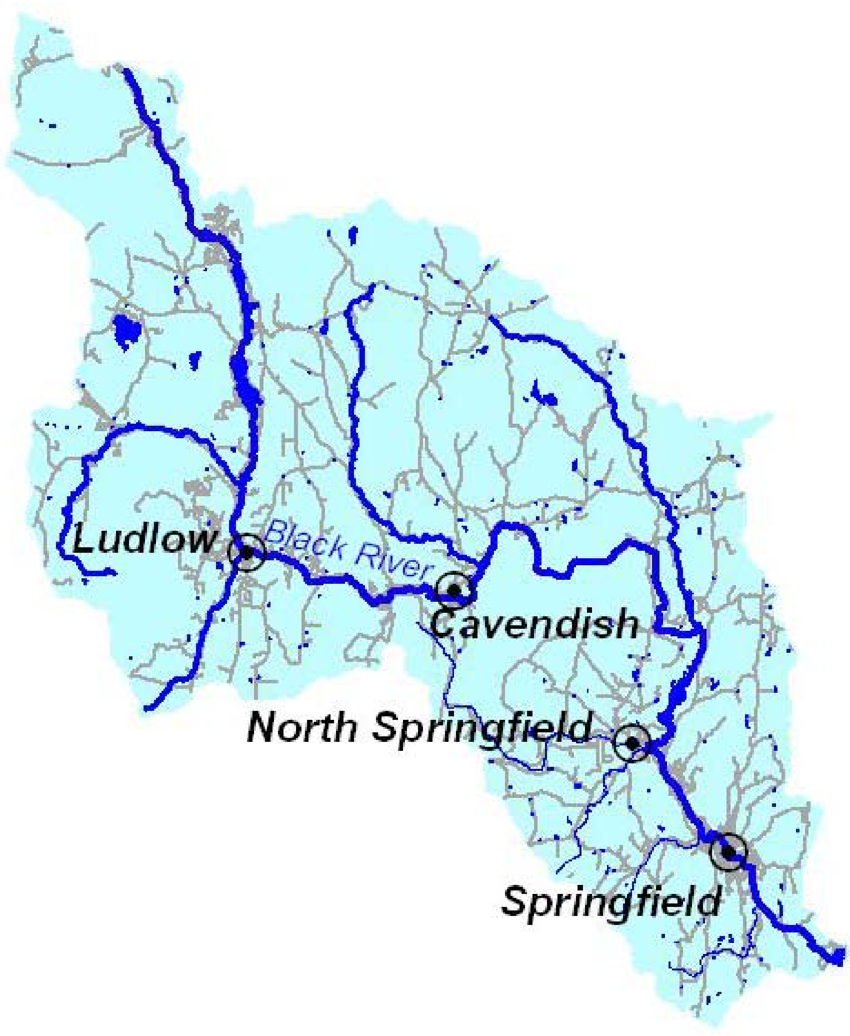
Phase 1 Stream Geomorphic Assessment
Black River Watershed
Windsor & Rutland Counties, Vermont
June 2007 (Revised September 2007)



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EXECUTIVE SUMMARY

A Phase 1 Stream Geomorphic Assessment has been completed for the Black River watershed, tributary to the Connecticut River, in Windsor & Rutland Counties, Vermont. This assessment has been conducted following protocols published by the Vermont Agency of Natural Resources. Work has been completed by South Mountain Research & Consulting Services, of Bristol, VT under contract to the Southern Windsor County Regional Planning Commission. Funding for this study was granted by the VTDEC Water Quality Division under the Clean and Clear program.

Phase 1 data have been compiled and summarized to assist watershed stakeholders in prioritizing select river reaches for further more detailed evaluation in Phase 2 Stream Geomorphic Assessments. Physical characteristics of the Black River watershed have been summarized and landscape and channel modifications have been identified, relying on readily-available resources, including: topographic maps, orthophotographs and historic aerial photographs, soil maps, surficial and bedrock geology maps, and land cover / land use maps. Remote-sensing methods have been supplemented by limited field-based observations of vehicle-accessible points in the watershed.

The Black River watershed is approximately 204 square miles in area and drains portions of Plymouth, Mount Holly, Ludlow, Cavendish, Weathersfield, Springfield, and additional surrounding towns in southeastern Vermont (Rutland and Windsor Counties). Since 1960, flow in this tributary to the Connecticut River has been regulated by an Army Corps of Engineers dam and impoundment at North Springfield, located approximately 9 miles upstream from the confluence with the Connecticut River.

Surface waters of the Black River watershed were delineated into a total of 341 reaches. Reach lengths ranged from approximately 440 feet (0.08 mile) to 12,000 feet (2.3 miles), with an average length of 3,310 feet (0.6 mile). Eight (8) major tributaries of the Black River were identified contributing 10% or more of the upstream watershed area at their point of confluence with the Black River main stem: Tinker Brook, Great Roaring Brook, Patch Brook, and Buffalo Brook draining to the upper main stem in Plymouth; Branch Brook and Jewell Brook draining to the main stem in Ludlow; Twentymile Stream draining the central portion of the watershed and joining the main stem at Whitesville just downstream of Cavendish; and the North Branch of the Black River draining portions of Reading and Weathersfield and joining the Black River main stem just upstream of the North Springfield Lake in Weathersfield.

Each of the delineated 341 reaches of the Black River watershed was assigned a provisional stream type (after Rosgen, 1994 and Montgomery & Buffington, 1997) based on calculated dimensions of valley confinement, gradient, and sinuosity. Twenty (20) of the 341 delineated reaches in the watershed corresponded to natural or artificially-impounded lakes or ponds, and were exempted from stream type classification. Sixty-two percent (63%) of the remaining delineated Black River reaches have valley slopes greater than 2% (generally typed as B or A streams, except where these steep reaches were in a broad valley setting). This relatively high proportion of steep-gradient reaches reflects the influence of underlying bedrock in the Black River watershed. The remaining 37% of reaches were lower-gradient reaches, generally located along the broader valley of the Black River main stem and its major tributaries.

Geology of the delineated reaches was summarized through review of readily available resources including USDA soil survey data, digital bedrock mapping and surficial geologic mapping available through the Vermont Geologic Survey, various regional publications, and limited field observations. Frequent bedrock exposures have influenced the position and profile of the Black River and its tributaries. Bedrock along the valley walls constrains the lateral adjustment of the river channel in select locations and contributes to the low sinuosity and reduced meander belt widths in many reaches. Several channel-spanning exposures of bedrock along the main stem and tributary reaches were catalogued as grade controls. Several of these are notable as recreational and scenic points in the watershed including Buttermilk Falls on the Branch Brook in Ludlow and Cavendish Gorge on the Black River in Cavendish.

Bedrock-controlled upland slopes of the watershed are dominated by a veneer of glacial tills, while more erodible sands, gravels and cobbles of alluvial and glacial outwash origin tend to be concentrated in the bedrock-controlled valleys of the Black River and its major tributaries. Soil types and characteristics including runoff potential and erodibility have been summarized for a defined corridor surrounding each reach and for the upland drainage area to each reach.

Approximately 80% of the Black River watershed is forested, while 4% is in agricultural use and 7% is developed (residential, commercial). While agricultural and developed uses comprise a relatively small percentage of the overall watershed area, these activities tend to be concentrated along the valleys of the Black River and its tributaries. Land cover / land use characteristics have been summarized for a defined corridor surrounding each reach and for the upland drainage area to each reach. Riparian buffer conditions have also been summarized for each reach.

Twenty-nine (29) dams located on 20 reaches have impounded water for purposes of recreation (e.g., Stoughton Pond, Lake Ninevah), flood control (e.g., North Springfield Lake in Springfield and Weathersfield; Jewell Brook Site No. 1 in Ludlow), water supply (e.g., Jewell Brook Site No. 2 in Ludlow), and power generation (e.g., Cavendish dam). Three of these dams sites are breached and no longer in service – Soapstone dam at Perkinsville; Smithville dam in Ludlow; and a historic mill dam on the Jewell Brook in Ludlow.

A subset of the 341 reaches of the Black River watershed was selected for further analysis in Steps 5 through 7 of the Phase 1 protocols, where impact ratings are assigned to reaches based on the identification of channel or watershed-level disturbances to the reaches. This subset is comprised of 108 reaches located along the Black River main stem and four of the Major Tributaries: Branch Brook, Jewell Brook, Twentymile Stream and the North Branch of the Black River. Impact ratings were assigned (following protocols) to these reaches based on land cover and buffer conditions, identification of recorded or potential channel or floodplain disturbances, including flow regulation, bridge / culvert crossings, channelization, dredging, gravel extraction, streambank armoring, berming, floodplain encroachment by roads, railroads, and development, depositional bars, channel migration or avulsions, atypical meander geometries, excessive bank erosion, and ice and debris jam potential. The highest Total Impact Score assigned to a Black River watershed reach was 21 - out of a possible 32.

Twenty-three reaches on the Black River main stem, North Branch, Twentymile Stream and Branch Brook have been recommended for field-based evaluation following Phase 2 Stream Geomorphic Assessment protocols. In general, these reaches tend to have the highest identified provisional impact scores, and thus are expected to demonstrate higher degrees of channel adjustment and sensitivity based on their topographic and geomorphic setting and provisional identification of past and current watershed and channel disturbances. Other considerations for prioritizing these reaches, included proximity to reach(es) with a high impact score, and potential for restoration or conservation projects that could support a reduction in sediment and nutrient mobilization and/or mitigation of fluvial erosion hazards.

1.0 INTRODUCTION

South Mountain Research & Consulting Services (SMRC) of Bristol, Vermont was contracted by the Southern Windsor County Regional Planning Commission (SWCRPC) to complete a Phase 1 Geomorphic Assessment of the Black River Watershed. This tributary to the Connecticut River is approximately 204 square miles in area and drains portions of Rutland and Windsor Counties.

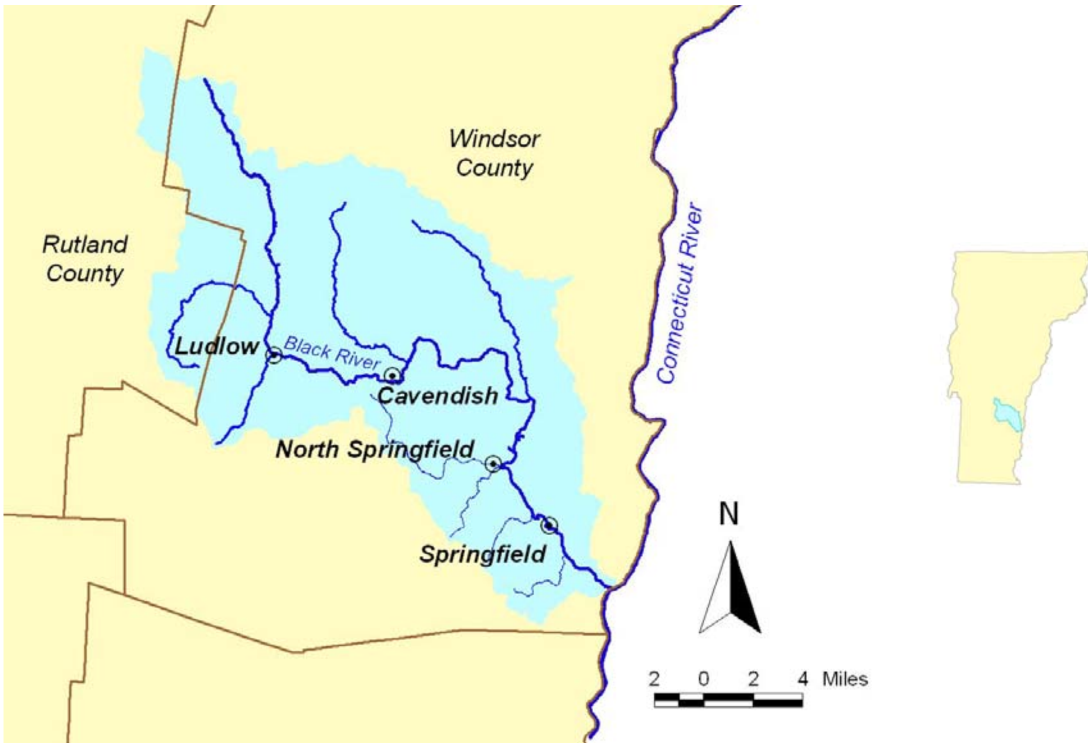

Figure 1. Black River Watershed Location within Windsor & Rutland Counties, Vermont.

