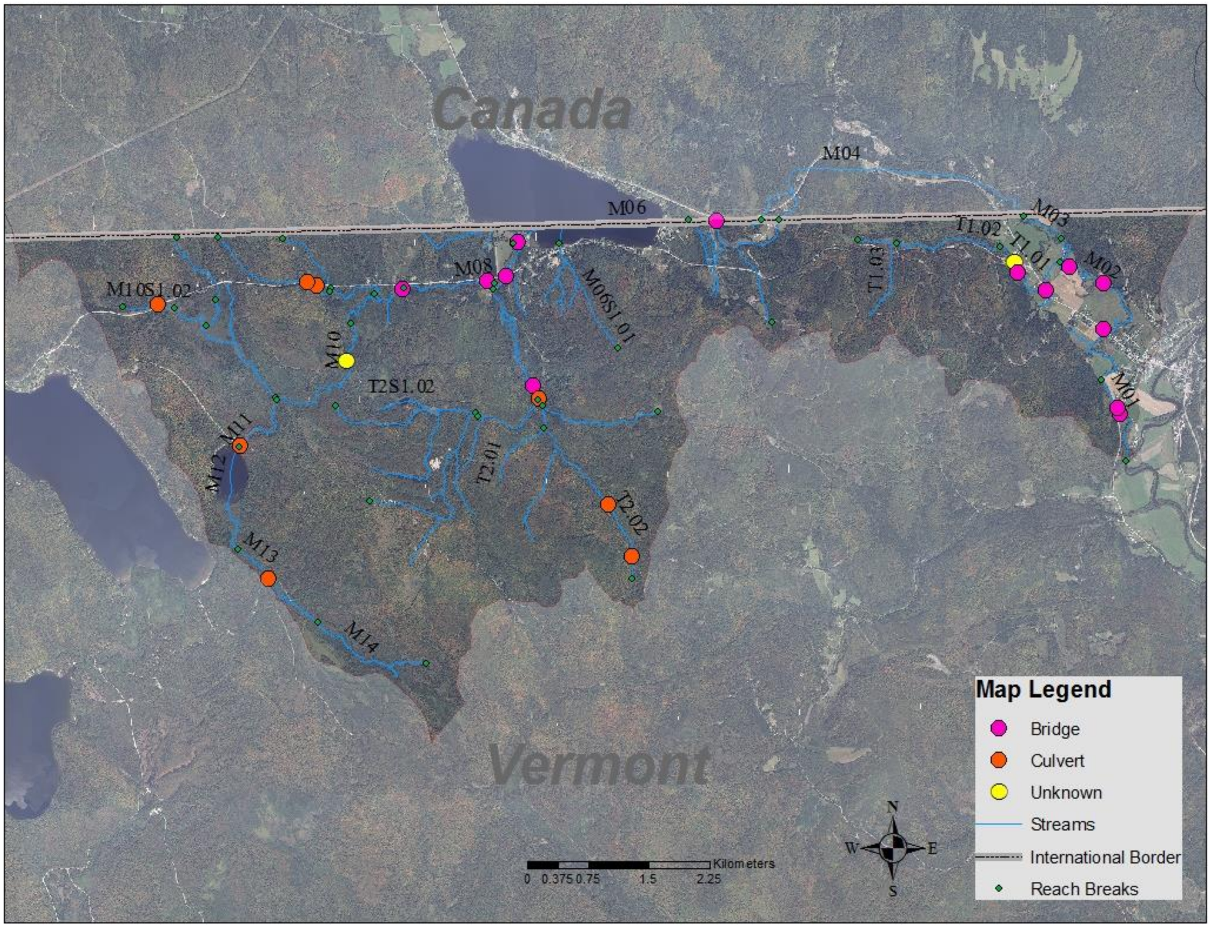

Figure 8 *Map of bridge and culvert locations in the Leach Stream watershed.*

<u>Bank Armoring (Step 5.3)</u>

Hard materials such as rip-rap or cement are installed along stream banks in an attempt to prevent property or infrastructure loss from erosion associated with channel adjustments. Frequently, however, bank armoring only delays the channel adjustment process or diverts its effects elsewhere. Armoring can also increase stream velocity, in turn worsening bank erosion downstream. Approximately 0.43 river-miles of bank armoring were found during the Phase 1 assessments, primarily in the form of stone rip-rap in areas where the stream flows adjacent to roadways or agricultural land (Figures 9 and 10).

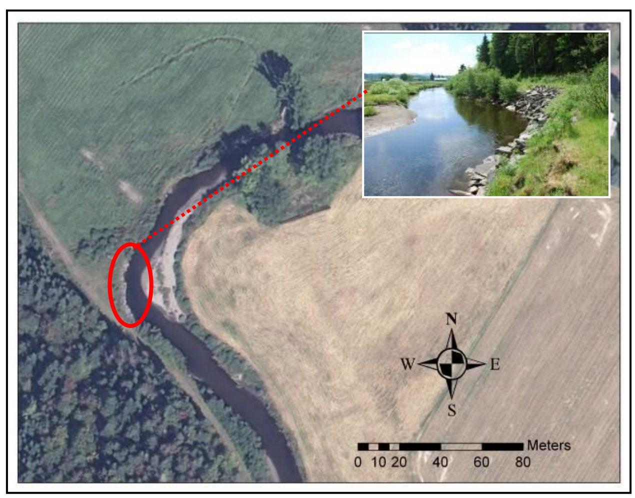

Figure 9. *Bank armoring on reach M02.*

Channel Straightening (Step 5.4)

Similar to (and often in conjunction with) bank armoring; stream channels have frequently been straightened in the past to make more land along a river corridor accessible for agriculture, development, transportation, or other purposes. Channel straightening however often also increases water velocity, leading to major adjustments downstream as this increased energy is dissipated and equilibrium with the slope and substrate is re-established. In the Leach Stream watershed, approximately 3.7 river-miles of Phase 1 assessed reaches have been straightened, most notably in sections near Vermont Route 114 southwest of Wallace Pond and in agricultural areas in the lower portions of the watershed (Figure 10).

