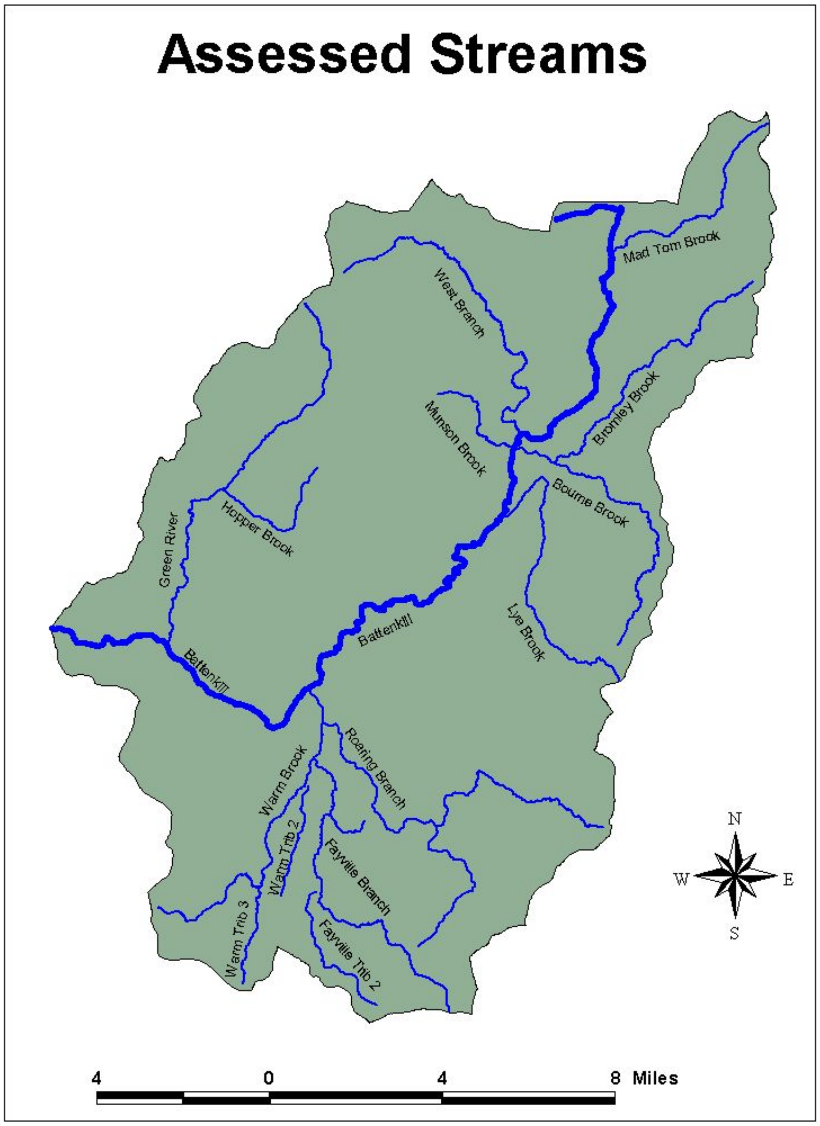
Phase 1 Geomorphic Assessment of the Batten Kill Main-Stem and Major Tributaries



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Abstract

Fluvial geomorphic studies (2000-2003) involving map and ortho-photo interpretation and field surveys have been completed on the Batten Kill main-stem and tributaries. The studies followed the Phase 1 and Phase 3 protocols of the Vermont Agency of Natural Resources (ANR) Stream Geomorphic Assessment Program. Phase 1 assessment revealed that, over half of the Batten Kill and major tributaries are undergoing varying forms and rates of channel adjustment. Phase 3 assessment on several reaches in the watershed provided field survey data verifying that adjustment processes are ongoing on those reaches. The channel adjustments appear to be a response to historic channel and floodplain modifications. Nineteenth-century deforestation, flood control, mill dams, agricultural practices and transportation development are historic activities documented in the current assessment that are likely factors in explaining the current-day fluvial geomorphic condition of the Batten Kill. More recently, flood remediation in the 1970s, may be largely responsible for the river conditions observed . Segments of the Batten Kill, Roaring Branch, Green River, and other tributaries have been extensively dredged and bermed. The majority of modification to the main-stem occurred sometime prior to the aerial photographs taken in 1942. Modifications to the tributaries occurred prior to 1940 and more recently following the 1973 flood. In large part, the Batten Kill main-stem and the lower reaches of its tributaries have become channelized.

It is likely that as low gradient meandering streams in the watershed were straightened, they became steeper, plain bed channels. This process would have caused these streams to erode their beds and lose access to their floodplains. Other streams were disconnected from their floodplains and/or prevented from adjusting channel slope through lateral migration by road and rail development. Many of these streams are currently aggrading with sediment. Mechanical disruption of bed features (riffles, steps, and pools), channel entrenchment, and sediment aggradation may be having a negative impact on the Batten Kill fishery. Disruption of sediment scour, transport, sorting, and depositional processes in the Batten Kill watershed may have resulted in: 1) a loss of deeper pools and structural elements that provide cover for adults, 2) embedded boulders and cobbles to the detriment of juvenile rearing; and 3) a loss of spawning gravels in some tributary reaches.

Introduction

With the goal of aiding fisheries biologists who are trying to explain the decline of the Batten Kill fishery, watershed scale fluvial geomorphic assessment was conducted in the Batten Kill watershed. More specifically, the geomorphic assessment was conducted to develop a better understanding of the inherent geomorphic condition of the Batten Kill and several of its major tributaries and document historic and current land and channel management activities that may be affecting the geomorphic condition of those rivers. The results of the geomorphic assessment will also help to predict the spatial distribution and extent of the various physical habitat types that exist in the Batten Kill system and indicate the spatial extent of probable habitat degradation due to channel adjustment processes. The specific objectives of this study are to:

1) Conduct a Phase 1 geomorphic assessment of the Batten Kill watershed to identify the geomorphically-significant stressors that are most likely impacting each reach;
2) Store the data in the statewide river morphology data management system;
3) Assign impact ratings and adjustment process predictions for each reach;
4) Utilize geomorphic assessment data to describe the general spatial distribution of physical habitat types and habitat-forming processes and the extent of potential degradation to those habitats and processes resulting from channel adjustments;
5) Provide training and skill development to agency personnel on river morphology assessment.

Phase 1 assessment work included a geomorphic characterization of the Batten Kill and surrounding landforms, using impact ratings for individual reaches based on the potential for changes to runoff patterns, channel geometry, and floodplain function. As part of a separate component of the overall project, Phase 3 field assessments were completed on eight main-stem and tributary segments to support scientific studies and assessment protocol development that further define the relationship of fluvial processes and the formation of riverine aquatic habitat. Nonetheless the Phase 3 data collected was usable in the following Phase 1 discussion to verify channel adjustment processes occurring in rivers of the Batten Kill watershed.

Methodology

This study of the geomorphic characteristics of the Batten Kill watershed utilized methods presented in Vermont Agency of Natural Resources Geomorphic Assessment Protocols (VT ANR, 2003). Phase 1 assessment consisted of selecting study streams, dividing streams into reaches of homogeneous channel and valley geomorphic characteristics and evaluating the following parameters on each reach: geology and soils, land cover and reach hydrology, in-stream channel modifications and floodplain modifications. The evaluation of these parameters allowed for the assignment of a numeric impact rating for each parameter assessed on each reach. Following the Phase 1 methodology the impact ratings for individual parameters were summed, resulting in a total impact score for each reach.

Phase 1 assessment was conducted on the entire main-stems of the Batten Kill, seven primary tributaries (direct tributaries to the main-stem), and eight secondary tributaries (see Figure 1). The seven primary tributaries chosen for assessment included all major tributaries. Major tributaries are defined in the Vermont ANR Geomorphic Assessment Protocols as tributaries that constitute 10 % or more of the watershed area at their confluence with the main-stem. The eight secondary tributaries selected for assessment include streams that after preliminary investigation were suspected of being impacted by significant land and channel management activities.

Phase 3 assessment consisted of in-field measurement of channel slope, cross section dimension, and bed substrate characterization. Measurement of the above geomorphic characteristics was conducted at sites using standard survey equipment in accordance with the Phase 3 assessment handbook. A site is a unit of a reach that is of homogeneous channel characteristics and is of a length equal to 10-20 times channel width. In general, sites are much shorter than the Phase 1 reaches that contain them.

Phase 3 assessment was conducted within eight of the Phase 1 reaches. The primary purpose of Phase 3 survey assessment work was to support development of a protocol to better define the role of fluvial processes in the development and maintenance of riverine aquatic habitat. In keeping with the primary goal of the Phase 3 assessment work; assessment locations were selected based on a necessity to provide examples of the various channel morphologies that exist in the Batten Kill and not to specifically provide definitive verification of Phase 1 results, however an attempt is made in this report to confirm Phase 1 results using the available Phase 3 data.