The Phase 1 Stream Geomorphic Assessment was completed following protocols published by the VT Agency of Natural Resources (2007). Objectives of the Phase 1 assessment are to:

- Delineate the watershed into sub-watersheds and discrete reaches for further study;
- Identify basic characteristics of each reach including slope, valley confinement, and sinuosity;
- Summarize soils and land cover / land use data by reach and by subwatershed; and
- Document natural and human disturbances to the watershed and to the river channel which, over time, may have resulted in changes to the water and sediment balance in the watershed.

Select reaches are targeted for field-based assessment based on their topographic and geomorphic setting, and impact ratings compiled from noted and inferred channel and floodplain modifications. Reaches assigned higher impact scores from this Phase 1 assessment are those expected to demonstrate higher degrees of channel adjustment and sensitivity based on their topographic setting and provisional identification of past and current watershed and channel disturbances.

2.0 BACKGROUND

2.1 Geographic Setting

Approximately 90% (183 square miles) of the Black River watershed is located in Windsor County, while 10% (21 square miles) is located in Rutland County (see Figure 1). Portions of twelve towns are contained in the watershed (see Figure 2). Five towns occupy a majority of the land area (Table 1): Plymouth, Ludlow, Cavendish, Weathersfield and Springfield.

Figure 2. Location of Black River watershed within towns of Rutland and Windsor Counties, Vermont

Table 1. Towns Located in the Black River watershed (summarized by land area).

Town	Area (sq miles)	Percent of Total Area
Andover	0.2	0.1%
Baltimore	4.8	2.3%
Cavendish	38.1	18.7%
Chester	8.2	4.0%
Ludlow	32.6	16.0%
Mount Holly	16.6	8.1%
Plymouth	25.8	12.7%
Reading	18.5	9.1%
Shrewsbury	4.6	2.2%
Springfield	29.9	14.7%
Weathersfield	23.9	11.7%
West Windsor	0.8	0.4%
Total Area	**203.9**	

2.2 Regional Geologic Setting

The headwaters of the Black River in the western and northwestern extents of the watershed are located in the Southern Green Mountain physiographic province, while the eastern portion of the watershed is located in the Southern Vermont Piedmont (Stewart & MacClintock, 1969; Thompson & Sorenson, 2000).

The Green Mountains and the Vermont Piedmont formed during the Grenville, Taconic and Acadian mountain-building events from more than 1 billion years ago to 380 million years ago. Bedrock underlying the watershed is complexly folded and faulted. The oldest Grenvillian basement rocks (comprised generally of gneisses, schists, and amphibolite) are located at the core of the Green Mountains – for example, Burnt Mountain and the Coolidge Range in the town of Plymouth and South Mountain and Ludlow Mountain in the town of Mount Holly. Grenvillian basement rocks are also exposed at the core of a dome-like structure in the mid-section of the Black River watershed known as the Chester Dome. These basement complex rocks are surrounded and overlain by thrust sheets of younger rocks (generally, schists, quartzites, conglomerates, dolomites). These younger rock sequences were emplaced and subsequently uplifted during later mountain-building episodes. Under compressional forces of these mountain-building events, the rock sequences were folded and faulted (Karabinos & Thompson, 1997; Ratcliffe, Armstrong, & Aleinikoff, 1997; Stewart, 1975).

The topography of the Black River watershed is largely controlled by the characteristics of the underlying bedrock. The western half of the Black River watershed is marked by several north-south trending faults. In the upper extent of the Black River valley from Plymouth to the village of Ludlow, the planform of the river valley - including Amherst Lake, Echo Lake, Lake Rescue and Lake Pauline - is controlled by the Black River fault (Walsh *et al.*, 1994; Walsh & Ratcliffe, 1994). The mid-portion of the Black River main stem from Proctorsville to Springfield flows through a landscape underlain by bedrock of the Chester Dome (Ratcliffe, 1995a; Ratcliffe, 1995b). Bedrock is exposed in the bed and banks of the Black River and tributaries in several locations.

In more recent geologic time (from 20,000 to 13,200 years before present) the landscape of Vermont was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness in many locations. In the vicinity of the Black River watershed, at least two major glacial advances are recorded in surficial deposits: the Bennington advance from the northwest which covered the entire state, and the Shelburne advance from the northeast which is thought to have covered all but the southern extent of Vermont. A later glacial advance from the north-northwest (the Burlington stage) did not extend into the Black River watershed (Stewart & MacClintock, 1969).

As the global climate warmed, the glaciers melted. Kame terrace deposits formed as outwash sediments accumulated along the margins of ice which persisted in the river valleys. In the Black River valley, isolated kame terraces and moraines are preserved along the Black River main stem north of Ludlow (Stewart, 1975; Stewart & MacClintock, 1969).

As the glaciers continued to melt and the glacial front retreated further northward, a large fresh-water lake inundated the Connecticut River valley – commonly referred to as Glacial Lake Hitchcock. This lake was initially impounded behind large deposits of sand and gravel outwash left by the glaciers near Rocky Hill, Connecticut. Later, water levels dropped slowly and were subsequently controlled by a natural spillway carved through glacial till to reach bedrock at New Brittain, Connecticut. At its highest stage, Glacial Lake Hitchcock's shoreline extended from the vicinity of Rocky Hill northward to St. Johnsbury, Vermont. Glacial Lake Hitchcock is thought to have persisted from approximately 15,000 to 12,000 years ago or more. This time period is similar to the occurrence of post-glacial Lake Vermont in the Champlain Valley of northwestern Vermont (Rittenour, T. M., 2007; Koteff & Larsen, 1989; Stewart & MacClintock, 1969; Doll, 1970).

Along the margins of the Connecticut River valley, Glacial Lake Hitchcock waters backed up into tributaries, including the Black River. As sediments were carried by the Black River into Lake Hitchcock, large deltas or fan-like deposits of sediments formed and prograded out into the lake. There is a very large, well-preserved Glacial Lake Hitchcock delta sequence within the Black River valley to the north and east of North Springfield (Stewart & MacClintock, 1969).

2.3 Hydrology

To characterize the hydrology of the Black River watershed, available records were reviewed for a current United States Geological Survey (USGS) gage on the Black River main stem at North Springfield. This gage is located approximately 600 feet upstream of the River Street (Route 106) bridge crossing. The upstream drainage area of the Black River at this point is approximately 158 square miles (USGS, 2007). This is a real-time monitoring station with flow records available on the internet (http://waterdata.usgs.gov/vt/nwis). This gage has been operational since 1930. There are approximately 30 years of gaging records available prior to the 1960 completion of the North Springfield dam, and approximately 47 years of available record for the flow-regulated condition of the river, post-1960.

The USGS (Olson, 2002) has estimated the approximate magnitude of peak flows for the Black River during the 30-year period (pre-1960) unaffected by flow regulation at the North Springfield Reservoir and dam (Table 2).

Table 2. Estimated flood magnitudes on the Black River for unregulated (pre-1960) conditions.

	USGS Stn #	01153000
	USGS Description	Black River at North Springfield, VT
	USGS Period of Record	1930 - 1960; 1973
	Upstream Dr. Area (sq mi)	158
	Geomorphic Reach	M12
Magnitude	**Data Source**	**Discharge (cfs)**
$Q_{1.5}$	*(VTDEC, 2001)*	3,980
Q_2	*(Olson, 2002)*	5,590
Q_5		8,920
Q_{10}		11,600
Q_{25}		15,600
Q_{50}		19,100
Q_{100}		23,000
Q_{500}		34,100

Figure 3 illustrates peak discharge measured at the gage over the full period of available record from 1930 to present. Flood peaks have been essentially eliminated in the 8.7 miles of the Black River downstream of the North Springfield dam since this store-and-release flood control structure was placed into operation circa 1960. Flow regulation has contributed to significant reductions in flood damages for downstream communities along the Black River (Springfield) and the Connecticut River (ACOE, 2007).

At the same time, flow regulation has reduced the frequency and magnitude of low-flow events (see Figure 3; USGS, 2007). The post-impoundment bankfull discharge is now lower than the pre-impoundment bankfull discharge (Magilligan & Nislow, 2001).

The bankfull discharge is considered the dominant discharge of rivers that reworks the channel margins to create the width, depth, slope and planform for optimal conveyance of water and sediments (Wolman & Miller, 1960). Reduced magnitude and frequency of bankfull discharge downstream of impoundments can lead to changes in the cross sectional area of channels, as well as channel slope and planform, and often results in progressive buildup of sediments in the downstream channel (Williams and Wolman, 1984).

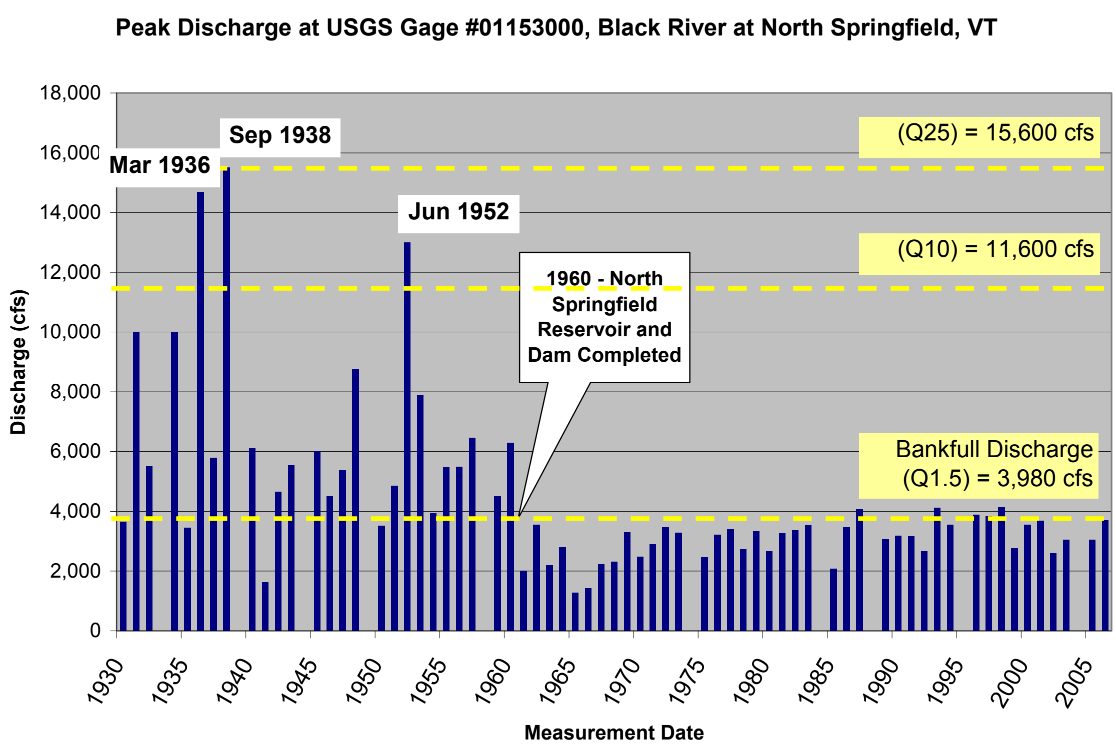

Figure 3. Peak Discharges for USGS Gage Station #01153000, Black River at North Springfield, VT. (Data obtained from USGS on-line surface water data, <http://waterdata.usgs.gov/vt/nwis> annotated with estimated bankfull discharge after VTDEC WQD, 2001, and pre-regulated flood peaks after Olson, 2002).