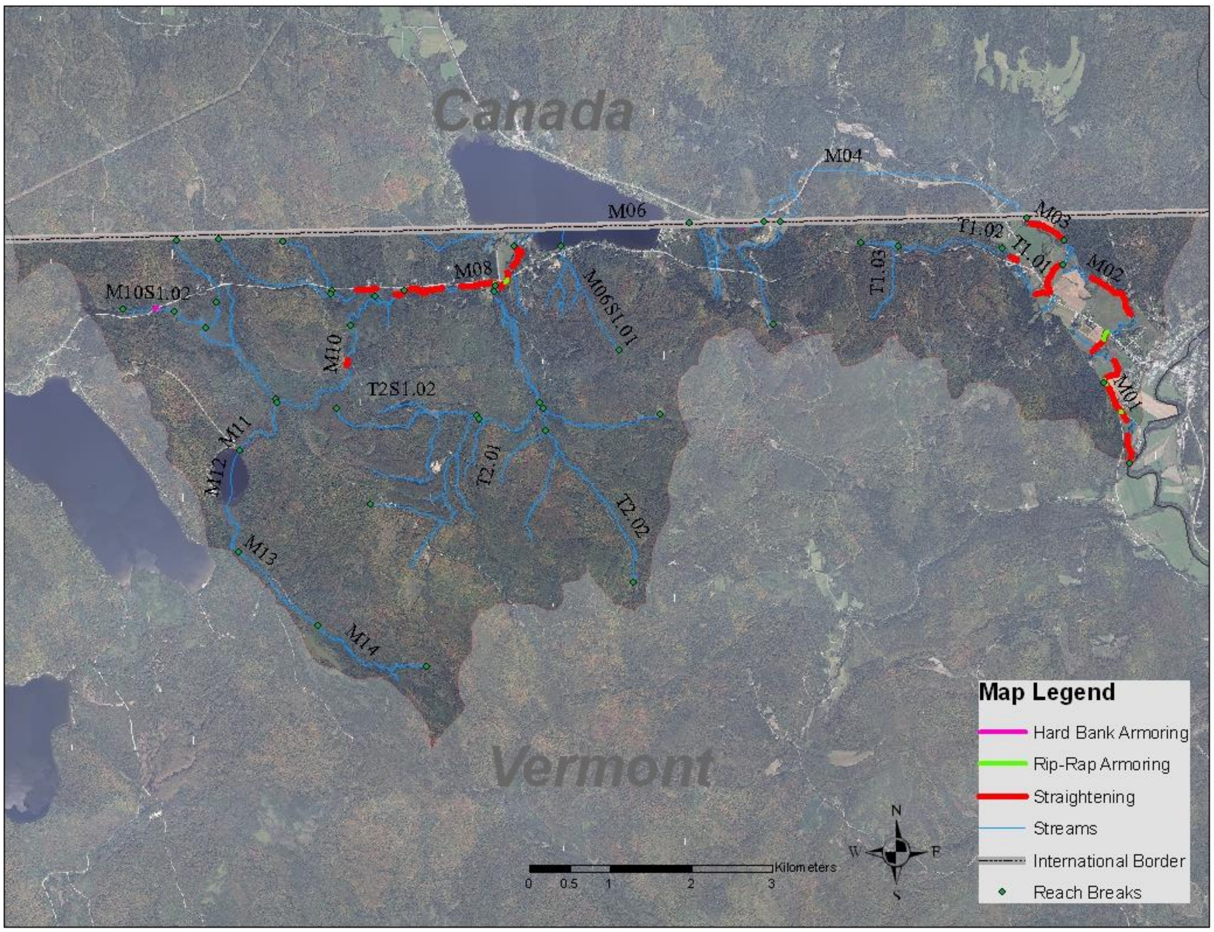

Figure 10. *Bank armoring and channel straightening locations in Leach Stream Phase 1 reaches.*

Floodplain Modifications and Planform Changes (Step 6)

Corridor Encroachments (Steps 6.1 & 6.2)

Roads, berms, improved paths, and railroads are considered encroachments when they run parallel to a stream within its defined corridor. These structures are often constructed on elevated surfaces, which act as artificial valley walls and reduce the ability of a stream to access its natural floodplain. When streams are unable to access their floodplains during high flow events, excess energy may cause them to cut downward into their beds (incise) or may lead to channel adjustments downstream. Corridor encroachments from roads, berms, and improved paths were found along 1.91 river-miles of Phase 1 assessed reaches in the Leach Stream watershed – primarily in reach M01, tributary T1, and along route 114 west of Wallace Pond.

Development such as houses, buildings, parking lots, etc. can also encroach on stream corridors and reduce a stream's ability to access its floodplain. In addition to the problems associated with encroachment, developed areas are often covered by impervious surfaces, such as concrete. These surfaces reduce water infiltration and cause excessive runoff, creating a flashy hydrologic regime, with high peaks during storm events followed by prolonged periods of low flows. Developed areas that encroach on stream corridors often also take the place of vegetated riparian buffers, further exaggerating the negative effects of the development.
Development is low overall in the Leach Stream watershed, encroaching on only approximately