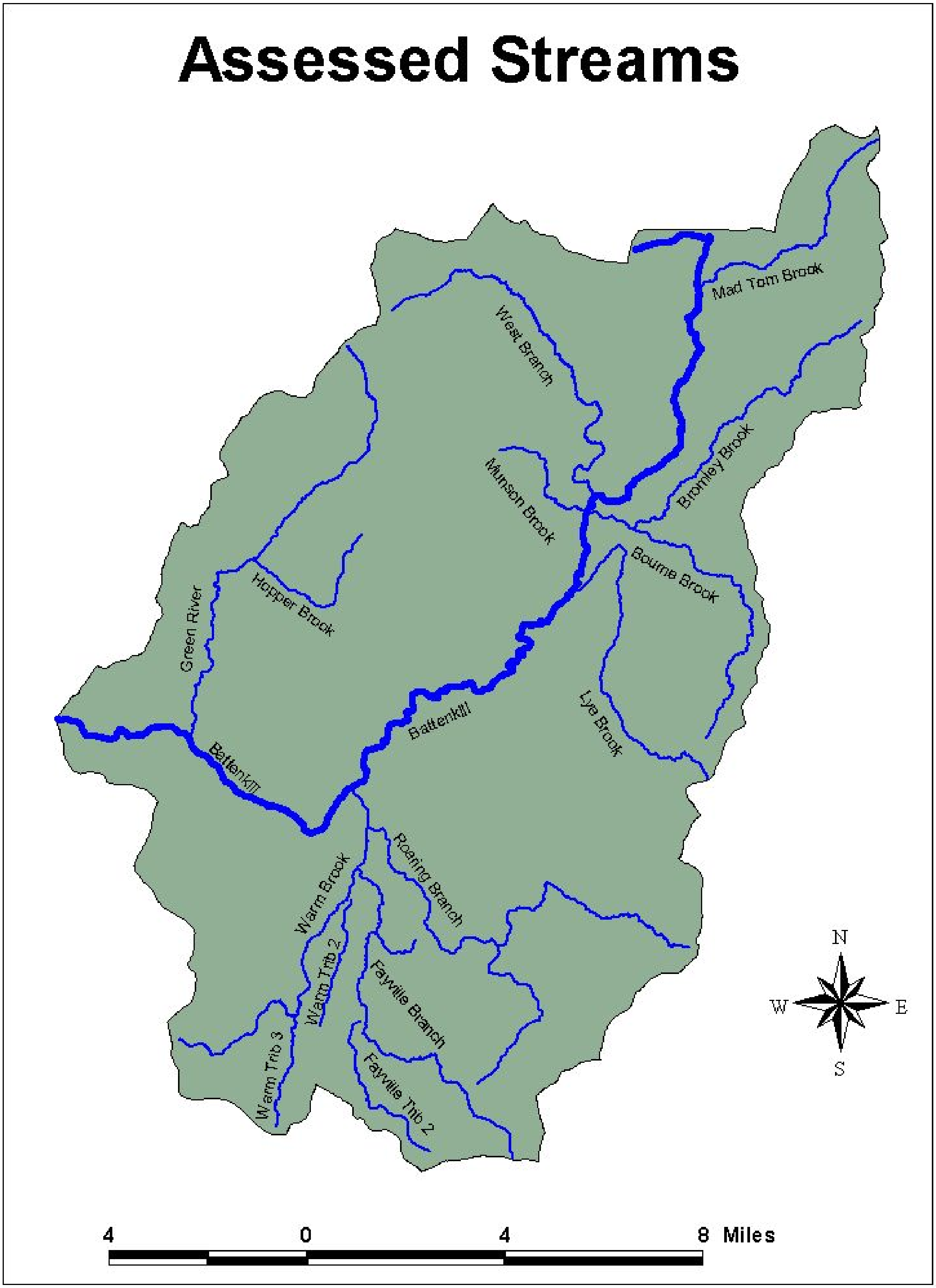

Figure 1 Phase 1 Assessment Streams

Stream Types

Through the assessment of stream and valley characteristics including valley confinement and slope, reference stream types were assigned to each geomorphic reach. Reference stream types are assigned to describe stream channel forms and processes that would exist in the absence of human-related changes to the channel, floodplain, and/or watershed. Phase 1 assessment utilizes a stream type classification system that is based on two classification schemes including Rosgen, 1996 and Montgomery and Buffington, 1996. Figure 2 shows the predicted reference stream type of each assessed reach. A majority of the assessed reaches are low to very low gradient, with broad valleys and flow through alluvial material (Stream Types C and E). Such reaches typically have riffle pool or ripple dune bed forms that play an important role as habitat for aquatic organisms. Habitat in the steeper more confined reaches (Types A and B) is provided by step-pool bed forms that are typical of such reaches. See Report 2 of Appendix A for a complete listing of reference stream and valley types for each reach.

Table 1 Reference Stream Type as determined by Phase 1 assessment.

Stream Type	**Confinement**	**Valley Slope (%)**	**As % of Assessed Reaches**
A	Confined	>4	2
B	Confined or Semi-confined or Narrow	2-4	20
C	Unconfined	<2	62
E	Unconfined	<2	15

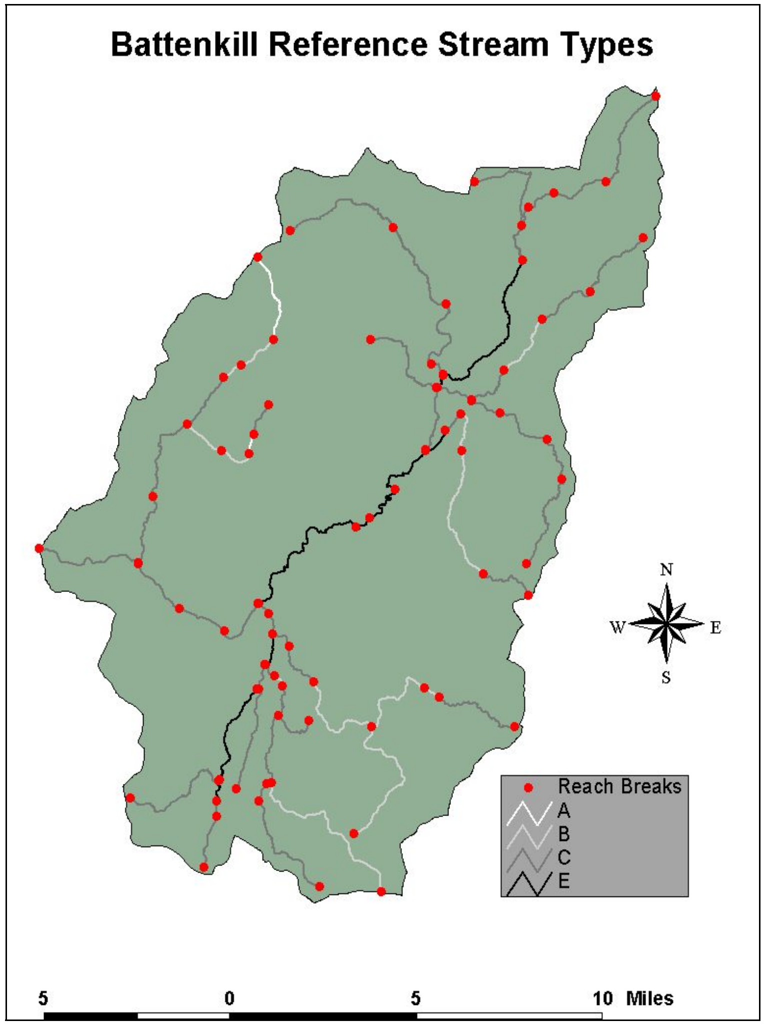

Figure 2 Reference stream types of the Batten Kill watershed as determined by P1 assessment.

Historic Channel Modifications

Channel modifications affect hydraulics and sediment regime, and where extensive the hydrology of a river, often leading to channel instability and adjustment. The conversion of meandering rivers to straight channels diminishes the alternating helical flow patterns that scour pools and build riffles and bars. Poorly designed stream crossing structures may impact hydraulics and sediment transport capacity of a stream resulting in excessive localized sediment deposition and eventual lateral channel migration or widening upstream and channel incision downstream.

Table 2 Percent of assessed stream length found to have been dredged , straightened, windrowed and armored).

Stream Name	Percent of Assessed Stream Modified
Roaring Branch	51
Batten Kill	47
West Branch	23
Green River	19
Warm Trib 2	15
Bourne Brook	13
Lye Brook	7
Mad Tom Brook	5
Fayville Branch	4
Warm Brook	3
Bromley Brook	3
Fayville Trib 1	0
Fayville Trib 2	0
Hopper Brook	0
Munson Brook	0
South Fork Roaring Branch	0
Warm Trib 3	0
Entire Watershed	21

As part of the Phase 1 assessment, channel modifications including: dredging, armoring, straightening, windrowing armoring, stream crossing structures and flow impoundments were evaluated to support prediction of channel condition and adjustment processes. The length of assessed stream channel impacted by dredging, straightening, windrowing and armoring was measured and results are shown in Table 2. The table shows that 21% of all assessed stream length was found to have been modified by these activities. These channel modifications have been concentrated on the Batten Kill main-stem and several tributaries, most notably the Roaring Branch. A reach by reach presentation of the impact rating associated with dredging, straightening and windrowing is given in the database Report 5 in appendix A.

Table 3 Normalized total stream crossing impact scores for those streams with highest crossing impacts.

Stream Name	Total Crossing Impact Normalized by # of Reaches Per Stream
Battenkill	1.00
Warm Trib 2	1.00
West Branch	1.00
Warm Brook	0.75
Fayville Branch	0.60
Green River	0.33
Mad Tom Brook	0.25
Roaring Branch	0.25
Bourne Brook	0.20
Lye Brook	0.20

Reaches were ranked as having high, low, or no impacts associated with stream crossings (i.e. bridges or culverts). A high impact rating indicates that more than 20% of the reach length contains mid channel bars, has an altered alignment or is armored in association with stream crossings. A low impact rating indicates that between 1 and 20% of a reach's length contains those same characteristics. Reaches ranked as highly impacted received a score of two and those ranked as having low impacts received a score of one. Table 3 presents the total impact scores for those streams with the highest crossing impacts due to stream crossing structures normalized by the number of reaches per each stream.