2.4 Flood History

Flood events can serve as a stressor to river networks, leading to localized or systemic channel adjustments. Online USGS discharge records and readily-available historic data were reviewed to identify flood events of significance in previous decades in the Black River watershed (Table 3). This limited historical review included town history books, state-wide flood publications, an online flood database maintained by the National Climatic Data Center (NCDC), and historic photodocumentation reviewed on the UVM Perkins Landscape Change Program website.

While the North Springfield dam (on the Black River main stem) and the Stoughton Lake dam (on the North Branch Black River) have served to control flood-event impacts on the downstream 9 miles of the Black River main stem since 1960, the upper main stem and tributaries of the Black River have been impacted to varying degrees by floods, before and after construction of the dam.

Table 3. Notable flood events in the Black River watershed.

Flood Date(s)	Description	Data Source
1996, July 13	"dirt roads around Ludlow, Vermont were washed out"; "remnants of Tropical Storm Bertha".	NCDC, 2007
1996, May 14	"flooding and minor washouts on several roads in …Ludlow…Proctorsville"	NCDC, 2007
1987, April	Largest flood since completion of the North Springfield Dam; reservoir was at 82% of its maximum 16.6 billion gallon capacity.	ACOE, 2007
1976, August	Flood impacting Southern Vermont	VTDEC WQD, 1999
1973, June	Damages in Ludlow; Cavendish WWTF destroyed; Flood flows at historic gaging sites on North Branch Black River at Felchville, VT and Black River at Covered Bridge at Weathersfield, VT (each upstream of the North Springfield Lake).	USGS, 1990 VTDEC WQD, 1976 USGS, 2007
1952, June	Estimated 15-year storm (see Figure 3)	USGS, 2007
1938, September	Estimated 25-year storm (see Figure 3)	USGS, 2007
1936, March	Estimated 20-year storm (see Figure 3)	USGS, 2007
1927	Largest flood on record in Vermont. A quarter-mile long channel avulsion bypassing the Cavendish Gorge eroded approximately 2 million tons of sediment down to bedrock leaving a channel 150 feet deep and 600 feet wide. Several buildings and a long section of the road were washed away. In Springfield, mill buildings and several bridges incurred damages.	USGS, 1990 Minsinger, W. E., 2002; Perkins Landscape Change Program images, 2007
1913	Springfield flood damages	Perkins Landscape Change Program images, 2007
1869, October	Tropical storm; Springfield flood damages: washouts of the Springfield Railroad, Gould's Mill dam.	USGS, 1990; Perkins Landscape Change Program images, 2007; Lyndes & Menard, 1927

3.0 ASSESSMENT METHODS

The Phase 1 Stream Geomorphic Assessment of the Black River watershed was completed in accordance with the *Stream Geomorphic Assessment: Phase 1 Handbook (VTANR, 2007)*. The reader is referred to this handbook for details of the assessment methods. Data sources and specific methods utilized in the completion of this Phase 1 assessment are further detailed in relevant Appendices of this report.

Steps 2 through 4 of the Phase 1 were completed using version 4.56 (issued in 2007) of the *Stream Geomorphic Assessment Tool* (SGAT), an extension of ArcView™ 3.x Geographic Information System software (Environmental Systems Research Institute, Inc.). Select features were geo-located using the Feature Indexing Tool of SGAT (v.4.56). Phase 1 data were entered into the VTANR web-based Data Management System (DMS) - https://anrnode.anr.state.vt.us/ssl/sga/index.cfm.

In select locations VTANR Bridge & Culvert Surveys were completed to support this Phase 1. Bridge & Culvert surveys at a total of five (5) structures were budgeted in this project. Phase 1 Bridge & Culvert surveys were completed following protocols contained in Appendix G of the VTANR protocols (April 2007).

The Phase 1 assessment was accomplished through a combination of remote-sensing methods, as well as field-based efforts including "windshield surveys" at vehicle-accessible points within the watershed, limited historical research, and interviews with persons knowledgeable of the watershed. The Black River watershed was delineated into geomorphic reaches using remote sensing methods supported by windshield surveys. Geomorphic reaches were defined based on variation in valley confinement, slope, and sinuosity. Reach delineation, stream typing, and evaluation of soils, geology and land cover / land use were accomplished for all delineated reaches of the watershed.

A subset of the Phase 1 reaches was then selected by the project Steering Committee to proceed through Steps 5 through 7 of Phase 1 where impact ratings are assigned to reaches based on the identification of channel or watershed-level disturbances to the reaches. The 108 short-listed reaches are those comprising the Black River main stem, the North Branch of the Black River, Twentymile Stream, Jewell Brook and Branch Brook.

3.1 Remote-Sensing Resources

Appendices A through D provide index maps to select resources utilized in remote sensing of the Black River watershed, including 1:5000 black and white orthophotographs (1994), USGS topographic maps (various dates), National Agricultural Imagery Program aerial photography (2003), and historic USGS topographic maps (various dates in the late 1800s and early 1900s). Additional resources included the Natural Resources Conservation Service (NRCS) soil mapping for Rutland and Windsor Counties, surficial and bedrock mapping resources available from the Vermont Geological Survey, land cover / land use coverage (1993) and other GIS data available from the Vermont Center for Geographic Information Services (see references, Section 7.0). Select 1939 and 1977 aerial photographs were also reviewed at NRCS offices in White River Junction, Vermont.

3.2 Windshield Survey, Historical Research and Non-SGAT steps

Windshield surveys were conducted in the Black River watershed to:

- orient to the watershed;
- confirm reach break selections;
- field-verify valley wall determinations (where visible); and
- field-verify other Phase 1 assignments that were otherwise based on remote sensing.

Due to constraints of the Phase 1 budget and timeline, only those portions of the river network easily accessed by vehicles or trails were assessed during the windshield surveys. Windshield survey site locations were logged with a Garmin™ eTrex Vista model GPS unit and mapped on a topographic map base; observations were recorded on a GPS / photo log worksheet (see Appendix E). Observations were subsequently reduced to pertinent records of Phase 1, Steps 5, 6, and 7. Windshield survey observations supported the placement of reach breaks (Phase 1 Step 1) and assignment of stream types (Phase 1 Step 2).

For select Phase 1 tasks, relevant local, state, and regional officials and resources were consulted, as defined in the Phase 1 metadata and the references section (7.0) of this report. A variety of published maps, reports, and internet resources were reviewed.

Data development (e.g., Steps 5.3, 6.3, 6.4, 7.1, 7.2) was limited for those reaches (typically headwaters) which were not accessible by road and which were small enough in width to limit visibility when reviewed on 1:24000 topographic coverage and 1:5000 orthophoto images. In these instances, the Phase 1 database indicates "No Data" for several parameters.

3.3 Quality Assurance Review

Precision, accuracy, representativeness completeness, and comparability of data collection were addressed through adherence to the standardized methods outlined in the current version of the VTANR protocols (2007). Data sources consulted for each Phase 1 step were recorded in the metadata section of the online DMS.

Delineation of the Black River watershed into geomorphic reaches, yielded a GIS coverage of reach breaks and "subsheds" outlining the aerial extent of lands draining to each reach. Reach breaks and subsheds were defined through a review of topographic maps and orthophotographs, as well as consultation of soils and geologic mapping. Reach break locations were also field-verified where vehicle-accessible. A Quality Assurance review of the reach break and subshed delineations was performed by River Management Section staff. A record of this QA review and QA response is contained in Appendix F.

During the use of SGAT to support stream typing and accomplish stream corridor generation, a Quality Assurance review of digitized valley walls and meander center lines was performed by River Management Section staff. A record of this QA review and QA response is contained in Appendix F. The QA-approved valley wall delineations and meander center lines were utilized to generate the Phase 1 / Phase 2 stream corridor for delineated reaches following Appendix E of the VTANR protocols (2007).

QA reviews were also performed by River Management Section staff following completion of Phase 1 Step 2 (stream typing) and periodically during development of Phase 1 Steps 3 through 7. Documentation for relevant steps is provided in Appendix F.

4.0 RESULTS

4.1 Reach Delineations

Surface waters of the Black River watershed were delineated into a total of 341 reaches. Reach lengths ranged from approximately 440 feet (0.08 mile) to 12,000 feet (2.3 miles), with an average length of 3,310 feet (0.6 mile). Reaches were delineated on the basis of valley confinement, gradient, and sinuosity, as well as tributary influence (see protocols for further background).

By convention expressed in VTANR protocols, tributaries contributing 10% or more of the upstream watershed area at their point of confluence with the main stem are considered Major Tributaries and are recommended for reach delineation like the main stem. Eight (8) Major Tributaries of the Black River were identified (see Figure 4, Table 4). Each reach was assigned a unique alphanumeric identification (e.g., see Appendix G). Reaches along the main stem of the Black River were prefixed with a capital "M". Major Tributary reaches were denoted with a capital "T"; Minor Tributaries with a capital "S". Further details of the reach-labeling procedure are outlined in VTANR protocols.

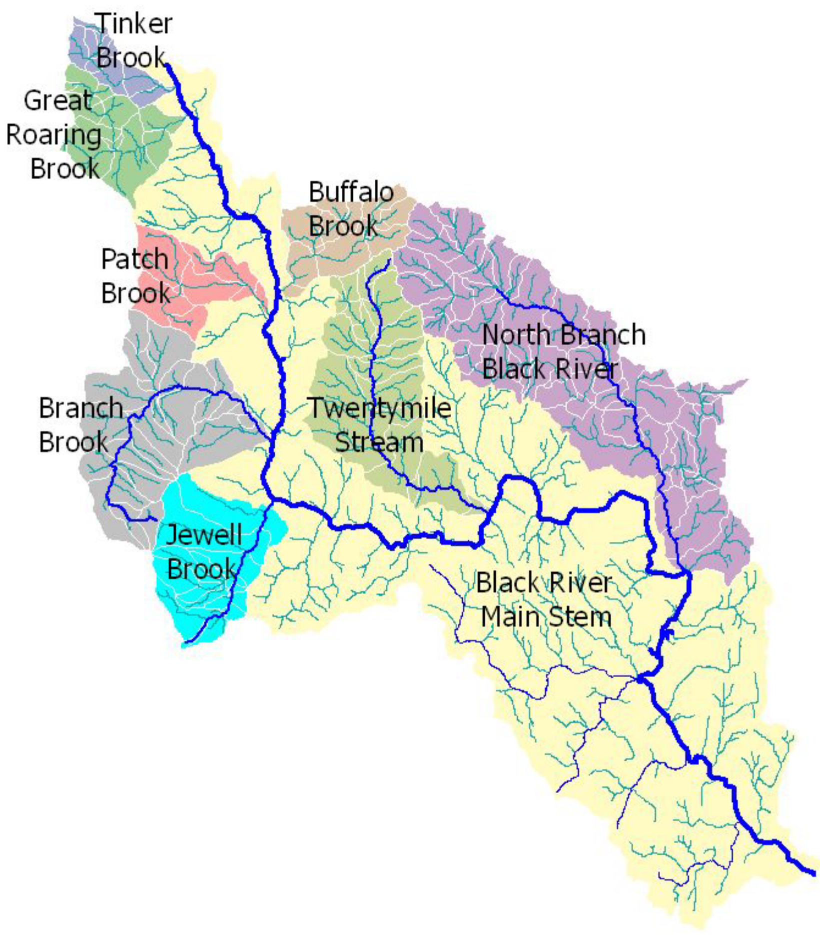

Figure 4. Major Sub-watersheds Delineated in the Black River Watershed

Table 4. Phase 1 Tributary Delineation in the Black River Watershed.