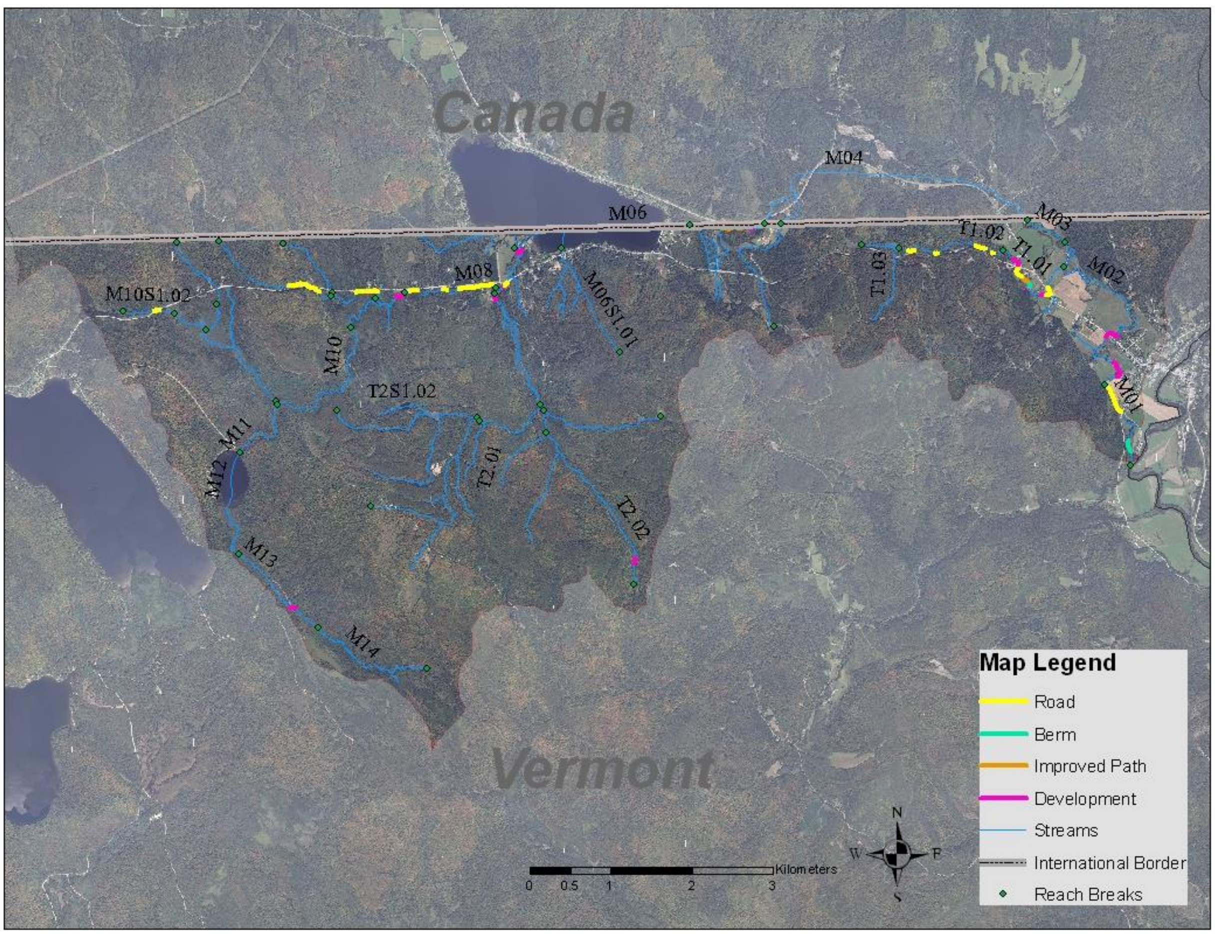

__Figure 11.__ Location of encroachments and development on Phase 1 assessed reaches.

1 river-mile of Phase 1 assessed reaches. In the Vermont portion of the watershed, encroachments and development are concentrated along Vermont Route 114 southwest of Wallace Pond, and in the lower portion of the watershed, near Leach Stream's confluence with the Connecticut River (Figure 11).

Figure 12. Mid channel bar below Route 114 bridge, leaving Canaan village (reach M02).

<u>Depositional Features (Step 6.3)</u>

Depositional features result from sediment accumulating in areas where the velocity of a stream, and its ability to carry sediment, are reduced. These features include point bars on the insides of meander bends, side bars along the channel margin in straight sections, diagonal bars that cross the channel at sharp angles, delta bars that occur where tributaries enter a stream, mid channel bars, and islands (mid channel bars that are vegetated). The presence of multiple

***Figure 13.** Upstream portion of reach M02, showing depositional features and recent channel migration downstream of straightened reach M03 (base photo 2008).*

large unvegetated bars usually indicates that a stream channel is undergoing active adjustment - or that it is receiving excessive sediment inputs from upstream.

We found depositional features on four Phase 1 assessed reaches, with the largest concentrations occurring in reach M02, between Canaan village and the Canadian border (Figures 12 and 13). Numerous depositional features are also evident on aerial photography in reach M04, an unassessed reach in Quebec, which flows in close proximity to a gravel pit.

Meander Migration (Step 6.4)

Streams are dynamic systems that change naturally over time. Lateral migration occurs as fast moving water at the outside of a bend erodes the bank, with sediments then deposited in the slower moving water at the inside of a downstream bend. As these sediments accumulate, they direct the flow outward, further promoting the migration process. In some cases, adjacent meander bends will develop until they erode away the bank separating them, resulting in an avulsion - where the former meandering channel is abandoned in favor of the new, more direct path. Though these migration processes occur naturally, the human impacts described earlier can increase the speed and frequency at which channel migration occur.

In the Leach Stream watershed, we found three reaches with evidence of active or recent migration. In reach M05 the migration feature was a short section of braided stream that no longer appeared to be actively adjusting. Evidence of both historic and recent channel migration (including avulsions) was most apparent in reaches M01 and M02, indicating that these areas are still undergoing active adjustment (Figure 13). Though the valley width and slope, and the glaciofluvial / alluvial soil parent materials in these reaches naturally support more active channel migration, the extent and rate of migration have likely been increased by human influences - including channel straightening- in this more agricultural and developed portion of the watershed.