The cumulative impact score for the entire channel modification category of geomorphic stressors, was derived for each reach by summing the dredging, straightening, windrowing, armoring stream crossing, and flow regulation impact scores (shown in Figure 3). Possible channel modification impact scores range from 0 – 10. See Phase 1 Summary of Categorical Impacts of Appendix A for a reach by reach listing of cumulative channel modification impact scores. Categorical channel modification impact scores were then summed for each stream and normalized by the number of reaches per stream. These scores are listed in Table 4. The table shows that the Main stem, the Roaring Branch and the West Branch are the streams most impacted by channel modification impacts.

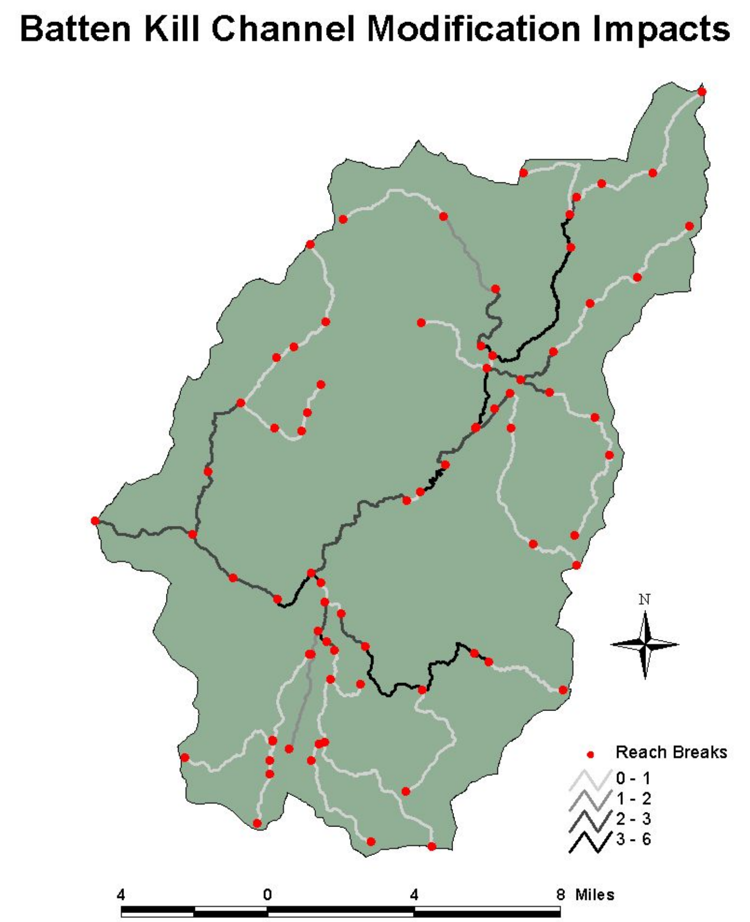

Figure 3 Categorical channel modification impact scores.

Table 4 Categorical channel modification impact score for each stream normalized by the number of reaches per stream.

Stream Name	Total Impact Score Normalized by # of Reaches per Stream
Battenkill	2.85
Roaring Branch	2.38
West Branch	2.25
Warm Trib 2	2.00
Fayville Branch	1.40
Lye Brook	1.40
Warm Brook	1.25
Bourne Brook	1.20
Green River	1.00
Bromley Brook	0.75
Mad Tom Brook	0.75
Fayville Trib 1	0.00
Fayville Trib 2	0.00
Hopper Brook	0.00
Munson Brook	0.00
South Fork Roaring Branch	0.00
Warm Trib 3	0.00

Floodplain Modifications

The ability of a river to dissipate excess energy during flood events relies on the presence of floodplain that flows can access at moderate to high discharges. When a river downcuts through its bed or is confined by infrastructure such as elevated road beds it becomes disconnected from its floodplain and loses the ability to dissipate flood flow energy. As a result the resistance of channel boundaries to erosion can become overwhelmed by the excess erosive energy and channel adjustment ensues. Another potential impact of roads and other infrastructure adjacent to a river is that its presence precludes the ability of the river to adjust to changes in flow and sediment regime or regain an equilibrium slope through lateral channel adjustment.

Table 5 Percent of assessed stream corridor that is modified

Stream Name	% of assessed stream length parallel to berm and road	%of assessed stream length developed
Green River	43	1
Batten Kill	42	3
Roaring Branch	42	2
Bromley Brook	31	1
Hopper Brook	21	1
Bourne Brook	17	1
West Branch	14	5
Mad Tom Brook	12	0
Warm Brook	11	2
Fayville Branch	5	2
Warm Trib 3	4	0
Lye Brook	2	0
Fayville Trib 1	0	0
Fayville Trib 2	0	0
Munson Brook	0	4
South Fork Roaring Branch	0	0
Warm Trib 2	0	0
Entire Watershed	23	2

Changes to lands adjacent to rivers that may affect or indicate the vertical and lateral containment of flood flows were evaluated. Parameters assessed include berms, roads, corridor development, channel migration rates, extent of depositional features and the meander geometry of the channel. For a more complete discussion see Step 6 of the Phase 1 Geomorphic Assessment Handbook (Vermont ANR 2003).

Table 5 shows the percent of assessed channel corridor containing roads, rail, berms and other development for each assessed reach. The table shows that roads and railroads are far more abundant in corridors of the Batten Kill and its tributaries than are other forms of floodplain development. Twenty three percent of all stream length assessed is adjacent to road or rail beds. Five streams including the main-stem are bordered by road, rail or berms for more than 20% of their total length. Report 6 of Appendix A includes a complete listing of road and development impacts for each reach.

Table 6 Percent of assessed reaches with high belt width impact ratings

Stream Name	# of Assessed C and E Type Reaches with High Belt Width Impact Rating	As % of C or E Type Reaches in Stream
Warm Trib 2	1	100
Batten Kill	11	92
Warm Brook	3	92
West Branch	3	75
Bromley Brook	2	75
Green River	3	67
Mad Tom Brook	2	50
Bourne Brook	2	50
Lye Brook	2	50
Roaring Branch	2	40
Fayville Branch	1	33
Total	33	69

Reduced meander belt width and increased wavelength values are often an indication of human modification of the channel and/or floodplain. Ratios of meander belt width and wavelength to the channel width for C and E type reaches were compared to expected values of between 5 and 8 and between 10 and 14 respectively (Leopold, 1994 and Williams, 1986). Table 6 presents the number of assessed C and E type reaches on each stream having high belt width impacts, where a high impact indicates that the belt width is either less than 3 or greater than 10 times the bankfull width of the channel. See Report 6 for a complete listing of belt width and wavelength impacts for each reach.

Table 7 presents the number of assessed C and E type reaches on each stream having high meander wavelength impact ratings where a high impact rating indicates that the wavelength is less than 6 or greater than 16 times the channel width. Planform measurements of the assessed streams indicate that a majority of the unconfined C and E type reaches have belt widths that are lower and wavelengths that are higher than what would be predicted by regime relations for alluvial streams. Nine of the assessed streams have high meander width impacts on over half of the reaches they contain. These results are consistent with the impacts predicted by the channel and floodplain modification scores (shown in Tables 2 through 5).

Table 7 Assessed Reaches with high meander wavelength impact rating

Stream Name	# of Reaches with High Wavelength Impact Rating	As % of Total Reaches in Stream
Warm Trib 2	1	100
Batten Kill	12	92
Warm Brook	3	100
West Branch	3	92
Green River	4	75
Lye Brook	3	75
Bromley Brook	2	50
Mad Tom Brook	2	50
Bourne Brook	2	50
Roaring Branch	2	40
Fayville Branch	1	33
Total	35	73

Cumulative floodplain impact scores were derived by compiling impact scores for berms, roads, corridor development, channel migration rates, extent of depositional features and the meander geometry of the channel. Possible scores, ranging from 0 – 12, are shown in Figure 4. See Phase 1 Summary of Categorical Impacts of Appendix A for a reach by reach listing of cumulative floodplain impact scores. Reaches with the highest cumulative floodplain modification impact scores are listed in Table 8. The table shows that the highest floodplain modification impact scores are on reaches of the Bourne Brook, Main stem, the Roaring Branch, the Green River, Lye Brook, Warm Brook and Mad Tom Brook. Eight of the twelve listed reaches are C and E type streams. Because these streams are low gradient and flow through erodible material they are particularly sensitive to the increases in stream power that result when flood plain capacity is diminished or altogether removed.

Table 8 Assessed reaches with the highest categorical floodplain modification impact scores.

Stream Name	Reach Number	Stream Type	Floodplain Modification Impact Score
Bourne Brook	T4.02	B3	10
Bourne Brook	T4.01	C4	9
Warm Brook	T2S1.01	E4	9
Roaring Branch	T2.01	C3	9
Mad Tom Brook	T7.02	B3	8
Lye Brook	T3.02	B3	8
Fayville Branch	T2S1S1.02	B4	8
Green River	T1.02	C4	8
Batten Kill	M05	E4	8
Batten Kill	M04	C4	8
Batten Kill	M03	C4	8
Batten Kill	M01	C4	8

Table 9 shows the cumulative floodplain modification impact scores for each stream normalized by number of reaches in each stream.