Tributary Identification	Name	Drainage Area (sq mi)	Channel Length (mi)	Number Reaches
M	Black River main stem	204.0	41.4	49
Major Tributaries				
M15T1	North Branch Black River	32.0	14.4	20
M26T2	Twentymile Stream	15.0	10.7	14
M33T3	Jewell Brook	9.4	4.9	10
M36T4	Branch Brook	15.9	9.5	15
M40T5	Patch Brook	5.4	5.0	4
M41T6	Buffalo Brook	5.7	3.4	6
M47T7	Great Roaring Brook	6.0	5.3	11
M48T8	Tinker Brook	2.5	3.9	6

4.2 Reference Stream Typing

Appendix H contains a summary of data for each of the 341 delineated reaches of the Black River watershed, including channel dimensions (length, estimated width, sinuosity, valley confinement), and the total drainage area above each reach break. From these data a preliminary stream type was assigned to each reach, after Rosgen (1994, 1996) and Montgomery-Buffington (1997). Assigned stream types are provisional. Until field-verified, these Phase 1 stream types should not be used to support channel management decisions or restoration designs. Twenty (20) of the 341 delineated reaches in the watershed were exempted from stream type classification. Seventeen (17) of the twenty reaches were classified as impounded by a constructed dam; three (3) reaches were coincident with a natural lake or pond, as further detailed in Table 5 (following page).

Table 6 summarizes the generalized stream type categories utilized to classify reaches; Table 7 defines the valley confinement classification (after protocols - VTANR, 2007). Assignment of stream type in this remote-sensing phase of assessment relied principally on the valley slope. Resolution of the 1:24000 USGS topographic maps was insufficient to quantify the valley width and valley confinement ratio with certainty for a majority of the reaches; measurement of these parameters is particularly limited for steeper-gradient, smaller-drainage-area reaches in the watershed. Therefore, a provisional confinement status was manually assigned to these reaches – inferred from the estimated valley slope. Where possible, field-based observations made during windshield surveys were relied upon to estimate valley confinement and assign stream type. No actual field-based measurements of channel width and valley width were made. Some of the reaches classified with a particular stream type based on the estimated valley slope, may have an estimated confinement ratio outside of the range indicated in Table 6 for the associated valley slope. This situation can result as a consequence of the uncertainty in the valley confinement ratio measurement discussed above. This condition may also result from natural variability in the landscape that does not conform to the classifications indicated in Table 6. For example, tributary reaches near the confluence with the Black River have relatively steep gradients (> 2%), but relatively wide available valley widths (> 6 times the channel width). Furthermore, a valley slope that is steeper than the overall valley confinement would suggest, may contain a short section of locally-steeper gradient (for example, a bedrock waterfall) that influences the overall reach slope. Such an occurrence is typically revealed from a field-based Phase 2 assessment of the reach and would typically involve segmentation of the reach to capture these sections of distinctly different stream type.

Table 5. Black River Watershed Reaches Exempted from Stream Type Classification (and excluded from Steps 2 through 7 of SGAT – except Steps 3.2 and 5.1).

Sub-watershed	Reach Number	Town	Description
Main Stem	M03S1.02	Springfield	Impoundment – Muckross Dam
	M03S1.04	Springfield	Impoundment – Springfield-11 Dam
	M07	Springfield	Impounded by 6 dams
	M10S1.06S1.02	Springfield, Weathersfield	4 in-stream ponds on golf course
	M14	Springfield, Weathersfield	Impoundment - North Springfield Lake
	M14S1.02	Weathersfield	Impoundment – Springfield Reservoir
	M14S1.06	Weathersfield	Pond
	M29	Cavendish	Impounded by Cavendish Gorge Dam
	M38	Ludlow	Impoundment – Reservoir Pond (Lake Pauline)
	M39	Ludlow	Impoundment – Lake Rescue
	M41	Plymouth	Echo Lake
	M41T6.02S1.03	Reading	Reading Pond
	M42	Plymouth	Impoundment – Amherst Lake
	M49	Plymouth	Impoundment – Black Pond
North Branch	M15T1.02	Weathersfield	Impoundment - Stoughton Pond
	M15T1.09S1.06	Cavendish, Reading	Impoundments (2) – Knapp Brook Ponds
Twentymile Stream	M26T2.09S1.04	Plymouth	Impoundment – Colby Pond
Jewell Brook	M33T3.04S1.02	Ludlow	Impoundment – Jewell Brook Site No. 2
	M33T3.07	Ludlow	Impoundment – Jewell Brook Site No. 1
Patch Brook	M40T5.03S1.02	Mount Holly	Impoundment – Lake Ninevah

Table 6. Classification of Reach Types in the Black River watershed (adapted from VTANR protocols, 2007)

Reference Stream Type	Confinement (Valley Type)	Valley Slope	Number of Reaches Exhibiting Valley Slope in the Indicated Range (% of the Total)
A	Narrowly Confined (NC)	Very Steep (> 6.5%)	58 (18%)
A	Confined (NC)	Very Steep (4.0 - 6.5%)	60 (19%)
B	Confined or Semi-confined (NC, SC)	Steep (3.0 - 4.0%)	41 (13%)
B	Confined or Semi-confined or Narrow (NC, SC, NW)	Moderate-Steep (2.0 –3.0%)	42 (13%)
C or E	Unconfined (NW, BD, VB)	Moderate–Gentle (< 2.0%)	120 (37%)
D	Unconfined (NW, BD, VB)	Moderate–Gentle (< 4.0%)	0 (0%)

Table 7. Classification of Valley Confinement, where confinement ratio is expressed as the estimated valley width / channel width (excerpted from VTANR protocols, 2007)

Valley Type	Confinement	Confinement Ratio
NC	Narrowly Confined	≥ 1 and < 2
SC	Semi-confined	≥ 2 and < 4
NW	Narrow	≥ 4 and < 6
BD	Broad	≥ 6 and < 10
VB	Very Broad	≥ 10

As noted in Table 6, sixty-three percent (63%) of the delineated Black River reaches have valley slopes greater than 2%. This relatively high proportion of steep-gradient reaches reflects the influence of underlying bedrock in the Black River watershed.

None of the delineated Black River watershed reaches was classified as an E stream type. Following Phase 1 protocols, the E stream type is assigned only to reaches with an estimated sinuosity of 1.5 or greater. None of the measured sinuosity values exceeded 1.46 (see App. H).

Although several reaches were identified as being located in a potential alluvial fan setting (see Section 4.3.1), the current reference stream type in these settings was conservatively set at C, pending field-based evaluation. Alluvial fan formation is thought to have been more active during post-glacial times (thousands of years before present), and then possibly was rejuvenated following wide-spread deforestation in the 1800s (Bierman, *et al.*, 1997). With subsequent reforestation, sedimentation rates in tributaries flowing to these depositional features are theorized to have declined. Determination of the true "reference" state of the channel, under the present climate and hydrologic regime at these potential alluvial fans and points of substantial slope reduction, would require further detailed field-based study.

4.3 Watershed Geology and Soils

4.3.1 Alluvial Fans / Points of Slope Reduction

Under Step 3 of the Phase 1 Stream Geomorphic Assessment, the delineated stream channels were reviewed to identify locations of notable reduction in channel gradient. Often this slope reduction is associated with an alluvial fan feature, as suggested by topographic contour patterns. As the channel transitions from a steeper-gradient, more narrowly-confined valley setting to a broader valley setting of lower gradient, flow velocities decrease, the sediment transport capacity of the channel is reduced, and sediment is deposited.

Given the change in flow dynamics and the associated sediment accumulation at these points of slope reduction, the channel is prone to dynamic lateral and vertical adjustments. The channel can become braided, and avulsions are common. Sensitivity of these locations can be enhanced by the removal of forested buffers, by encroachment of transportation networks and other developed or agricultural land uses, and by land use or channel activities in upstream reaches that result in increased flows or sediment loading to the channel. Often, where investments have been made along the river at these points of slope reduction, channel management activities have been undertaken to constrain the natural tendencies of the channel – including channelization, windrowing, berming, armoring and gravel extraction.

Points of significant slope reduction, including potential alluvial fan sites, have been indexed for the Phase 1 delineated waters of the Black River watershed, as summarized in Appendix I. These are locations which would benefit from further field assessment to characterize their condition and sensitivity.

4.3.2 Grade Controls

Delineated reaches of the Black River and tributary channels were reviewed to identify the presence of channel-spanning bedrock or constructed dams and weirs. These features can serve as a vertical grade control in the river channel, preventing possible downward erosion of the channel in response to regional or local stressors. These grade control structures are also notable as potential obstructions to upstream fish passage. Available resources and windshield surveys did not reveal the presence of constructed weirs. Occurrences of bedrock and dams are discussed in the sections below.

Bedrock

Frequent bedrock exposures have influenced the position and profile of the Black River and its tributaries. Bedrock along the valley walls constrains the lateral adjustment of the river channel in select locations and contributes to the low sinuosity of many reaches. Notable examples are sections of the upper Black River main stem in Plymouth upstream of Amherst Lake (reach M45), and lower reaches of the main stem in Springfield where bedrock cliffs can be viewed from Route 11 (reaches M02, M05).

Several channel-spanning exposures of bedrock along the delineated main stem and tributary reaches were catalogued as grade controls, as recorded in Appendix I, and illustrated in Figure 5. Following protocols, bedrock was classified as either a **waterfall** ("bedrock that forms a vertical, or near vertical, drop in the channel bed") or **ledge** (lower-profile drop in channel-spanning bedrock). Conservatively, bedrock exposures were classified as ledge unless field observations or other data sources confirmed the status as waterfall. Resources reviewed to determine locations of channel-spanning bedrock grade controls included:

- digital bedrock mapping data (Ratcliffe, 1996, 1995a 1995b; Walsh *et al*., 1996, 1994; Walsh & Ratcliffe, 1994);
- field observations during windshield surveys;
- orthophotographs, aerial photographs, and topographic maps (current and historic);
- The Waterfalls, Cascades and Gorges of Vermont (Jenkins & Zika, 1985); and
- Waterfalls of the Northeastern United States website (http://www.northeastwaterfalls.com)

Figure 5. Locations of channel-spanning bedrock grade controls in Black River watershed (on Phase 1 delineated reaches only).

Prominent examples of channel-spanning bedrock in the Black River watershed include:

- Buttermilk Falls on Branch Brook in Ludlow (reach M36T4.05; Figure 6);

Figure 6. One of three main tiers which comprise the Buttermilk Falls on Branch Brook in the town of Ludlow (reach M36T4.05).

- Bedrock falls at Felchville (town of Reading) on the North Branch of the Black River (reach M15T1.11);
- Amsden Falls on the North Branch of the Black River (reach M15T1.04) in Amsden (town of Weathersfield), the site of historic saw mills and a grist mill (Beers, 1869);
- Cavendish Gorge on the Black River (reach M28) at Cavendish, site of the CVPS power generation facility and dam (reach M29);
- Upper Falls at Perkinsville (town of Weathersfield) on the Black River (M18), the site of a historic dam and mills (Beers, 1869; USGS, 1929); and
- Comtu Falls at Springfield on the Black River (reach M07) – a series of bedrock falls through downtown Springfield, which has been the site of multiple, historic, power generation dams.

Dams

Several dams were indexed along the delineated main stem and tributary reaches, as summarized in Table 8, illustrated in Figure 7, and recorded in Appendix I. Most are in service for purposes of recreation, flood control, hydropower generation, or water supply (see Table 8). A few are breached and no longer in service. Pending field confirmation, these breached structures are inferred to have retained enough of the remnant structure to serve as a vertical grade control, and have been indexed as such.

Resources reviewed to determine locations of dams included:

- Vermont Dam Inventory (EmergencyOther_DAMS coverage obtained from VCGI);
- A listing of dams obtained 27 June 2006 from Brian Fitzgerald, VTDEC Dam Safety & Hydrology Section;
- field observations during windshield surveys;
- orthophotographs, aerial photographs, and topographic maps (current and historic);
- Sanborn Fire Insurance Maps for Ludlow - 1894, 1905, 1921, 1928;
- 1869 Beers Atlas for Windsor County; 1869 Beers Atlas for Rutland County;
- Historic photographs maintained on Perkins Landscape Change program website.