Meander Width Ratio (Step 6.5)

Meander belt width is a measure of the horizontal distance between the outside edges of two fully formed successive meander bends. The meander width ratio is calculated by dividing the meander belt width by the bankfull channel width. This value is only calculated for C and E type reaches occurring in broad, unconfined valleys, where streams are relatively free to migrate laterally. In naturally occurring stream channels, the meander width ratio is often 5-8, however anthropogenic changes to the watershed can alter this ratio. Values lower than five indicate that a stream is straighter and steeper than normal, and is likely to incise and lose access to its floodplain. Eight of the nine assessed reaches had meander width ratios of less than five; six of these contained straightened sections along some part of their length. Values greater than 8 indicate that a stream is more sinuous than would normally be expected and it is undergoing active adjustment processes. One of the assessed reaches (M02) had a meander width ratio greater than 8 and this reach appears to be undergoing active channel adjustment.

Wavelength Ratio (Step 6.6)

A meander wavelength consists of two successive meander bends and is measured as the straight line distance between the two channel crossover points that make up the ends of the wavelength. The meander wavelength ratio is calculated by dividing the meander wavelength by the bankfull channel width. Similar to meander width ratio, wavelength ratio can only be calculated for C and E type stream channels with broad valleys. In natural stream channels, the wavelength ratio is most often 8-14, but changes in the watershed can again alter this parameter. Two of the nine assessed reaches had normal wavelength ratios (between 8 and 14). The remaining seven reaches had wavelength ratios of less than 8, indicating that the reaches have become straighter and steeper, possibly losing access to their floodplains.

Windshield Survey (Step 7)

Windshield surveys were conducted on 13 of the 19 Phase 1 reaches. Windshield surveys provide an opportunity to field check remotely sensed Phase 1 data, and to investigate parameters not easily detected remotely, such as bank erosion and debris jam potential.

Human alterations to the stream channel and watershed can greatly accelerate the normally slow process of bank erosion, leading to large increases in the stream's sediment load and rapid adjustments in the stream channel. During windshield surveys, bank erosion was detected in four reaches. Of those, M01, M02, and T1.01 were located in the lower portion of the watershed in areas with reduced vegetated riparian buffers. Bank erosion was particularly high in reach M02, possibly in part due to the straightened channel found upstream in reach M03, and the higher stream velocity that has resulted from this straightening. There was evidence of bank erosion in M08 as well, which is has experienced straightening due to its proximity to Route 114.

Debris jams provide habitat for many aquatic organisms, but also increase the potential for channel avulsions and flooding during high flow events. Ice and debris jams are especially hazardous (and likely) at stream crossings, such as bridges and/or culverts. Windshield surveys revealed that ice and debris jam potential was high in two reaches (T1.02 and M13), low in nine reaches, and not significant in the other eight assessed, but not evaluated, reaches. M13 is located in a headwaters region of the watershed, where potential for infrastructural damage is minimal. T1.02, however, is located along Route 114, and ice or debris jams here could result in infrastructural damage.

Stream and Watershed Impact Ratings (Step 8)

Each parameter measured in steps 4 through 7 was given an impact rating of high, low, or not significant. These ratings; based on land use, stream modifications, floodplain modifications, and bed and bank conditions, were combined to calculate a *total impact score* for each reach.

This score provides an objective overall measure of stream health and is useful in determining which reaches have been most heavily impacted by human activity. Total impact scores have a potential range from 0-32, with 0 being least impacted and 32 being the most heavily impacted. In the Leach Stream watershed, total impact scores ranged from 2 to 18 (Table 3). In general, headwater reaches tended to be the least impacted reaches, while the lowest reaches in the watershed and those in close contact with Route 114 were the more heavily impacted (Figure 14).

Table 3. *Total impact score, and reach condition/ sensitivity for assessed reaches in the Leach Stream watershed.*

Reach Number	Total Impact Score	Reach Condition	Reach Sensitivity
M01	18	Fair	High
M02	15	Fair	High
M03	11	Fair	High
M05	11	Good	Moderate
M07	16	Fair	High
M08	11	Fair	Moderate
M09	4	Reference	High
M09S1.01	10	Fair	Moderate
M09S1.02	7	Good	High
M10	2	Reference	Moderate
M10S1.01	2	Reference	High
M10S1.02	7	Good	Moderate
M11	2	Reference	High
M13	4	Reference	High
M14	3	Reference	High
T1.01	17	Poor	High
T1.02	6	Good	High
T2.01	5	Reference	High
T2.02	2	Reference	High

Adjustment Processes and Reach Conditions (Step 9)

Channel Adjustment Processes (Step 9.1)

Streams naturally exist in a state of dynamic equilibrium, where channel morphology and migration is predictably tied to the stream type and setting. When streams or their watersheds are affected by a significant stressor, either natural or human caused, the result is often a series of adjustment processes to the stream channel before it returns to the more stable state of dynamic equilibrium. The four adjustment processes that stream channels commonly undergo are degradation, aggradation, widening, and planform change. Degradation occurs when the stream down cuts into its bed, resulting in an incised channel. Aggradation occurs when excessive sediments build up on the stream bed. Widening occurs where both the right and left banks are eroded, resulting in channel that is overly wide for its stream volume. Planform change occurs when a stream channel meanders and migrates at a higher rate than normal for its type and substrate.