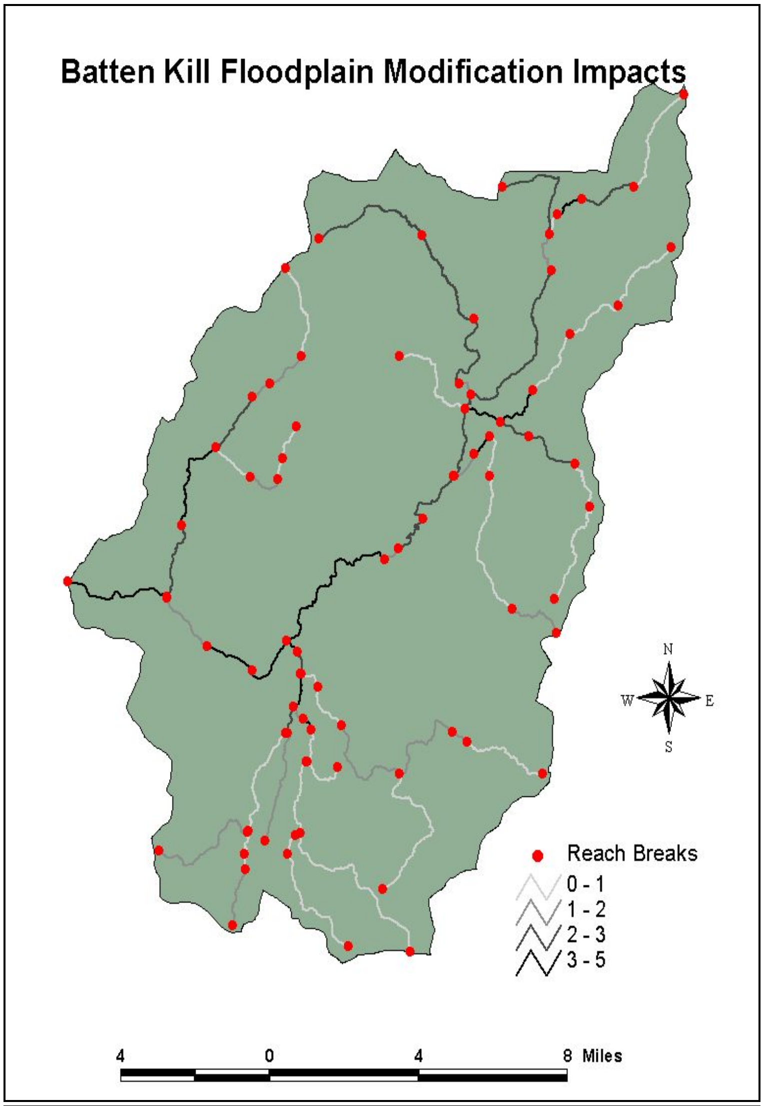

Figure 4 Floodplain modification impact scores.

Table 9 Total floodplain modification impact scores.

Stream Name	Total floodplain modification impact score normalized by number of reaches per stream
Battenkill	6.38
West Branch	6.00
Warm Brook	5.50
Green River	5.17
Warm Trib 2	5.00
Bourne Brook	4.60
Lye Brook	4.40
Mad Tom Brook	4.25
Bromley Brook	4.00
Roaring Branch	3.75
Fayville Branch	3.40
Warm Trib 3	2.67
South Fork Roaring Branch	2.00
Hopper Brook	1.50
Fayville Trib 1	1.00
Munson Brook	1.00
Fayville Trib 2	0.00

Land Use / Land Cover and Riparian Buffer

Watershed land use and riparian vegetative cover influence the quantity and rate of water and sediment run-off that may occur in a reach after storm events. Changes in runoff characteristics may explain observed changes in channel size and shape, why the channel is adjusting, or why the channel may be sensitive to further modifications. For further discussion on this topic refer to Step 4 of the Phase 1 Geomorphic Assessment Handbook (Vermont ANR 2003).

Table 10 Percent Land uses and land cover types for each assessed stream.

Stream Name	% of Watershed Forested	% of Watershed in Urban Lu	% of Watershed in Crop
Munson Brook	64	9	4
Warm Trib 2	75	8	4
West Branch	73	6	4
Warm Trib 3	77	6	1
Warm Brook	81	6	3
Fayville Trib 2	86	5	1
Hopper Brook	90	5	1
Batten Kill	83	4	2
Roaring Branch	86	4	2
Fayville Branch	90	4	1
Bourne Brook	86	3	1
Green River	90	3	1
Fayville Trib 1	95	2	1
Mad Tom Brook	89	2	0
Lye Brook	93	1	1
Bromley Brook	91	0	0
South Fork Roaring Branch	96	0	0

The land use and land cover types for the watershed and corridor of each reach were evaluated. Table 10 shows the percent of various land use and land cover types for each assessed sub-watershed. The table shows that eighty three percent of the entire Batten Kill watershed is forested, four percent is in urban use and 2% is tilled land used for growing crops. See Report 4 of Appendix A for a listing of Land Cover / Land Use impacts for each sub-watershed.

In accordance with Phase 1 protocols, the reaches with greater than 10% of their watershed in urban or crop land uses were rated as being highly impacted. Those reaches with high watershed land use / land cover impact ratings are listed in Table 11. Five of the seven reaches listed are C4 or E4 streams. These low gradient streams with gravel beds are moderately sensitive to changes in hydrology and sediment load that high levels of urban or cropped land uses may cause.

Table 11 Reaches with High Land Use / Land Cover Impact Ratings.

Stream Name	Reach Number	Stream Type
Bourne Brook	T5.01	C3
Warm Brook	T2S1.04	C4
Batten Kill	M13	C4
Warm Brook	T2S1.03	E4
Warm Trib 2	T2S1S2.01	C4
Warm Brook	T2S1.02	C4
West Branch	T6.01	C3

Table 12 shows the percent of all stream bank for each assessed stream having various widths of vegetated riparian buffer. An organization of this data on a reach by reach basis can be found in Report 4 of Appendix A. The table shows that the Batten Kill and it tributaries are relatively well buffered with 79% of all assessed streambank having riparian zones greater than 100 feet wide, and only ten percent of all assessed streambank having riparian buffers that are only 0 to 25 feet wide. The Warm brook, with 43% of its banks having buffers less than 25 feet wide is the only stream that meets the Phase 1 protocol definition of being impacted by lack of riparian buffer. See Report 4 of Appendix A for a listing of riparian impacts for each sub-watershed.

The categorical land cover / land use impact rating scores which are derived by compiling riparian buffer, watershed and corridor land use / land cover impact scores for each reach are shown in Figure 5. Possible impact scores range from 0-6. See Phase 1 Summary of Categorical Impacts of Appendix A for a reach by reach listing of cumulative land use land cover impact scores. The figure shows that the highest impact scores are on reaches of the Warm brook, Munson brook, the Main stem, the Green river and the West Branch.

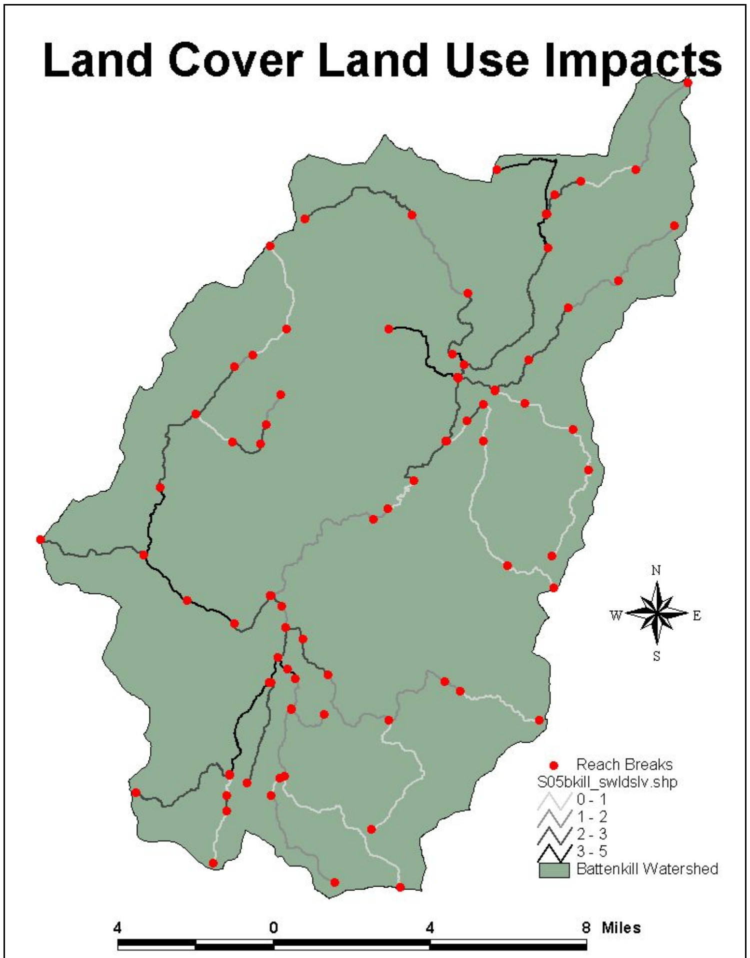

Figure 5 Categorical land cover / land use impact scores for each reach.

Table 12 Percent all stream bank on assessed streams that is buffered by various widths of riparian vegetation, compiled by stream.

Stream name	% of Bank with 0-25ft. Buffer	% of bank with 25-50ft buffer	% of bank with 50-100ft buffer	% of bank with >100ft buffer
Warm Brook	43	4	5	47
West Branch	24	12	10	54
Green River	16	9	12	64
Batten Kill	15	7	18	61
Munson Brook	5	0	0	95
Warm Trib 2	5	0	0	95
Mad Tom Brook	4	0	0	96
Fayville Branch	3	2	2	92
Bourne Brook	3	3	7	88
Lye Brook	2	0	0	98
Roaring Branch	1	1	1	97
Bromley Brook	0	0	0	100
Fayville Trib 1	0	0	0	100
Fayville Trib 2	0	0	0	100
Hopper Brook	0	0	0	100
South Fork Roaring Branch	0	0	0	100
Warm Trib 3	0	0	0	100
Entire Watershed	10	4	7	79

Bank Erosion and Bank Height

Accelerated bank erosion is both a result and cause of channel instability. Higher banks have greater susceptibility to erosion and provide a larger source of sediment than due low banks. High banks in low gradient valley settings can also serve as an indicator of past channel adjustment.