Construction dates for these dams (presented in Table 8) were obtained from the Vermont Dam Inventory; typically these are 20th century dates. However, based on review of the 1869 Beers Atlas, historic topographic maps, and town history books (Lyndes & Menard, 1927; Harris, 1949), it is apparent that dams were present at some of these locations decades earlier than the date of construction presented in Table 8. In these cases, the current dam represents a rehabilitated or replacement structure.

At several additional locations in the watershed, historic dams associated with saw mill, grist mill and other industrial operations were noted on the 1869 Beers Atlas for Windsor County, 1869 Beers Atlas for Rutland County, and the historic Sanborn Insurance Maps (for Ludlow). Often, these historic dams were constructed at bedrock falls, such as the locations identified above. Presence of a dam at many of these historic sites could not be confirmed by review of orthophotographs or visual observation during windshield surveys. The historic presence of these dams was noted for relevant reaches under Step 7 of the Phase 1 (Comments) in Appendix N (for those short-listed reaches which proceeded through Steps 5 - 7). It is expected that a majority of these historic dams, especially those associated with small mill operations in the headwater streams, were previously dismantled or washed away in major floods, such as those that impacted the region in 1830, 1869, 1913, and 1927 (see Section 2.4). While these structures no longer impound the Black River and its tributaries, knowledge of their historic presence aids in characterizing the overall sensitivity of the river reaches and their degree of departure from reference condition, where applicable. The present condition and adjustment processes may still be influenced by the disruption of fluvial and sediment transport processes imparted by these historic impoundments.

Table 8. Dams Identified as Grade Controls on the 341 Delineated Reaches of the Black River watershed.

Tributary Name	Reach (Town)	Dam Name	Associated Impoundment	Owner	Date Installed (1)	Dam Site Noted on Historic Maps	Purpose - current (original) (1) (2)	Present Status
Black River main stem	M49 (Plymouth)	Black Pond (1)	Black Pond	Private (1)	1897		R (R)	In Use
	M42 (Plymouth)	Amherst Lake (1)	Amherst Lake	Lakeside Associates, Inc. (1)	1950	1869 Beers (saw mill, grist mill)	R	In Use
	M39 (Ludlow)	Lake Rescue (1)	Lake Rescue	Town of Ludlow (1)	1978		R, S (R)	In Use
	M38 (Ludlow)	Reservoir Pond (1)	Reservoir Pond (Lake Pauline)	Town of Ludlow (1)	1920		R (H)	In Use
	M32 (Ludlow)	Smithville (1)	None	N/A (1)	N/A	1869 Beers (saw mill); 1929 topo, 1905 Sanborn		Breached
	M29 (Cavendish)	Cavendish (1)	None	Central VT Public Service (1)	1907	1869 Beers (dam, woolen mill)	H	In Use
	M18 (Weathersfield)	Soapstone (1) (Perkinsville)	None	N/A (1)	N/A	1869 Beers (mills); 1929 topo (dam)		Breached
	M14 (Springfield / Weathersfield)	North Springfield (1)	North Springfield Lake	US Army Corps of Engin (1)	1960		C, R (C)	In Use
	M07 (Springfield)	Fellows (1)	None	Westinghouse Electric (1)	1900	1869 Beers (dam)	O	In Use
	M07 (Springfield)	Gilman (1)	None	Factory Falls Inc. (1)	1913		- (H)	In Use
	M07 (Springfield)	Slack (upper) (1)	None	N/A (1)	N/A	1869 Beers (dam)		In Use
	M07 (Springfield)	Comtu Falls (1)	None	Jeff Wallin (1)	1952	1869 Beers (dam)		In Use
	M07 (Springfield)	Slack (lower) (1)	None	Scott Nielson (1)	N/A	1869 Beers (dam)		In Use
	M07 (Springfield)	Lovejoy (1)	None	Westinghouse Electric (1)	1912	1869 Beers (dam)		In Use
North Branch Black River	M15T1.02 (Weathersfield)	Stoughton Pond (1)	Stoughton Pond	US Army Corps of Engin (1)	1960		R	In Use
Jewell Brook	M33T3.07 (Ludlow)	Jewell Brook Site No. 1 (1)	Unnamed	Town of Ludlow (1)	1969		- (C)	In Use
	M33T3.02 (Ludlow)	Historic mill dam	None	unknown		1921 Sanborn	- (C)	Breached

Table 8 (cont). Dams Identified as Grade Controls on the 341 Delineated Reaches of the Black River watershed.

Tributary Name	Reach (Town)	Dam Name	Associated Impoundment	Owner	Date Installed (1)	Dam Site Noted on Historic Maps	Purpose - current (original) (1) (2)	Present Status
Unnamed trib to Black River	M03S1.02 (Springfield)	Muckross Dam (1)	Unnamed	Edgar May (1)	1900	1957 topo map	R (R)	In Use
Unnamed trib to Black River	M03S1.04 (Springfield)	Springfield-11 Dam (1)	Unnamed	N/A (1)	N/A	1957 topo map	N/A	In Use
Unnamed trib to Carley Book	M10S1.06S1.02 (Weathersfield)	*Not Identified (1)*	Unnamed - 4 ponds on golf course	unknown	N/A		N/A	In Use
Unnamed trib to Black River	M14S1.02 (Weathersfield)	Springfield Reservoir (1)	Springfield Reservoir	Town of Springfield (1)	1903	1957 topo map	S, O (S)	Not In Use
Knapp Brook	M15T1.09S1.06 (Cavendish)	Knapp Brook Site No. 1 (1)	Knapp Brook Pond	State of VT - DFW (1)	1958		R (R)	In Use
	M15T1.09S1.06 (Cavendish)	Knapp Brook Site No. 2 (1)	Knapp Brook Pond	State of VT - DFW (1)	1961		R (R)	In Use
Unnamed trib to Twentymile Stream	M26T2.09S1.04 (Plymouth)	Colby Pond (1)	Colby Pond	State of VT - DFW (1)	1959		R (R)	In Use
Great Brook, trib to Jewell Brook	M33T3.04S1.02 (Ludlow)	Jewell Brook Site No. 2 (1)	Unnamed	Town of Ludlow (1)	1969		C (C)	In Use
Unnamed trib to Patch Brook	M40T5.03S1.02 (Mount Holly)	Lake Ninevah (1)	Lake Ninevah	Wilderness Corporation (1)	1930	1869 Beers, 1893 topo (Patch's Pond)	R (H)	In Use

***Data Sources**: (1) Vermont Dam Inventory (EmergencyOther_DAMS) obtained from Vermont Center for Geographic Information on 6/27/2006. Publication date: 3/7/2005. (2) USACOE National Inventory of Dams: Methodology, Version 3.0, July 2005: C = Flood Control; R = Recreation; H = Hydroelectric; S = Water Supply; O = Other* ***Notes**: N/A = Not Available*

Figure 7. Locations of Dams (either in use or breached) indexed as grade controls under Step 3.1 in the Black River Watershed (on 341 Phase 1 delineated reaches only).

4.3.3 Geologic Materials

Surficial geologic materials were summarized for the Black River watershed through analysis of soil survey mapping data available from USDA Natural Resources Conservation Service. GIS coverage of soil data (available through VCGI) was analyzed and compiled using SGAT software to summarize by geologic parent material. Data are presented in Appendix I. Soils are illustrated by parent material for the Black River watershed in Figure 8. Bedrock-controlled upland slopes are dominated by a veneer of glacial tills, while more erodible sands, gravels and cobbles of alluvial and glacial outwash origin tend to be concentrated in the bedrock-controlled valleys of the Black River and its major tributaries. The distribution of soil parent materials illustrated in Figure 8 is largely consistent with the surficial geologic mapping available for the watershed (Stewart & MacClintock, 1969; Doll, 1970).

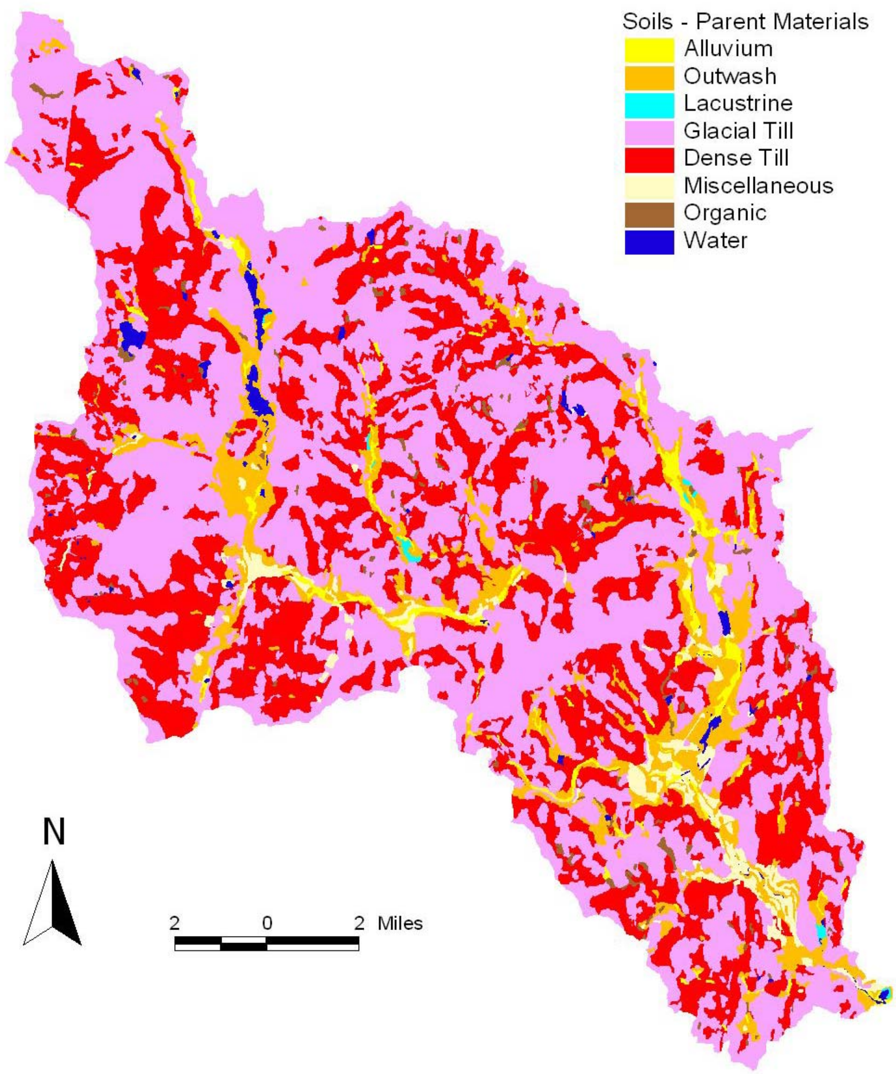

Figure 8. Generalized map of soil parent material in the Black River watershed (NRCS Soil Survey mapping).

4.3.4 Valley Side Slopes

Valley side slopes were estimated and categorized for each of the Phase 1 delineated reaches, through review of topographic maps. Results are recorded in Appendix I. The high percentage of reaches with valley side slopes in the very steep (16 to 25%) and extremely steep (> 25%) categories reflects the mountainous, bedrock-controlled nature of the watershed topography.

4.3.5 Soil Properties

Soil survey mapping data available from USDA Natural Resources Conservation Service were further analyzed using SGAT software to compile summary data for each reach corridor. Characteristics extracted from the NRCS soil data included: infiltration (or runoff) potential (Hydrologic Soil Group), flooding potential, erodibility (Highly Erodible Land classification); water table depth; and presence of hydric soils. Data are summarized in Appendix I.