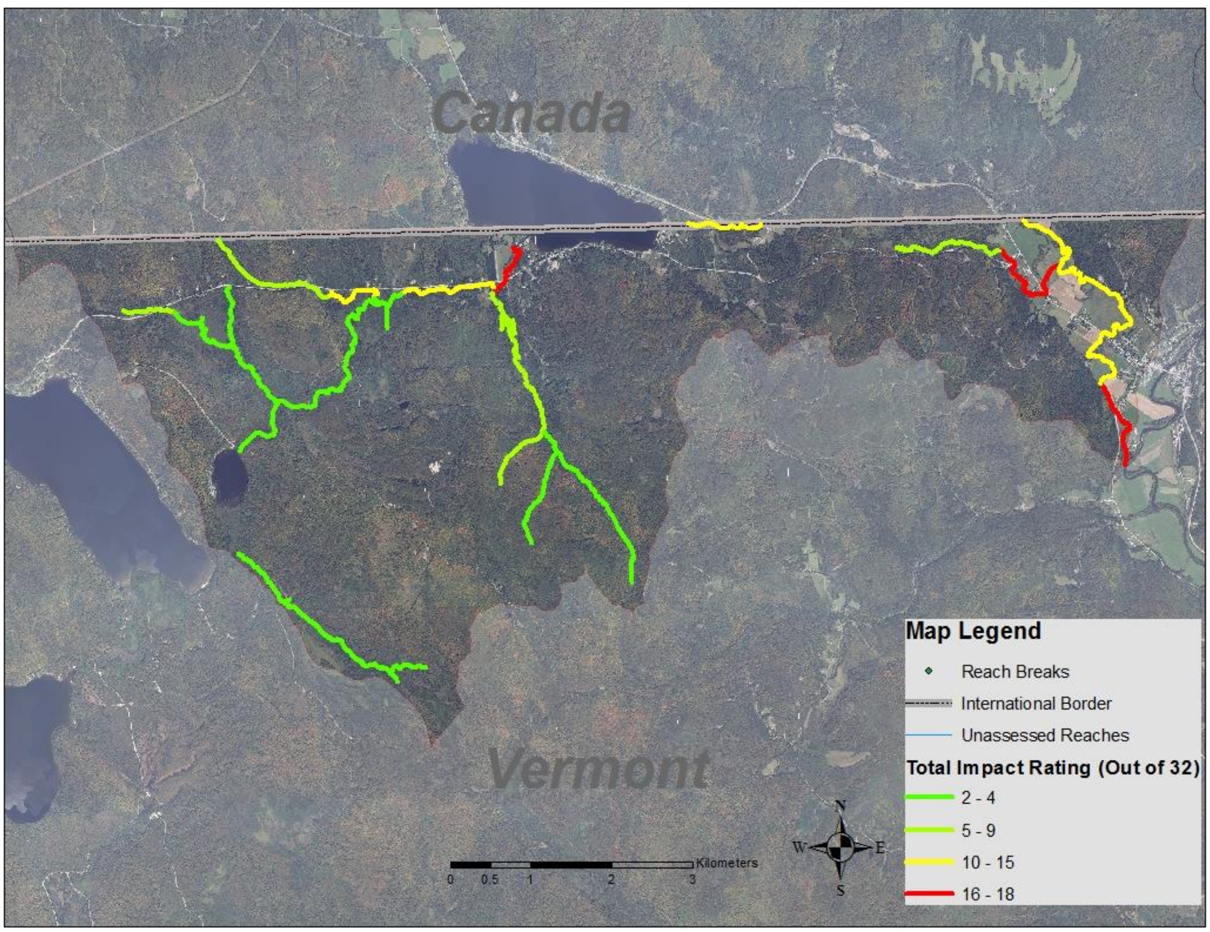

Figure 14. *Total impact ratings for assessed reaches in the Leach Stream watershed.*

Many of the parameters discussed in steps 4 through 7 influence channel adjustment processes, and these parameters were used to calculate adjustment process scores for each assessed reach in the Leach Stream watershed. The adjustment process with the highest score was considered the dominant adjustment process for that reach. If two or more adjustment processes shared the highest score, then the two together were considered to be the dominant adjustment process. Reaches with all adjustment process scores lower than four were considered to be in equilibrium (e.g. to have no dominant adjustment process). The adjustment scores for each process and reach are presented in Table 4.

Table 4. *Channel adjustment scores for Phase 1 reaches in the Leach Stream Watershed.*

Reach Number	Degradation Score	Aggradation Score	Widening Score	Planform Score	Dominant Adjustment Process
M01	6	7	5	8	Planform
M02	3	5	4	9	Planform
M03	4	5	4	6	Planform
M05	6	5	3	0	Degradation
M07	5	7	5	9	Planform
M08	6	5	3	5	Degradation
M09	3	1	0	1	None
M09S1.01	8	5	3	7	Degradation
M09S1.02	4	3	0	0	Degradation
M10	2	2	0	0	None
M10S1.01	0	1	0	0	None
M10S1.02	3	4	0	0	Aggradation
M11	2	1	0	0	None
M13	2	3	0	0	None
M14	2	0	0	0	None
T1.01	11	8	7	11	Degradation & Planform
T1.02	4	4	0	0	Degradation & Aggradation
T2.01	2	2	0	0	None
T2.02	2	2	0	0	None

Reach Condition (Step 9.2)

Most watersheds and stream channels in North America have undergone at least some degree of human modification, such as deforestation, development, channel straightening, and/or bank armoring. In many streams, these actions have led to increased peak flow levels, increased stream power, and changes in sediment storage. This has in turn led to decreased floodplain function and increased erosion and flood damage. When stream channels or floodplains are modified, the stream adjusts to maintain equilibrium with its flows and sediment loads.