Table 13 Assessed reaches Highly Impacted by erosion and high banks

Stream name	Reach Number
Batten Kill	M04
Batten Kill	M09
Roaring Branch	T2.03
Roaring Branch	T2.07
South Fork Roaring Branch	T2S2.01
Lye Brook	T3.02
Lye Brook	T3.03
Lye Brook	T3.04
Bourne Brook	T4.02

The impact of bank erosion and bank height was evaluated for each reach. Table 13 shows that nine reaches have a high impact rating due to bank erosion / bank height factors, where a high impact indicates that 30% or more of the reach length has eroding banks. Although only nine reaches are highly impacted by combination of erosion and high banks a large percentage of all assessed reaches were rated as having a low impact due to bank erosion, which indicates that upwards of 20% of their banks are eroding. Table 14 lists the number of reaches for each assessed stream that have low bank erosion impact ratings and what that number is as a percent of the total number of reaches on each stream. The table shows that 83% of all reaches assessed were rated as having low bank erosion / bank height impact rating.

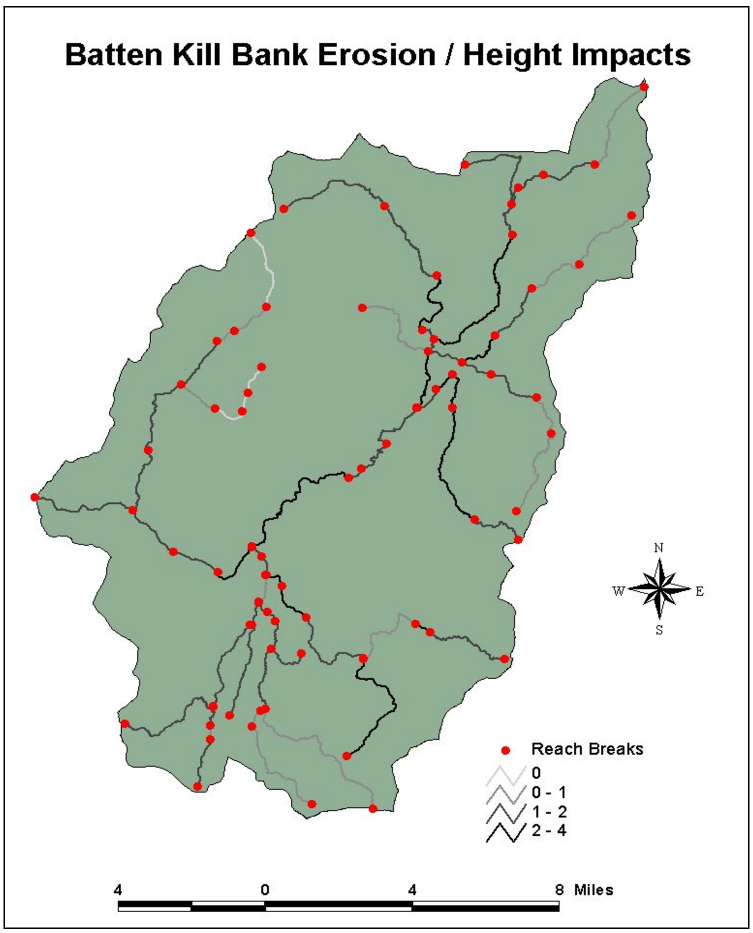

Figure 6 Bank erosion and bank height impact scores

Figure 6 shows the bank erosion / bank height impact scores for each assessed reach. Possible scores range from 0-4. For a complete reach by reach listing of bank erosion / bank height impacts see Report 7 of Appendix A.

Table 14 Percent of all assessed reaches with low bank erosion / bank height impact scores

Stream Name	Number of Reaches With Low Bank Erosion Impact Ratings	As % of Reaches in Stream
Batten Kill	11	85
Bourne Brook	4	80
Bromley Brook	4	100
Fayville Branch	5	100
Fayville Trib 1	1	100
Fayville Trib 2	2	100
Green River	5	83
Hopper Brook	1	25
Lye Brook	2	40
Mad Tom Brook	4	100
Munson Brook	1	100
Roaring Branch	6	75
Warm Brook	4	100
Warm Trib 2	1	100
Warm Trib 3	3	100
West Branch	4	100
Total	58	83

Cumulative Impacts

In order to rank the cumulative level of impact to each reach, the impact scores for the parameters listed in Table 15 were totaled for the reach. The reaches with scores of ten or greater are listed in Table 16 . Total Impact scores for all reaches are shown in **Error! Reference source not found.**. For the purpose of ranking the impacts by stream, the total impact scores were summed and then normalized by the number of reaches contained in each stream (see Table 17). The table shows that those streams with the highest normalized impact scores include the Batten Kill, West Branch, Warm Brook, the Roaring Branch, and Bourne Brook.

Table 15 Parameters included in total impact score.

Step #	Parameter Description
4.1	Watershed Land Cover / Land Use
4.2	Corridor Land Cover / Land Use
4.3	Riparian Buffer Width
5.1	Flow Regulations and Water Withdrawals
5.2	Bridges & Culverts
5.3	Bank Armoring or Revetments
5.4	Channel Modifications
5.5	Dredging and Gravel Mining History
6.1	Berms and Roads
6.2	River Corridor Development
6.3	Depositional Features
6.4	Meander Migration / Channel Avulsion
6.5	Meander Width Ratio
6.6	Wavelength Ratio
7.1	Dominant Bed Form / Material
7.2	Bank Erosion – Relative Magnitude

Table 16 Reaches with impact scores of ten or greater.

Stream name	Reach Number	Total Impact
Batten Kill	M04	21
Bourne Brook	T4.02	20
Roaring Branch	T2.01	19
Batten Kill	M09	18
Batten Kill	M03	17
Bourne Brook	T4.01	17
Batten Kill	M11	17
Fayville Branch	T2S1S1.02	17
Lye Brook	T3.02	17
Green River	T1.01	16
Batten Kill	M01	16
Warm Brook	T2S1.01	16
Green River	T1.02	16
West Branch	T6.02	16
Batten Kill	M05	16
Warm Brook	T2S1.02	15
Fayville Branch	T2S1S1.01	15
Batten Kill	M08	15
Batten Kill	M12	15
West Branch	T6.01	15
Roaring Branch	T2.07	14
Mad Tom Brook	T7.02	13
Batten Kill	M07	13
Bromley Brook	T4S1.01	12
Warm Trib 2	T2S1S2.01	12
Batten Kill	M10	12
West Branch	T6.03	12
Batten Kill	M02	12
Batten Kill	M13	12
Roaring Branch	T2.04	11
West Branch	T6.04	11
Lye Brook	T3.01	11
Green River	T1.03	11
Roaring Branch	T2.05	11
Warm Brook	T2S1.04	10
Roaring Branch	T2.02	10
Roaring Branch	T2.06	10

Table 17 Normalized impact scores for assessed streams (normalized by # of reaches per stream).

Stream Name	Normalized Impact Score
Batten Kill	15
West Branch	14
Warm Brook	13
Warm Trib 2	12
Roaring Branch	11
Bourne Brook	10
Fayville Branch	9
Lye Brook	9
Green River	9
Mad Tom Brook	9
Bromley Brook	6
Munson Brook	6
Warm Trib 3	6
Fayville Trib 1	5
South Fork Roaring Branch	5
Hopper Brook	4
Fayville Trib 2	3