4.4 Land Cover and Reach Hydrology

4.4.1 Watershed Land Cover / Land Use

Land cover / land use in the Black River watershed (Step 4 of Phase 1) was summarized by review of the following data set available from the Vermont Center for Geographic Information (www.vcgi.org):

- Landcover / Landuse for Vermont and Lake Champlain Basin (LandLandcov_LCLU, edition 2003). Source dates of 1991 to 1993. Further details of this land cover / land use data set are available at: http://www.vcgi.org/metadata/LandLandcov_LCLU.htm.

Table 9 summarizes the land cover / land use in the overall Black River watershed, as well as four of the major tributaries.

Table 9. Land cover/ land use in Black River watershed and select Major Tributaries.

Watershed	Drainage Area (sq mi)	Commercial / Industrial	Residential	Agricultural	Forest / Shrub	Water / Wetland
Black River	204.0	0%	7%	4%	80%	4%
North Branch Black River	32.0	0%	5%	3%	83%	5%
Twentymile Stream	15.0	0%	5%	3%	82%	4%
Jewell Brook	9.4	0%	7%	1%	84%	4%
Branch Brook	15.9	0%	4%	2%	85%	4%

(Note: Due to rounding preferences established in the Data Management System, the sum of the land cover / land use classifications does not equal 100%. Values noted as 0% are actually a fraction of a percent, i.e., less than 1%).

Appendix J provides a record of estimated dominant and sub-dominant land cover / land use categories in the ***upstream watershed*** draining to each Phase 1 delineated reach. Impact ratings were assigned to each reach on the basis of percentages of crop and urban land cover / land use.

Watershed Land Cover / Land Use Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	10% or more of the reach watershed is crop and/or developed.
LOW	Between 2 and 10% of the reach watershed is crop and/or developed.
Not Significant	Less than 2% of the reach watershed is crop and/or developed.

4.4.2 Corridor Land Cover / Land Use

While agricultural and developed uses comprise a relatively small percentage of the overall watershed area, these activities tend to be concentrated along the valleys of the Black River and its tributaries. Appendix J provides a record of estimated dominant and sub-dominant land cover / land use categories in the ***corridor*** surrounding each Phase 1 delineated reach. Impact ratings were assigned to each reach on the basis of percentages of crop and urban land cover/land use.

Corridor Land Cover / Land Use Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	10% or more of the reach corridor is crop and/or developed.
LOW	Between 2 and 10% of the reach corridor is crop and/or developed.
Not Significant	Less than 2% of the reach corridor is crop and/or developed.

Results are presented in Appendix J (Step 4 report in the DMS). The automated methods for analyzing land cover / land use tend to overstate the impacts of transportation networks in the small streams. The land cover / land use data set is a pixilated representation of land cover features (minimum mapping unit of 2 acres, with a resultant grid cell size of 25 meters square). For a narrow linear feature such as a road or railroad, the pixel-based classification tends to over estimate the total area of road coverage. In a small stream (with a relatively narrow buffered stream corridor) the pixel-based representation of transportation corridors can comprise a very large percentage of the overall corridor – while the actual area of the road represented as a percentage of the total corridor area may be far less.

4.4.3 Riparian Buffer

The 341 Phase 1 delineated reaches of the Black River watershed were reviewed on orthophotograph (1994) and aerial imagery (NAIP, 2003) base layers to identify portions of each reach with buffers less than 25 feet wide on either the left bank or right bank, or both. Results are documented in the FIT files for the project, and are summarized in the tables in Appendix J. Impact ratings were assigned to each reach as follows:

Riparian Buffer Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	Greater than 20% of the right and/or left bank has a buffer less than 25 feet.
LOW	Between 5 and 20% of the right and/or left bank has a buffer less than 25 feet
Not Significant	Less than 5% of the right and/or left bank has an inadequate buffer (width).

Portions of the Phase 1 delineated Black River watershed channels with naturally vegetated buffers less than 25 feet wide are indicated in orange on Figure 9. Often, buffer widths were reduced due to the presence of roads alongside the channel. Buffers widths were also reduced as a result of development in the urbanized areas and cultivation of fields in agricultural areas.

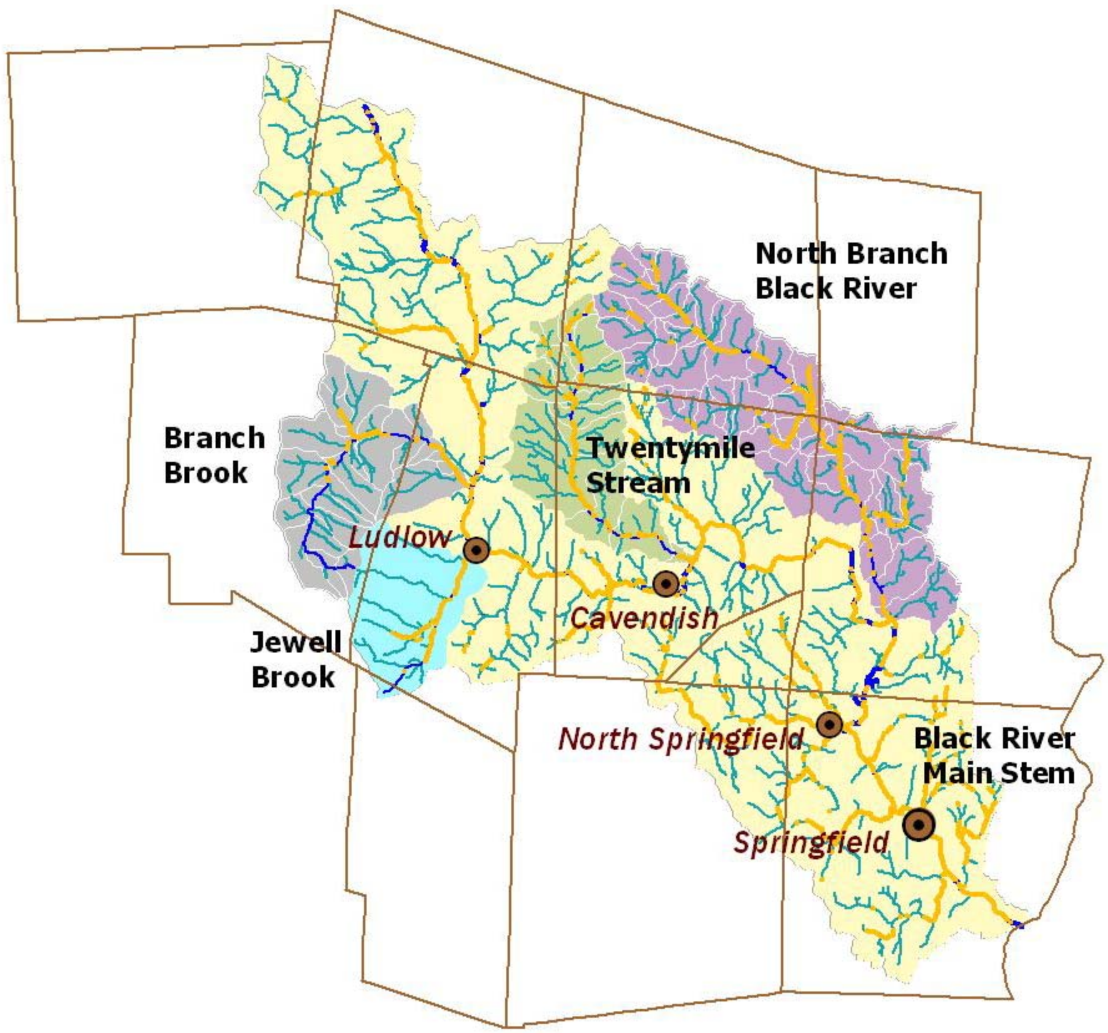

Figure 9. Occurrence of buffers less than 25 feet wide along either the left bank or right bank, or both – Phase 1 delineated reaches of the Black River watershed. (town boundaries in brown – see Figure 2 for town identifications).

4.4.4 Groundwater Inputs

Following protocols, groundwater inputs to each Phase 1 delineated reach were estimated as either Abundant, Minimal or None, base on presence and frequency of tributaries, seeps, springs, and wetlands in close proximity to the channel. Presence or absence of these features was ascertained through a review of topographic maps, Vermont Hydrography Dataset coverage, orthophotographs, and National Wetland Inventory mapping. Results are recorded in Appendix J.

4.5 Channel Modifications

4.5.1 Flow Regulation and Water Withdrawals

Locations of flow regulation (such as dams or diversions) or substantial water withdrawal were indexed during the Phase 1 Stream Geomorphic Assessment. Changes in the flow characteristics of the river can interrupt the sediment transport functions of rivers and potentially result in areas of exacerbated erosion or systemwide instability in the river. Resources reviewed to identify current flow regulation or water withdrawal features in the watershed included:

- Vermont Dam Inventory (EmergencyOther_DAMS coverage obtained from VCGI);
- A listing of dams obtained 27 June 2006 from Brian Fitzgerald, VTDEC Dam Safety & Hydrology Section;
- Vermont Water Supply Division file review on 13 February 2007; including an interview with Tina Hubbard, Source Water Protection Specialist;
- Stream Alteration Permit file review (Nicholson, 2007);
- field observations during windshield surveys;
- orthophotographs, aerial photographs, and topographic maps (current and historic);

Dams/ Impoundments

Table 10 (on the following page) characterizes the impoundment and flow regulation status of dams identified on those reaches short-listed for completion of Phase 1, Steps 5 through 7. Three of the 17 dams identified in Table 10 are breached and do not impound large volumes of water to result in a significant change in channel geometry and/or increase in upstream sedimentation. These three dams – Smithville (M32), Soapstone at Perkinsville (M18), and a historic dam site along the Jewell Brook in Ludlow (M33T3.02) – were assigned a "Not Significant" impact under Step 5.1 (see Appendix K).

The remaining 14 dams impound the channel to significantly change the channel geometry and potentially alter sediment transport dynamics. As such they were assigned a High impact under Step 5.1 (see Appendix K). Several of these impoundments are considered "Large" in size by protocols, creating an upstream reservoir – for example, Black Pond (M49), Amherst Lake (M42), Lake Rescue (M39), Lake Pauline (M38), North Springfield Lake (M14), Stoughton Pond (M15T1.02) and Jewell Brook Site No. 1 (M33T3.07).

Most of these dams appear to be Run-of-River structures, meaning that the flow of water entering the upstream impoundment equals the flow of water leaving the impoundment. Three dams with primary or secondary flood control purpose were classified as Store-and-Release structures, where flows entering the reservoir upstream of the dam are detained for some period of time and released at a controlled rate which may not equal the rate of flow entering the reservoir. These Store-and-Release structures include the North Springfield Lake (see Figure 10), Stoughton Pond, and Jewell Brook Site No. 1.

Table 10. Impoundment and Flow Regulation Status of Dams Identified on the 108 Short-listed Reaches of the Black River main stem, North Branch Black River, Twentymile Stream, Jewell Brook, and Branch Brook.