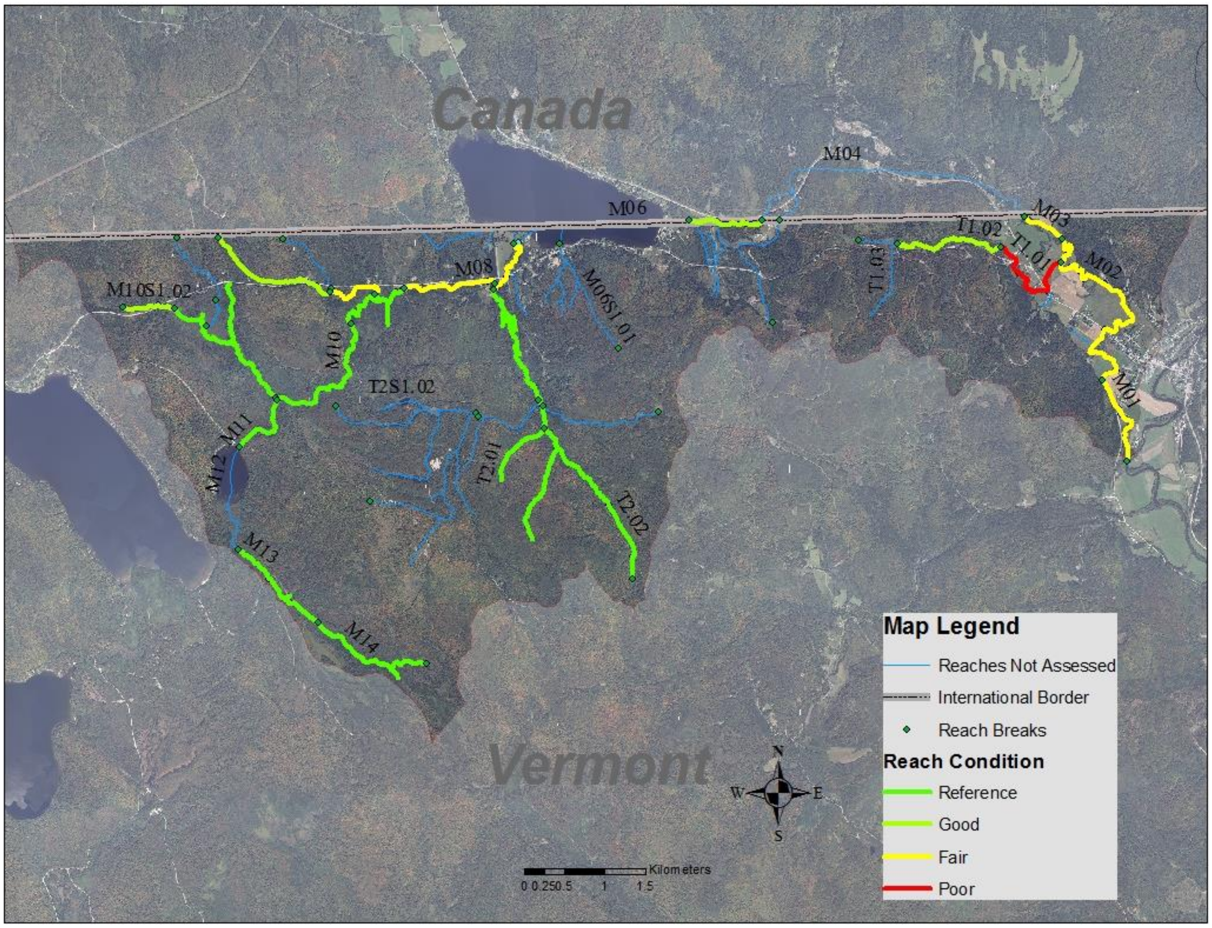

Figure 15. *Geomorphic conditions of assessed reaches in the Leach Stream watershed.*

Figure 15 depicts the geomorphic conditions found along the Leach Stream and its tributaries, as determined in the Phase 1 Stream Geomorphic Assessments. These condition rankings are based on the intensity of channel and floodplain modifications, as well as the overall stream condition observed during the field assessments, and include reference, good, fair, or poor. The Vermont Agency of Natural Resources Stream Geomorphic Assessment Protocol describes these conditions as follows (State of Vermont 2007):

"In Regime: A stream reach in *reference and good* condition that is in dynamic equilibrium which may involve localized, *insignificant to minimal change* to its shape or location while maintaining the fluvial processes and functions of its watershed over time and within the range of natural variability.

In Adjustment: A stream reach in *fair* condition that has experienced *major change* in channel form and fluvial processes outside the expected range of natural variability; and may be poised for additional adjustment with future flooding or changes in watershed inputs that could change the stream type.

Active Adjustment and Stream Type Departure: A stream reach in *poor* condition that is experiencing extreme adjustment outside the expected range of natural variability for the reference stream type; likely exhibiting a new stream type; and is expected to continue to adjust, either evolving back to the historic reference stream type or to a new stream type consistent with watershed inputs and boundary conditions."

Reach conditions of all assessed Phase 1 reaches are reported in Table 3. The majority (42%) of Phase 1 assessed reaches in the Leach Stream watershed were in reference condition, covering a total of approximately 11.58 river-miles. In general, these reaches were stable, low order streams, located in forested headwater areas removed from significant human development. Four reaches totaling 4.87 river-miles were in good condition. These reaches were also located within forested areas, but lay adjacent to roadways, which contributed some impact. Six reaches, totaling 5.98 river-miles, were in fair condition. These reaches flow through corridors with moderate levels of agriculture and development. Finally, one reach measuring 1.15 river-miles was in poor geomorphic condition. This reach was located just above the lowermost portion of the watershed near the confluence with the Connecticut River. This portion of the watershed is the most heavily impacted by agricultural use and development, vegetated buffers are limited along one or both banks in many areas, and there are multiple signs of active channel adjustment.