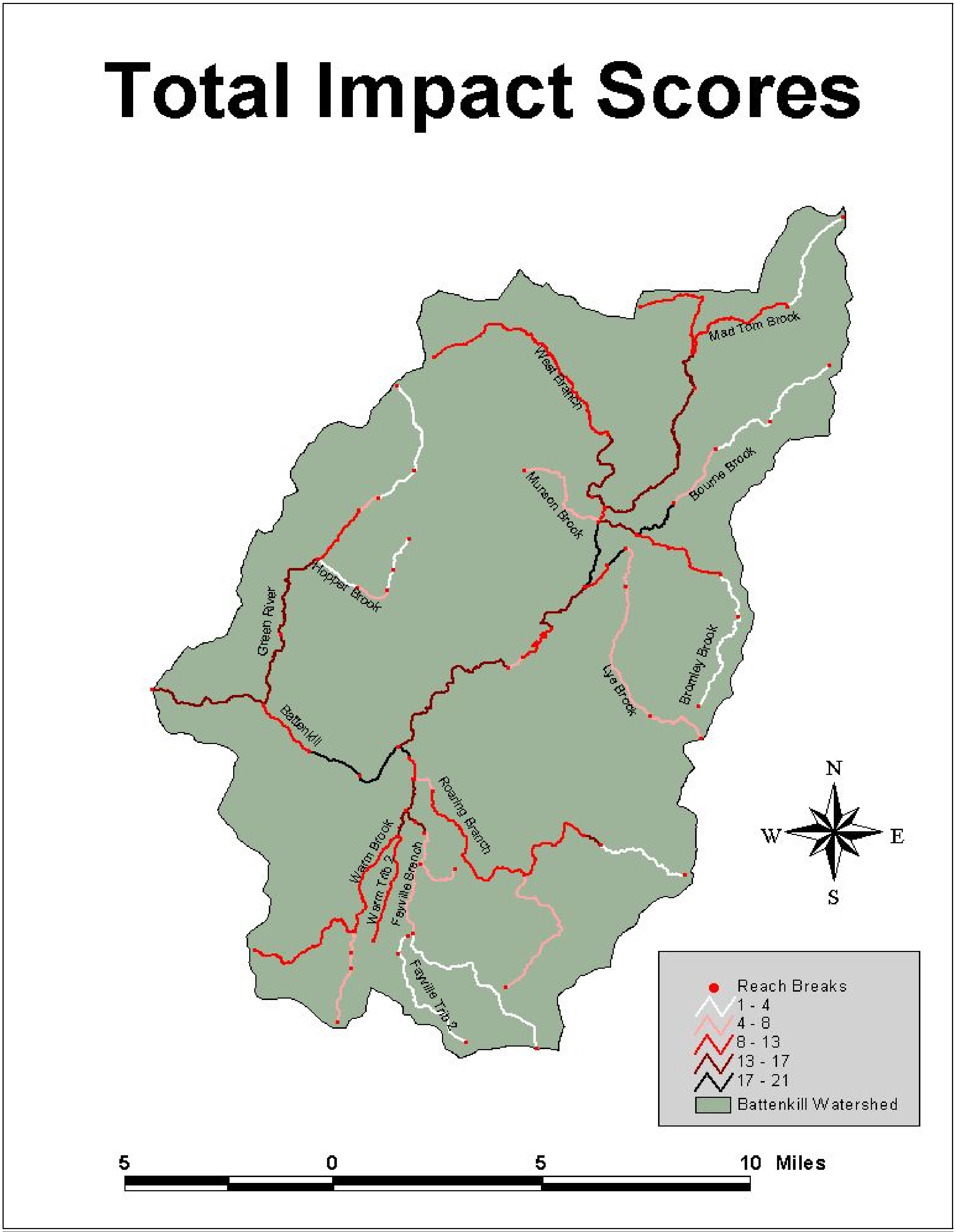

Figure 7 Total impact scores for assessed reaches.

Adjustment Processes

The values for many of the assessed parameters such as floodplain and channel modification can help to predict channel adjustment processes. Channel adjustment typically follows a predictable sequence where channel incision is followed by widening and aggradation. Throughout the entire process planform adjustments may or may not be ongoing. Channel adjustment processes can be damaging to in-stream habitat as spawning gravels and pools become filled with sediment from eroding banks.

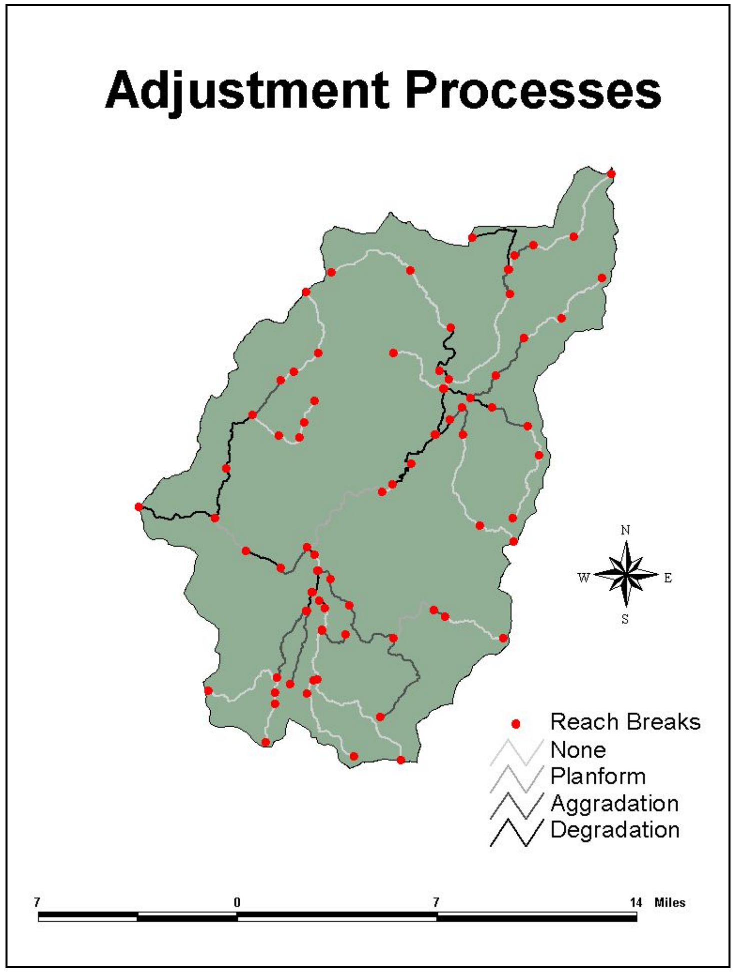

Figure 8 Reach by reach channel adjustment processes indicated by Phase 1 impact ratings

Results from analysis of these parameters are shown in Table 18. The historic channel and land management practices in the Batten Kill watershed are likely to have triggered both vertical and lateral channel adjustment. A Phase 1 report uses a data query to generate scores for each adjustment process. While attempting to factor the sequence of vertical and lateral adjustments in the Channel Evolution Model (Figure 15), the query cannot fully capture important temporal and spatial relationships within the watershed and therefore is not able to accurately predict a current adjustment process. While the Adjustment Process Report predicts, based on highest scores, which adjustment process may be ongoing in the reach (Figure 8), the query typically generates high scores for several adjustment processes given the interrelationship of the stressors that initiate channel evolution. With this in mind, the most salient point of the data presented in Table 15 is that of the assessed reaches, 54% are likely to be experiencing or undergoing some channel adjustment process.

Table 18 Percent of assessed reaches that are likely to be experiencing channel adjustments

Adjustment Process	Percent of Reaches
Degradation	24
Aggradation	24
Planform Adjustment	6
None	46

Photo Documentation of Historic Impacts

Due to a lack of records, historic land use and channel management activities are difficult to precisely document. Photographs are often the only evidence of such activities. In order to document historic land use and channel management activities a search for historic photos of the Batten Kill watershed was conducted.

The photographs collected document far less forest cover, a higher degree of in-channel modification and adjustment than exist today, and the presence of historic floodplain modifications,. A typical impoundment associated with timber mills is shown in Figure 9. Figure 10 documents that channel modifications were implemented as part of post flood mitigation efforts following the floods of 1973 and 1976. Figure 11 and Figure 12 show an example of the type of channel and floodplain modifications that occurred to accommodate transportation development. See additional photos in Appendix B.

Figure 9 Chiselville Bridge over Roaring Branch ca 1880's

Figure 10 Roaring Branch post flood channel management, 1973

Figure 11 Historic photo showing modification of floodplain by raised rail bed.

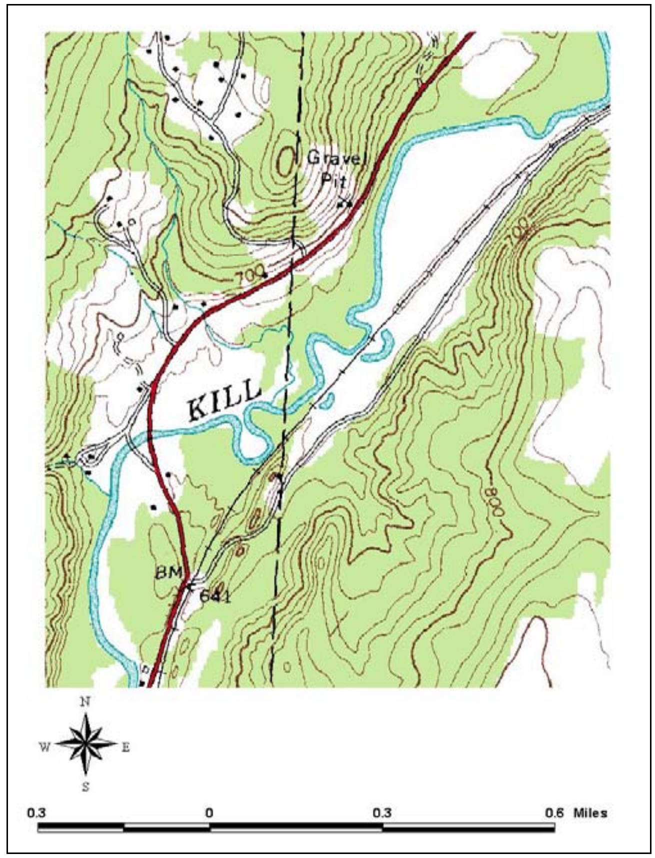

Figure 12 Mainstem of the Batten Kill modified to accommodate rail.

Phase 3 Results

Phase 3 assessments were conducted on eight of the reaches assessed in Phase 1. Phase 3 assessment is a detailed quantitative assessment conducted in the field on a length of river that is typically much shorter than a Phase 1 reach. The Phase 3 assessment measures, in detail: the longitudinal profile, cross section, and gradation of the bed material at a site. The data collected can be used as a verification of the condition predictions made in Phase 1 and determine the stage of channel evolution.

Table 19 lists Phase 3 adjustment process determinations and Phase 1 total impact scores and adjustment predictions for reaches containing Phase 3 assessment sites. The table suggests that Phase 3 results largely verify Phase 1 predictions about whether or not channel adjustment is occurring on a particular reach. Given the inherent limitation of predictions made based on remote sensing data the results in Table 19 are encouraging. The table also shows that two of the three reaches with the lowest Phase 1 impact ratings, MT6.03 and M07 are shown by the Phase 3 results to not be undergoing major channel adjustments at this time.