Tributary Name	Reach (Town)	Dam Name	Associated Impoundment	Owner	Date Installed (1)	Dam Site Noted on Historic Maps	Purpose - current (original) (1) (2)	Present Status	Inferred Flow Regulation Type & Size (Step 5.1)
Black River main stem	M49 (Plymouth)	Black Pond (1)	Black Pond	Private (1)	1897		R (R)	In Use	Run of River, Large
	M42 (Plymouth)	Amherst Lake (1)	Amherst Lake	Lakeside Associates, Inc. (1)	1950	1869 Beers (saw mill, grist mill)	R	In Use	Run of River, Large
	M39 (Ludlow)	Lake Rescue (1)	Lake Rescue	Town of Ludlow (1)	1978		R, S (R)	In Use	Run of River, Large
	M38 (Ludlow)	Reservoir Pond (1)	Reservoir Pond (Lake Pauline)	Town of Ludlow (1)	1920		R (H)	In Use	Run of River, Large
	M32 (Ludlow)	Smithville (1)	None	N/A (1)	N/A	1869 Beers (saw mill); 1929 topo, 1905 Sanborn		Breached	None, Small
	M29 (Cavendish)	Cavendish (1)	None	Central VT Public Service (1)	1907	1869 Beers (dam, woolen mill)	H	In Use	Run of River, Small
	M18 (Weathersfield)	Soapstone (1) (Perkinsville)	None	N/A (1)	N/A	1869 Beers (mills); 1929 topo (dam)		Breached	None, Small
	M14 (Springfield / Weathersfield)	North Springfield (1)	North Springfield Lake	US Army Corps of Engin (1)	1960		C, R (C)	In Use	Store and Release (ACOE, 2007), Large
	M07 (Springfield)	Fellows (1)	None	Westinghouse Electric (1)	1900	1869 Beers (dam)	O	In Use	Run of River, Small
	M07 (Springfield)	Gilman (1)	None	Factory Falls Inc. (1)	1913		- (H)	In Use	Run of River, Small
	M07 (Springfield)	Slack (upper) (1)	None	N/A (1)	N/A	1869 Beers (dam)		In Use	Run of River, Small
	M07 (Springfield)	Comtu Falls (1)	None	Jeff Wallin (1)	1952	1869 Beers (dam)		In Use	Run of River, Small
	M07 (Springfield)	Slack (lower) (1)	None	Scott Nielson (1)	N/A	1869 Beers (dam)		In Use	Run of River, Small
	M07 (Springfield)	Lovejoy (1)	None	Westinghouse Electric (1)	1912	1869 Beers (dam)		In Use	Run of River, Small
North Branch Black River	M15T1.02 (Weathersfield)	Stoughton Pond (1)	Stoughton Pond	US Army Corps of Engin (1)	1960		R	In Use	Store and Release, Large
Jewell Brook	M33T3.07 (Ludlow)	Jewell Brook Site No. 1 (1)	Unnamed	Town of Ludlow (1)	1969		- (C)	In Use	Store and Release, Large
	M33T3.02 (Ludlow)	Historic mill dam	None	unknown		1921 Sanborn	- (C)	Breached	None, Small

***Data Sources**: (1) Vermont Dam Inventory (EmergencyOther_DAMS) obtained from Vermont Center for Geographic Information on 6/27/2006. Publication date: 3/7/2005. (2) USACOE National Inventory of Dams: Methodology, Version 3.0, July 2005: C = Flood Control; R = Recreation; H = Hydroelectric; S = Water Supply; O = Other* ***Notes**: N/A = Not Available*

Photo Credit: Marie Caduto

(a) North Springfield Lake, view to the north, July 2006.

Figure 10.
North Springfield Lake (M14)

Waters of the Black River are impounded behind a flood control dam constructed by the Army Corps of Engineers from 1957 to 1960 (a). The dam is 2,940 feet long and 120 feet high. At maximum capacity the reservoir can hold back 16.6 billion gallons of water. ACOE credits this dam with preventing $57.3 million in potential flood damages over its more than 45 years in existence (ACOE, 2007).

The reservoir project area occupies more than 1000 acres of land in the town of Weathersfield. 40 homes, six farms and the village of Lower Perkinsville were sacrificed for the construction (Bodin, 2005).

(b) Black River prior to construction of the dam, 1939 aerial photograph

(c) Black River and North Springfield Lake and dam following construction, prior to construction of the dam, 1994 orthophotograph

Dams serve valuable functions in society related to flood control, provision of safe drinking water, fire prevention, power generation and recreation. From a geomorphic standpoint, this Phase 1 assessment identifies dams for further review to understand their potential influence on the conveyance of water and sediments in the river network. Dams disrupt the flow dynamics and sediment transport continuity of streams to varying degrees and extents, depending on their size, height, topographic setting, and operational status, and depending on the hydrologic, geomorphic and geologic characteristics of the river being impounded (Williams and Wolman, 1984; Kondolf, 1997).

Sediments are trapped in the impoundment upstream of a dam; bed load and a portion of the suspended sediment load settle out in the still water environment of the reservoir. For example, Figure 11 illustrates the deposition of sediments carried in the North Branch of the Black River at the point where this Black River tributary enters Stoughton Pond in Weathersfield. Water leaving the impoundment is essentially devoid of its sediment (bed) load, and possesses enhanced energy to erode the stream bed and banks. Depending on the nature of sediments in the channel margins and underlying surficial deposits, and vegetative boundary conditions, this increased erosional potential can lead to channel incision and/or widening downstream of the dam as the river seeks to restore its sediment load – a condition often termed "hungry water" (Kondolf, 1997). If scour is significant, the channel can incise below the surrounding floodplain.

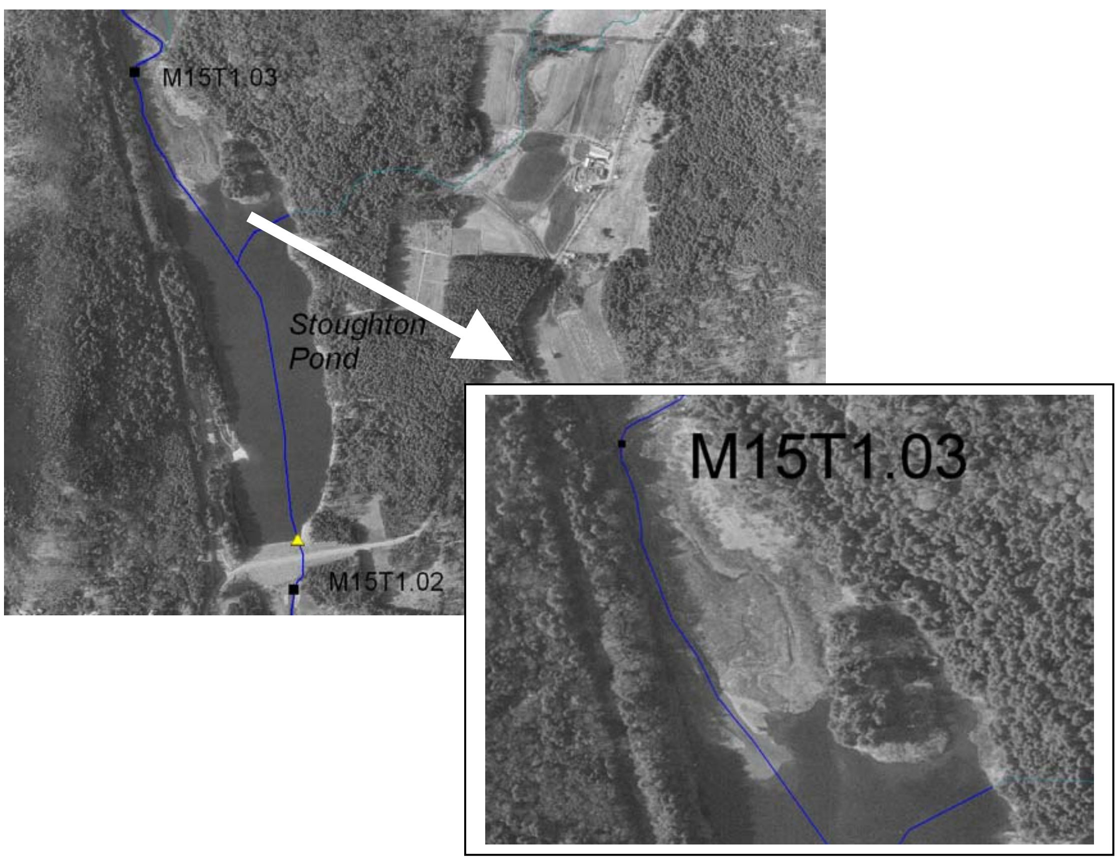

Figure 11. Delta of fine sediments extending into upstream end of Stoughton Pond from the North Branch of the Black River (base map: 1994 orthophoto).

On the other hand, if flows are regulated so as to significantly reduce flood peaks and magnitudes, channel aggradation and/or narrowing may result downstream of the dam. Sediments may accumulate in the downstream channel, where they are mobilized from tributaries, if flushing effects of bankfull flows and low-magnitude flood events have been eliminated or reduced as a result of flow regulation (Kondolf, 1997). As detailed in Section 2.3, regulation of Black River flows at the North Springfield dam (and indirectly, impoundment of the North Branch at the Stoughton Pond dam) has successfully controlled for flood events occurring since 1960. However, flow regulation has also resulted in a reduced frequency and magnitude of bankfull flows in the 8.7 river miles downstream of the dam.

Flow Diversions or Water Withdrawals

No current flow diversion sites were identified within the Black River watershed. (An apparent flow diversion structure exists at the downstream end of the North Springfield Lake; however, this structure is inferred to be an emergency and/or maintenance diversion that does not operate regularly). Evidence of several historic flow diversion sites was revealed from a review of the Beers Atlas for Windsor County (1869) and Sanborn Fire Insurance maps for Ludlow (1885, 1905). These sites were not indexed under Step 5.1, as they are no longer operational. However, notes were placed in the Comments section (Step 7) of the Phase 1 database. Knowledge of these historic diversion sites aids in characterizing the overall sensitivity of the river reaches and their degree of departure from reference condition, where applicable. The present condition and adjustment processes may still be influenced by the disruption of fluvial and sediment transport processes imparted by these historic diversions.

Historic flow diversion sites include:

- Diversions to mills from the Jewell Brook (reach M33T3.01) and Black River (M33) in Ludlow (1885 Sanborn);
- Raceway from the Black River (M32) to mills at Smithville (1905 Sanborn);
- Flow diversion to a Woolen Mill and marble shop from the Black River (M31) at Proctorsville (Beers, 1869);
- Raceway leading from a dam (now absent) on the Black River (M30) to mill buildings in Cavendish (Beers, 1869);
- Flow diversion on the North Branch channel (M15T1.11, M15T1.12) leading to manufacturing buildings in Felchville (Beers, 1869).

One site of periodic water withdrawal from the Black River main stem is located in reach M34 behind a shopping plaza off Route 100 in Ludlow (Figure 12). This water withdrawal site supports snow making at Okemo Mountain Ski Resort and has been in use since 1988. In early years, water was pumped to the West Hill Reservoir for storage. In 1994, an additional 73-million-gallon capacity storage reservoir – the Okemo Snow Pond - was built on the hillside east of the Black River just north of Ludlow village. Land Use Permits allow the withdrawal of a maximum of 3000 gallons per minute (gpm) from the Black River, and require that a minimum flow is maintained in the Black River downstream of the intake – specified as 0.8 cubic feet per second for each square mile of upstream drainage area (VT Environmental Board, 1992; Okemo Mountain Resort, 2007; Vermont Dam Inventory). This maximum withdrawal rate (3,000 gpm) represents less than 1% of the total estimated flow of the river at this point during a bankfull event (1,330 cubic feet per second, or 597,000 gpm) based on VT Regional Hydraulic Geometry Curves (VTDEC, 2001). Therefore, this withdrawal was categorized as a "Small" withdrawal in accordance with protocols, and was assigned a "Low" impact.

A historic water withdrawal or diversion site was identified on the Black River main stem reach M06 along the right bank upstream of the Bridge Street crossing (see Appendix E, Site A5, Photo 26. This site is associated with historic industrial and manufacturing uses in the right-bank corridor and is reportedly no longer in use (BRAT, 2005). Therefore it was not indexed; a note regarding its presence and status was added to Step 7 (Comments section) of the database.

Figure 12. Water withdrawal intake structure for Okemo Mountain snow making located on the Black River (reach M34) in Ludlow. 29 May 2006.