Reach Sensitivity (Step 9.3)

Streams are subjected to a variety of stressors, from both natural disturbances and anthropogenic sources. The propensity of a given stream to be negatively impacted by these stressors is known as its sensitivity. Sensitivity varies from stream to stream and is highly influenced by several factors, including the stream substrate, confinement type, and slope. In general, unconfined streams with low slopes and fine bed materials are more sensitive than confined streams with steep slopes and very coarse bed materials. In the Leach Stream watershed, 14 of the 19 assessed reaches were ranked as highly sensitive to stressors (Table 3). The remaining 5 reaches were moderately sensitive.

Recommendations

Northeastern Vermont was one of the last areas of the state to be cleared and settled by Euro-Americans, and remains largely rural and forested today. Like some other watersheds in northern Essex County (Dyer 2010), the Vermont portion of the Leach Stream watershed retains over 93% natural land cover – high even in comparison to other watersheds in northern Vermont that are considered high quality, such as the Barton (71%), the Black (75%), the Clyde (69%), and the Johns (62%) (Dyer 2008; Dyer et al.2008; Dyer, unpublished data).

Portions of the Leach Stream watershed have nevertheless been impacted by human development and agricultural use, resulting in localized degradation of the stream itself, diminishment of watershed functions, and high potential for the export of sediments and other pollutants to the Connecticut River. Based on our Phase 1 assessments, the reaches most heavily impacted and in the poorest geomorphic condition are concentrated in two areas within the Leach Stream watershed. These include the reaches closest to the confluence with the Connecticut River (M01, M02, M03, and T1.01) and those further upstream in the vicinity of Wallace Pond (M05 and M07). Both areas occupy relatively flat, low-lying and fertile valleys, and have attracted a mix of agricultural use, development for industry and homes, and road infrastructure. The lower area is most impacted by agriculture and buildup associated with Canaan village, while the upper area is impacted more by seasonal and year round residences clustered near Wallace Pond.

Table 5. *Reaches recommended for Phase 2 Assessment.*

Proposed Phase II Reaches	Reach Condition	Reference Stream Type	Reason for Phase II
M01	Fair	C	Reach Assessment
M02	Fair	E	Reach Assessment
M03	Fair	C	Reach Assessment
T1.01	Poor	C	Reach Assessment
M05	Fair	B	Reach Assessment
M07	Fair	C	Reach Assessment
M09	Reference	C	Baseline Reach Condition
M10S1.02	Good	B	Baseline Reach Condition
M11	Reference	C	Baseline Reach Condition
T2.01	Reference	E	Baseline Reach Condition

All of these reaches are currently in poor or fair geomorphic condition and should be considered high priorities for Phase 2 field assessments and for subsequent targeted restoration projects. Some reference condition reaches in the watershed with similar confinement and stream types should also be included in the Phase 2 assessments when possible, as an aid to gauging impacts and crafting restoration efforts for the degraded reaches.

As one of only a handful of international watersheds in Vermont, Leach Stream presents unique challenges to achieving accurate assessments or watershed restoration, but also possible unique opportunities for international cooperation. Nearly 72% of the watershed lies within Canada, and we were unable to locate comparable cross-border data that would allow a watershed-wide Phase 1 assessment. Phase 2 field assessments and restoration efforts would likely encounter similar challenges and might best be achieved through alliances with Canadian groups focused on watershed protection and water quality issues.

The most recent Google Earth imagery (early October, 2013) provides a general sense of land cover and land use across the entire watershed, suggesting that the Canadian portion also benefits from a high proportion of natural land cover. Some development, including road infrastructure, a large gravel pit, and farmland occur north of the border in proximity to the Leach Stream mainstem, and could be negatively impacting the geomorphic condition of the stream. The identification through our Phase 1 assessments of degraded reaches in Vermont both immediately upstream and downstream of the Canadian border further underscores the likelihood of cross-boundary impacts and the importance and potential benefits of cross-boundary coordination.

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Glossary

Aggradation – Accumulation of sediment on the channel bed.

Alluvial – Refers to sediment materials deposited by a river or stream.

Avulsion – A change in a stream's course caused by the stream breaking through the banks and forming a new channel.

Basin – see Watershed

Degradation –Process of scouring of the channel bed due to changes in flow rates or sediment loads.

Entrenched – Having little space to flood. A stream's entrenchment is represented by its entrenchment ratio (the width of the floodprone area divided by the width of the channel).

Erosion – The loosening and transport of soil and other particles. Erosion is a natural process but can be accelerated by human activities, such as vegetation removal and stream channel alteration.

Flood chute – An area outside the main channel that a stream accesses during high flows. These areas may become the future location of the channel as the stream migrates.

Floodplain – The area adjacent to a stream that becomes inundated with water during high flows. This land is built of sediment originating from flooding of the stream. Floodplains have important roles in reducing sediment transport and stream power during floods.

Incision – The process by which a river erodes its channel bed to a lower level than existed previously.

Incision ratio – The lower floodplain height divided by the depth of the channel at bankfull. A stable stream in reference condition would have an incision ratio of 1, meaning that degradation of the channel bed has not occurred. A stream which has undergone degradation of the channel bed would have an incision ratio greater than 1. The higher the ratio, the less likely a stream can access its floodplain.

Neck Cutoff – The narrow strip of land that exists between two meanders migrating closer to one another; eventually, the channel may break through this strip of land and the old channel will form an oxbow.

Planform – The shape and pattern that a stream forms on a landscape.

Riffle – A section of stream characterized by fast, shallow water flowing over coarser bed materials, such as cobbles and boulders
Riparian buffer – A strip of natural vegetation growing along a waterbody which serves to reduce erosion, filter sediment and pollutants, and enhance aquatic biodiversity.

River (or stream) corridor – The area of land adjacent to a stream that influences and is influenced by that stream. As delineated in Vermont's Phase 1 and Phase 2 Stream Geomorphic Assessments, this corridor is at least 100 feet on either side of the stream.