Table 19 Phase 1 total impact and adjustment prediction and Phase 3 adjustment determination for reaches assessed by Phase 3.

Stream Name	Reach Number	Phs 1 Total Impact	Phs 1 Adjustment Indicated	Phs 3 Adjustment
Main-Stem	**M02**	12	Yes	Widening
Mad Tom	**T6.03**	12	No	None
Main-Stem	**M07**	13	Yes	None
Main-Stem	**M12**	15	Yes	Planform
Green River	**T1.02**	16	Yes	Widening
Bromley Brook	**T4.01**	17	Yes	Incised (due to bermed banks)
Main-Stem	**M09**	18	Yes	Planform
Roaring Branch	**T2.01**	19	Yes	Aggrading

Conclusions

Phase 1 assessment shows that Batten Kill watershed has a long history of land and channel management activity that have had and continue to have an impact on the rivers of the watershed. Alterations to channel dimension and profile on the main stem and tributaries affected sediment transport processes. Historic deforestation and urban, mill dams, and agricultural land uses changed water and sediment runoff patterns. Floodplain function was reduced by development of road and rail beds. Post flood mitigation works, most recently conducted in the 1970's, furthered channel and floodplain modifications.
The results of this history can be witnessed in the form of various channel adjustment processes in the Batten Kill and its tributaries.

Figure 13 Historic Photo of Lye Brook showing incision.

Phase 1 assessment predicts that fifty four percent of assessed streams have gone through or are going through channel adjustment processes. Phase 3 data largely verify for a sub-set of the Phase 1 assessed reaches that channel adjustments are occurring. Because the Phase 1 assessment did not fully capture detailed spatial and temporal aspects of geomorphic stressors and channel response it is not possible to accurately predict the stage of channel evolution or sequence of adjustments that have occurred on each reach. Further investigation into these spatial and temporal aspects (i.e., Phase 2 Assessments) would allow for a more precise recounting of the timing and sequencing of channel adjustment processes. The results of Phase 1 assessment in combination with our understanding of typical channel evolution processes (Figure 16) do enable us to develop a sound hypothesis about timing and sequence of adjustment processes on the Batten Kill main-stem and the assessed tributaries.

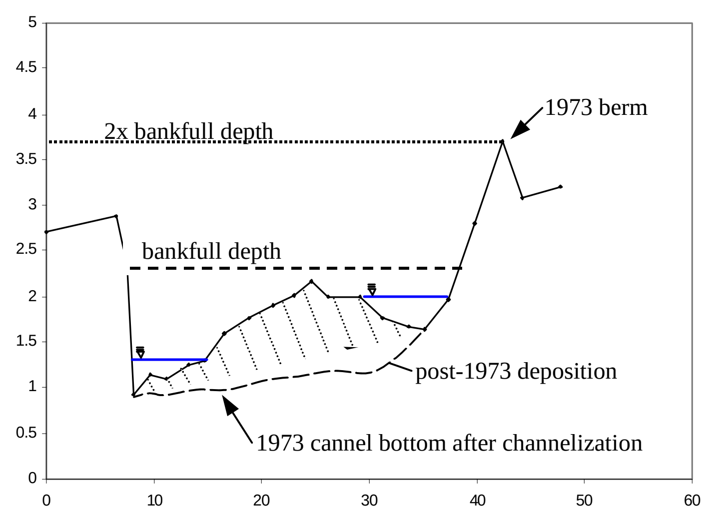

Figure 14 2002 Cross-section of the Roaring Branch where post flood dredging and berming was completed showing 30 years of sediment aggradation in the incised channel (Stage IV of Channel Evolution Process shown in Figure 2).

Channel incision was likely the dominant adjustment process to initially occur following early impacts to the watershed (see Figure 13). As incision progressed, storage of the eroded material took place at lower gradient reaches (see Figure 14 and Figure 15) and a complex series of adjustment processes was set into motion. Channel evolution likely advanced greatly with the energy provided by the floods of the 1970's, however, post flood mitigation works acted to re-establish the incised condition of major tributaries. In the years since the 1970's floods, the occurrence and rate of channel incision is likely to have slowed on most reaches but may still be active at certain locations.

In those reaches where incision has ceased, aggradation and widening may be occurring as the reaches transition into Stage 3 and 4 of the channel evolution model (see Figure 16. Phase 1 and Phase 3 data suggest that the greatest aggradation is occurring at lower gradient reaches of the tributaries, including locations near their mouths and reaches of the main stem above Dufresne Dam. Aggradation is present but not as dramatic on the lower reaches of the main-stem below Reach M09. Main-stem E type reaches do not appear to be aggrading at all. It seems that they are either not receiving excess bed load from the tributaries or they have a enough sediment transport capacity to keep from aggrading.

Figure 15 Aggradation filling entire channel on Lye brook

The lower reaches of the main stem have gone through incision and lack well formed bed features (i.e., having long featureless segments of plane bed channel) but have not widened significantly. The slow rate of widening is likely attributable to a fairly resistant boundary condition, a lack of significant floods discharges and the accompanying gravel deposition necessary to precipitate changes (Field, 2001). The lack of large floods has likely inhibited the transport of excessive bed-loads from the tributaries to the main-stem reducing significant deposition and bar development in the lower reaches. The absence of this process is a likely factor in the slow rates of lateral channel movement. The extent of aggradation in the tributaries may trigger further incision and the movement of bed material that will eventually make its way downstream. When the process is re-energized by floods, significant lateral adjustments will likely become more prevalent.

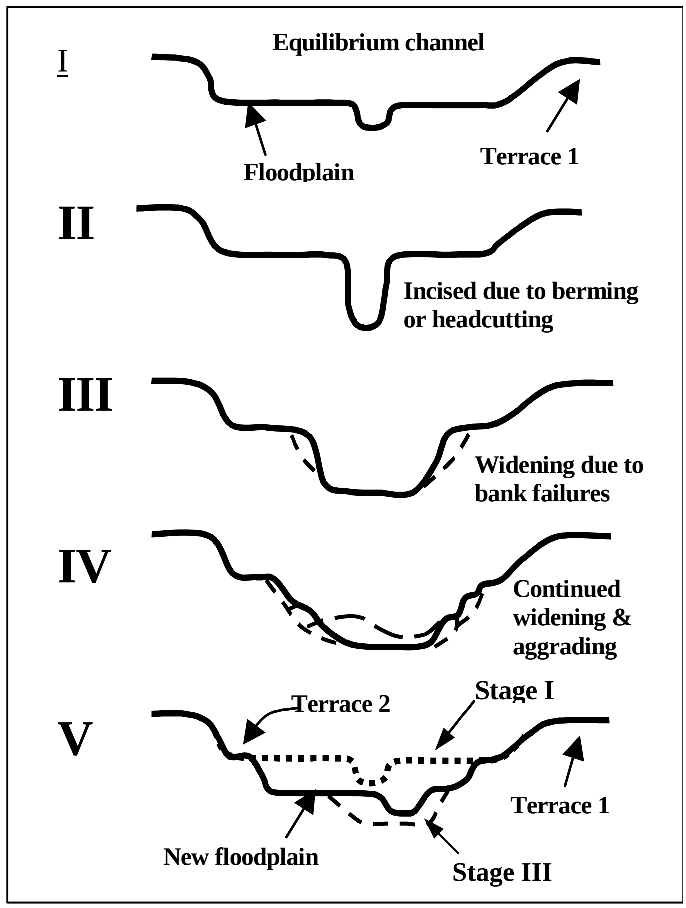

Figure 16 Diagrammatic representation of channel evolution process (Schumm, 1984) ongoing in reaches of the Batten Kill in response to historic watershed, channel, and floodplain modifications.

In equilibrium condition the Batten Kill would provide a variety of habitat types. Table 1 shows that 22% of the reference stream types for assessed reaches are either A or B type streams, 62% are C type streams and 15% are E type streams. The fact that 15% of the Batten Kill rivers is of E type may be noteworthy. This amount of E type stream in a river the size of the Batten Kill is unusual for current-day Vermont watersheds.

A and B type streams provide habitat in the form of step-pool bed forms and bedload deposits that are sorted by size which makes them good spawning and rearing habitats as well as providing pocket holding pools used by adult and juvenile salmonids. Many of these habitat features were mechanically destroyed (by windrowing and berming) during the post flood mitigation works that were carried-out on the major tributaries of the Batten Kill. Habitat in the downstream lower valley reaches may be impacted as an indirect consequence of post-flood tributary channel works. In their reference or equilibrium condition, these unconfined, alluvial streams (C and E types) maintain abundant riffles with clean spawning gravels and deep pools. The predicted and observed downstream aggradation stemming from widening and planform adjustments and the sediment buildup originating from upstream vertical adjustments or bed scour processes are likely to have reduced the quality and quantity of such riffle-pool habitat features.

A Preliminary List of Recommendations

Consistent with Alternatives for River Corridor Management (Vermont DEC, 2003) addressing geomorphic issues in the Batten Kill Watershed may include:

Corridor protection along the Batten Kill to minimize the human encroachments that lead to channel adjustment. This strategy may be orders of magnitude more cost-effective than paying for the restoration of reaches that are undergoing major channel adjustments (Figure 3), particularly if encroachments and conflicts are minimal. Implementation of an effective and comprehensive riparian corridor and watershed protection strategy should involve: 1) fluvial erosion hazard mapping to assist public and private entities in identifying the riparian corridor necessary to accommodate attainment of an equilibrium condition, functioning, river system: and 2) land use incentives necessary to encourage and support municipal implementation of fluvial assessment and river corridor protection strategies. Such strategies will define community and individual land use management or protection mechanisms to minimize conflicts between the physical imperatives of fluvial systems and human investments on the landscape

Management of the Batten Kill and its tributaries to address the everyday conflicts between river dynamics and human investments in the landscape. These day-to-day conflicts arise from an alarming cycle where instability and erosion caused by a flood are followed by spot fix channel management activities that cause streams to unravel further and increase their susceptibility to greater erosion and damage to public and private investments during the next flood. An effective riparian corridor and watershed management strategy must involve technical assistance to agriculture, transportation infrastructure, and flood hazard mitigation projects that focus on treating the cause of fluvial conflicts rather than the symptom of erosion and place a greater emphasis on the long-term maintenance attainment of long term equilibrium condition..

Restoration of geomorphically unbalanced channels to a natural, equilibrium condition is expensive. Nevertheless, tremendous opportunities exist in conjunction with projects designed to restore aquatic ecosystems or mitigate flood hazards. Tributary reaches, dredged and bermed following the 1973 flood (see Figure 4), may provide restoration opportunities, especially should any future flood damage remediation become necessary. Implementation of an effective and comprehensive riparian corridor and watershed restoration strategy will involve demonstration projects based on natural channel design techniques to redefine the public's perception of its relationship with fluvial systems.

An **education program** for the Batten Kill watershed targeted at landowners, municipalities, consultants, watershed associations, public sector scientists and engineers, teachers and students, and other parties to effectively communicate the results of stream geomorphic assessments and build the constituency necessary for protection, management, and restoration projects. Reference the white paper management alternatives approach.

References

Field, J. 2001. A Geomorphical Study of Channel Stability and Physical Habitat Conditions of the Batten Kill in Vermont. Directed by U.S. Forest Service. Green Mountain College, Poultney, VT.

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

Montgomery, D., and J. Buffington. 1997. Channel-reach Morphology in Mountain Drainage Basins. Geological Society of America Bulletin; v. 109; no. 5; pp 596-611.

Rosgen D. 1996. Applied Fluvial Morphology. Wildland Hydrology. Pagosa Springs, CO.

Vermont Agency of Natural Resources. 2003. Vermont Stream Geomorphic Assessment Handbook Phase 1 and Phase 3. Waterbury, VT

Vermont Department of Environmental Conservation. 2003. Alternatives for River Corridor Management. Waterbury, VT

Williams, G.P. 1986. River Meanders and Channel Size. Journal of Hydrology 88:147-164.

Appendices

Appendix B
Historic Photographs

Chiselville Bridge over Roaring Branch ca 1880's

Figure 1 Batten Kill from RR Fowler collection. Note deforested hillside in background.

Figure 2 Looking west across the Demming Meadows ca 1860 at Arlington. Note deforested hillside.

Figure 3   Batten Kill in Arlington with Tibbet's on left. Note deforestation.

Figure 4

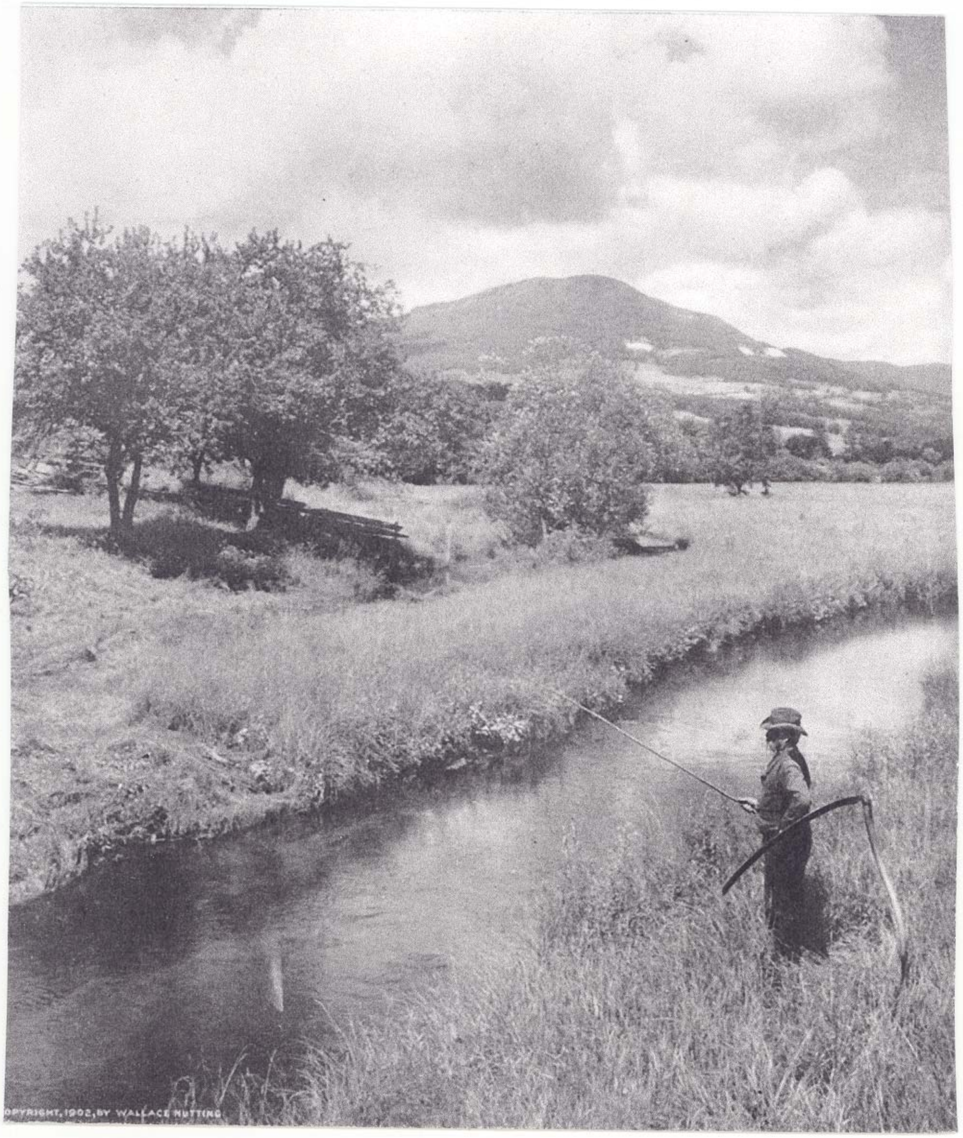

Figure 5 Fishing Batten Kill. Note deforested hillside.

Figure 6 Batten Kill with Mt. Equinox

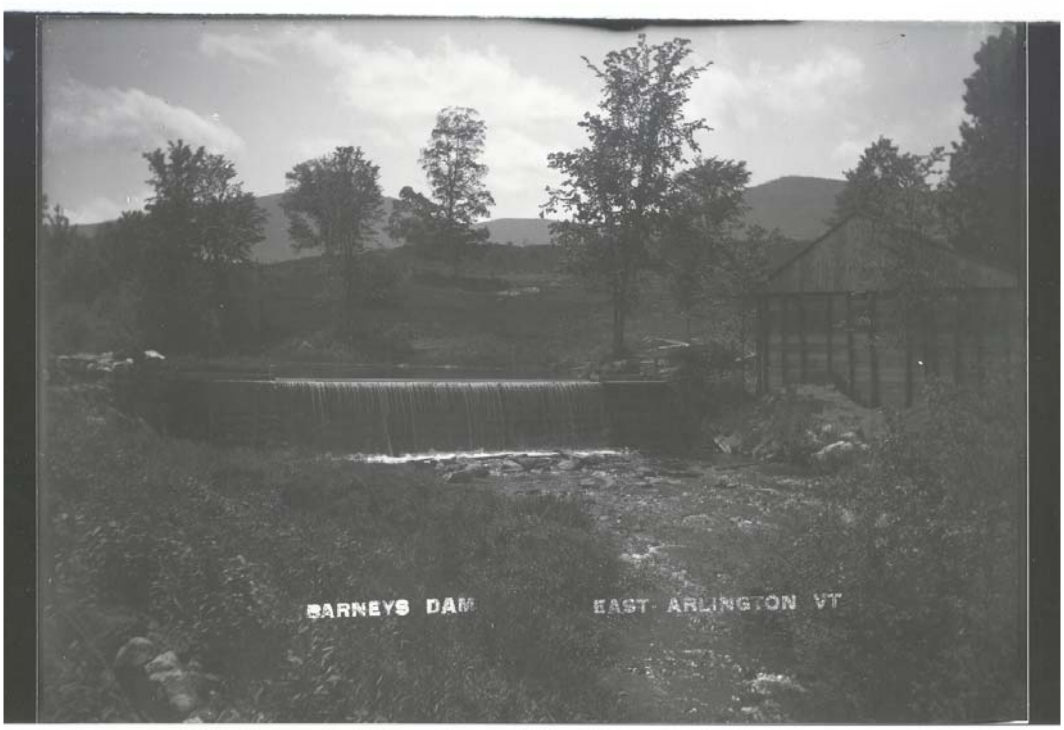

Figure 7 Barney's Dam in E. Arlington. Note impoundment.

Figure 8 Lathrop dam

Figure 9 Upper Falls Peter Branch E. Arlington

Figure 10   Lathrop's Mill Pond looking east with logs before 1907

Figure 11 Kelly Stand-Bronson Job Sunderland-Chiselville marked

Figure 12 Safford's Mill in Sunderland

Figure 13 Batten Kill from RR Fowler collection. Note impact of elevated railbed to floodplain.