Sensitivity – A measure of how likely a reach would react to human or natural stressors to the watershed or the reach itself. This takes into account the current geomorphic condition of the reach and the composition and erodibility of its bed and bank materials.

Sinuosity – A measure of how meandering a stream is. Sinuosity is displayed as a ratio of the length of the river divided by the length of its valley.

Tributary – A body of water, such as a stream, that flows into another body of water.

Watershed (or basin) – A region drained by all of the rivers and streams flowing into a lake, river, or ocean. The relative size of a watershed and the human alterations to that watershed greatly affect the quality of the water in the waterbody into which it drains.

Appendix A. Phase 1 Project Metadata.

Parameter	**Source**
Alluvial fan	1:24K topos
Bank armoring and revetments	1:24K topos, orthos, files, field obs
Bank erosion - relative magnitude	Field obs. at access point along reach
Dominant bed form and material	Field obs. at access point along reach
Belt width	1:5K NHD, 1:5K orthos
Berms and roads	1:24K topos, 1:5K orthos, files, field obs
Bridges and culverts	1:24K topos, 1:5K NHD & orthos, files
Channel length	SGAT automated
Channel straightening	1:24K topos, 1:5K NHD, orthos, files, field
Confinement type	1:24K topos
Corridor land use - land cover data	Land use - land cover (1990s statewide)
Corridor soil data	No Data
Debris and ice jam potential	Field obs. at access point along reach
Depositional features	1:5K orthos, field obs
Dredging and gravel mining history	Not Evaluated
Downstream and upstream elevations	1:24K topos
Flow regulations and water withdrawals	1:24K topos, 1:5K NHD & orthos
Grade controls	1:24K topos, field obs.
Latitude and Longitude	SGAT automated
Meander centerline	1:24K topos, 1:5K NHD
Meander migration and channel avulsion	1:5K orthos (1990s & 1970s), other aerial photographs
Historic corridor land use - land cover	1:5K orthos (1970s), old aerial photos
Historic watershed land use - land cover	1:5K orthos (1970s), old aerial photos
Reach breaks	1:24K topos, 1:5K NHD
Riparian buffer width	1:5K orthos, recent coverages & photos
River corridor development	1:24K topos, 1:5K orthos, files
Stream type	1:24K topos, field observation
Towns that reaches are in	SGAT automated
Valley length	SGAT automated
Valley side slopes	1:24K topos, soils slope data
Valley walls	1:24K topos
Valley width	1:24K topos
Groundwater and small tributary inputs	1:24K topos, 1:5K NHD, NWI maps
Wavelength	1:5K NHD, 1:5K orthos
Watershed delineations	1:24K topos, 1:5K NHD
Watershed land use - land cover data	Land use - land cover (1990s statewide)

Appendix B: Rosgen Stream Classifications and Descriptions of Channel Bed Forms

Rosgen Stream Classifications (Rosgen 1994)

Stream Type	Sinuosity	Slope (%)	Features
A	Low	>10	Steep, entrenched, high energy/debris transport stream. Contain vertical steps, deep scour pools, waterfalls
B	Low to moderate	4-10	Moderately entrenched, dominated by riffles, pools infrequent. Stable bed and banks
C	High	<2	Low gradient, meandering, alluvial channels with broad and well defined floodplains. Exhibit point bars and riffle-pool characteristics
D	Variable	<4	Braided, very wide channels with eroding banks, in broad valleys with abundant sediment supply
E	Very high	<2	Low gradient, highly sinuous channel with very broad and alluvial floodplain
F	High	<2	Entrenched stream in highly weathered, low gradient material. Laterally unstable, high bank erosion. Riffle-pool characteristics
G	Low to moderate	2-4	Entrenched stream in narrow valley or deeply incised in alluvial or colluvial materials. Unstable, high bank erosion rates

Descriptions of Channel Bed Forms (State of Vermont 2007b)

Bed Forms	Description
Cascade	Generally occur in very steep channels, narrowly confined by valley walls. Characterized by longitudinally and laterally disorganized bed materials, typically bedrock, boulders, and cobbles. Small, partial channel-spanning pools spaced < 1 channel width apart common.
Step-Pool	Often associated with steep channels, low width/depth ratios and confining valleys. Characterized by longitudinal steps formed by large particles (boulder/cobbles) organized into discrete channel-spanning accumulations that separate pools, which contain smaller sized materials. systems exhibit pool spacing of 1 to 4 channel widths.
Plane Bed	Occur in moderate to high gradient and relatively straight channels, have low width/depth ratios, and may be either unconfined or confined by valley walls. Composed of sand to small boulder-sized particles, but dominated by gravel and cobble substrates. Channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed.
Riffle-Pool	Occur in moderate to low gradient and moderately sinuous channels, generally in unconfined valleys, and has well-established floodplain. Channel has undulating bed that defines a sequence of bars, pools, and riffles. Pools spaced every 5 to 7 channel widths in a self-formed (alluvial) riffle-pool channel.
Dune-Ripple	Usually associated with low gradient and highly sinuous channels. Dominated by sand-sized substrates. Channel may exhibit point bars or other bedforms forced by channel geometry. Typically undulating bed does not establish distinct pools and riffles.
Bedrock	Lack a continuous alluvial bed. Some alluvial material may be temporarily stored in scour holes, or behind obstructions. Often confined by valley walls.
Braided	Multiple channel system found on steep depositional fans and deltas. Channel gradient is generally the same as the valley slope. Ongoing deposition leads to high bank erosion rates. Bed features result from the convergence/divergence process of local bed scour and sediment deposition. Unvegetated islands may shift position frequently during runoff events. High bankfull widths and very low meander (belt) widths.

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