No direct surface water withdrawal sites for drinking water use were identified within the Black River watershed, from a review of Surface Water Source Protection Areas on file with the VT Water Supply Division (records reviewed 13 February 2007). There are three public water supplies whose Source Protection Areas extend across the Black River or selected major tributaries, and which may be recharged in part from surface water which infiltrates from the river. Notes to this effect were included in the comments section (Step 7) of the Phase 1 database under relevant reaches. These include:

- Springfield Municipal Wellfield (WSID #5333) – which consists of multiple shallow gravel-pack wells and suction points located within 300 feet from the Black River along the west side of reach M10 near North Springfield. The Source Protection Area for this well field extends along the southeast side of reaches M12 and M13 and along both west and east sides of the river in reaches M10 and M11 (Hoffer & Associates, 1999).

- Black River Overlook water system (WSID #20618) – which consists of a shallow gravel well located along the west side of the Black River in reach M36. The SPA for this well includes an area of 200-foot buffer along the Black River for the full length of reach M36 (Wagner, Heindel, & Noyes, 1995).

- Cavendish Town Water System (WSID #5317) – which is supplied by a shallow source well in unconsolidated deposits within 100 feet north of the Black River (reach M29) in Cavendish.

4.5.2 Bridges and Culverts

Locations of bridge and culvert crossings were indexed on the Black River main stem, North Branch, Twentymile Stream, Jewell Brook, and Branch Brook tributaries (short-listed reaches). The number of crossing structures and the length of channel inferred to be impacted by each structure is recorded in Appendix K (Step 5 report in the DMS). Impact ratings were assigned to each assessed reach based on the percentage of the reach impacted by the crossing, as follows:

Bridge and Culvert Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	≥ 20% of the reach length is channelized, has split flow, or makes a sharp "S" bend upstream or downstream of a crossing structure
LOW	≥ 5% and < 20% of the reach is impacted by crossing structure(s), as described above.
Not Significant	< 5% of the reach is impacted by crossing structure(s)

Based on observations during windshield surveys (see Appendix E), several bridge crossings had stepped footers, indicating a history of channel incision and scour at the abutments (e.g., along the North Branch in the town of Reading from South Reading to Felchville).

4.5.3 Bank Armoring / Revetments

Locations of bank armoring and revetments on the short-listed reaches were documented under Phase 1 Step 5.3. Data were populated from a variety of sources including:

- Interview with VT WQD Stream Alteration Engineer (Nicholson, 2007)
- Windshield Surveys (see Appendix E)
- Information provided by Watershed Volunteers, including BRAT (see Appendix E)

Approximate locations of armoring (e.g., rip-rap, hard bank) were documented using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database. Impact ratings were assigned to each reach based on the percentage (by length) of bank armoring on the left bank and/or right bank:

Bank Armoring/Revetment Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	≥ 20% of the reach armored on the right and/or left bank
LOW	≥ 5% and < 20% of the reach armored on the right and/or left bank
Not Significant	< 5% of the reach armored on the right and/or left bank

Results are presented in Appendix K (Step 5 report in the DMS). Given the size of the study area (approximately 204 square miles) and due to budget limitations, none of the Phase 1 reaches were inventoried in their entirety. Estimated lengths of bank armoring are expected to be less than actual lengths; and bank armoring impacts are likely underestimated for many reaches. Field-based assessment of reaches will yield a more comprehensive evaluation of bank armoring and revetments. It is possible that impact ratings would change considerably following consideration of field-based estimates of bank armoring.

4.5.4 Channelization

Channelization refers to the straightening of river segments and the associated removal of meanders, potential channel deepening, potential channel widening, and removal of woody debris. Occasionally straightening is associated with windrowing, where stream bed sediments are pushed to the margins of the channel by heavy equipment and may be used to berm the channel. Straightening is of concern to the equilibrium of channels, since channelization shortens the channel length and steepens the gradient. Water is conveyed by the channel at faster velocities. If stream power is substantially increased and sediments of the channel bed and banks are sufficiently erodible, channelization can lead to vertical scour and/or channel widening. Aggradation can also be increased in downstream reaches of the river. Often channelization (and the associated channel degradation) reduces the stream's access to its surrounding floodplain and contiguous wetlands, and can result in lowering of the surrounding groundwater table.

Through a review of orthophotographs, occurrences of potential channel straightening were identified as sections with a linear planform for a distance greater than 20 times the channel width. Most often straightening is associated with lower-gradient (< 2%) channels in close proximity to agricultural fields or infrastructure including roads, railroads and buildings. Additional resources reviewed to support identification of channelized reaches included:

- Interview with VT WQD Stream Alteration Engineer (Nicholson, 2007);
- Field observations during Windshield Surveys (see Appendix E);
- Comparison of historic aerial photographs (1939, 1977) to more recent photographs (1994 orthophotographs, 2003 aerial imagery);
- Annual town reports / History Books (Lyndes & Menard, 1927)
- (Several attempts to were made to interview NRCS personnel in the White River Junction office in June and July 2007; personnel were not able to accommodate an interview within the timeframe. Some cross referencing of NRCS projects requiring channel modifications was contained in the Stream Alteration Permit records).

Approximate locations of channel straightening on the Black River main stem and major tributaries were documented using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database. Impact ratings were assigned to each reach based on the percentage of inferred straightening (see Appendix K):

Channel Straightening Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	≥ 20% of the reach channelized
LOW	≥ 5% and < 20% of the reach channelized
Not Significant	< 5% of the reach channelized

Sections of the Black River main stem and major tributaries inferred to be impacted by straightening are indicated in red on Figure 13. Notable examples of channelization are presented in Figures 14, 15 and 16 on the next pages. In each case the previous planform of the Black River has been interpreted from 1939 aerial photographs and superimposed on a 1994 orthophoto base map.

Figure 13. Occurrence of known or inferred channel straightening on the Black River main stem, and the North Branch, Twentymile Stream, Jewell Brook and Branch Brook tributaries. (town boundaries in brown – see Figure 2 for town identifications).

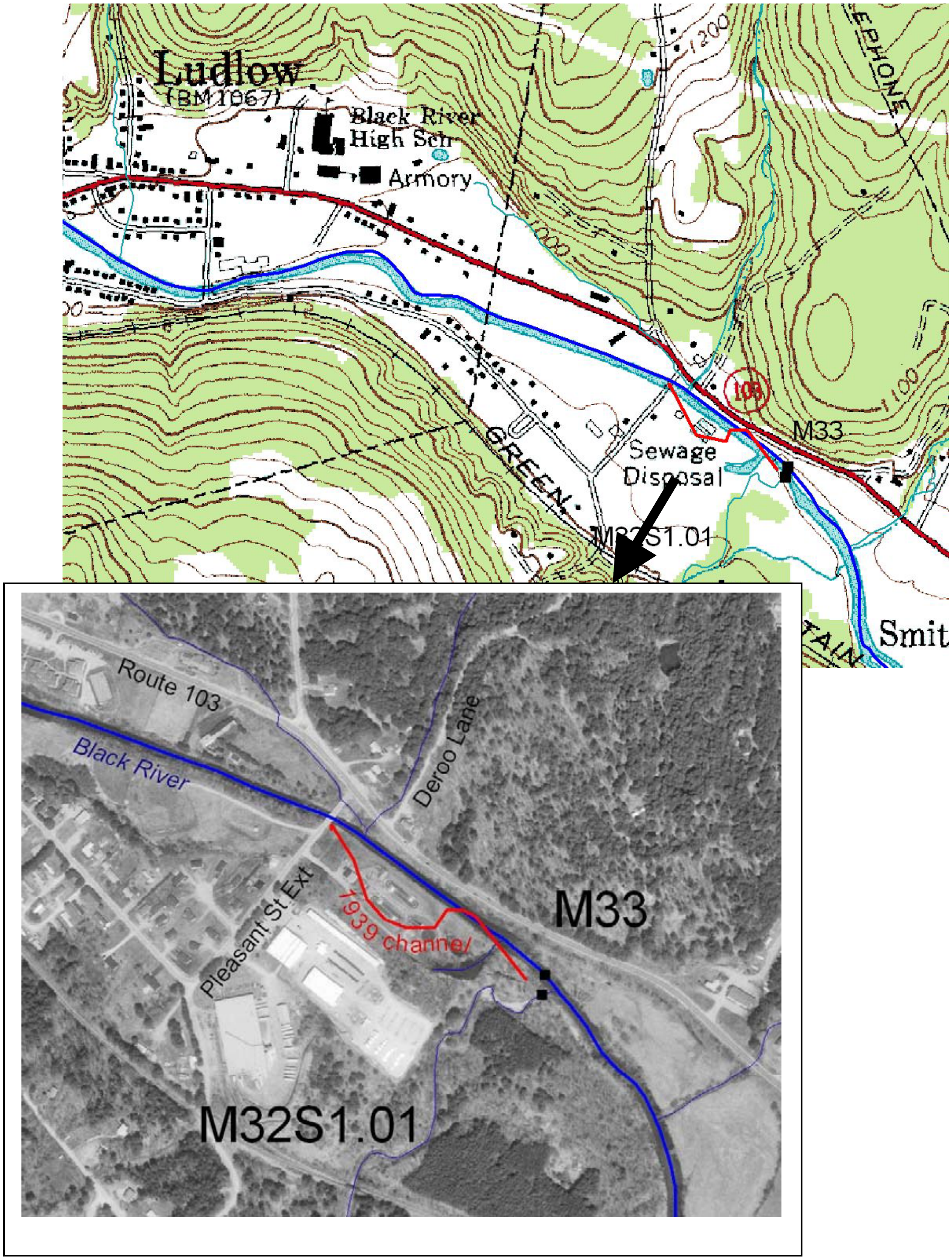

Figure 14. Example of post-1939 channelization of the Black River (Reach M33) along Route 103 in the area of the present-day wastewater treatment plant, Ludlow, Vermont.

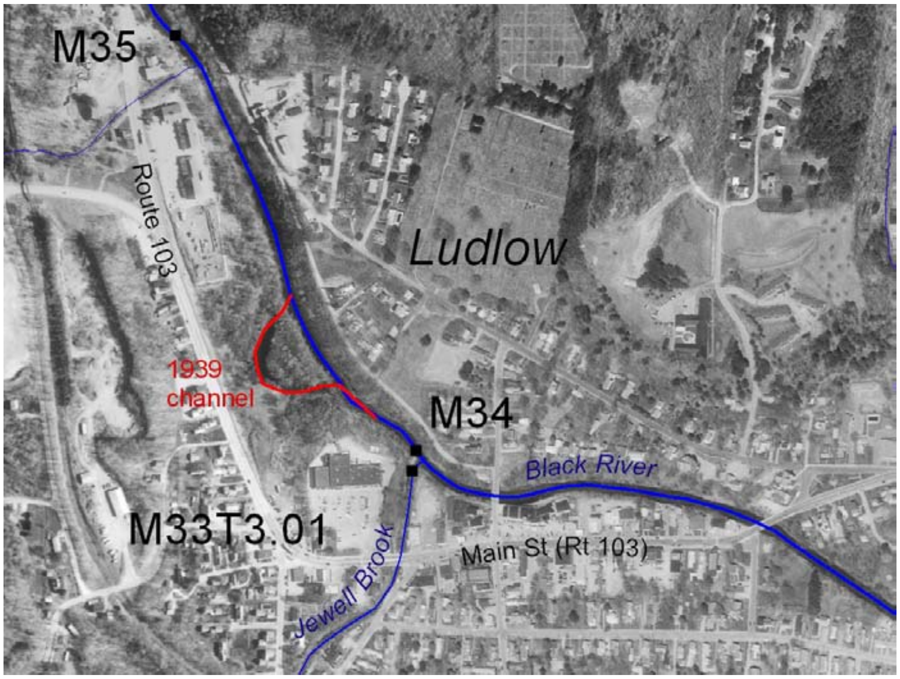

Figure 15. Example of post-1939 channelization of the Black River (Reach M34) along Route 103 just upstream of the Shaws supermarket, Ludlow, Vermont.

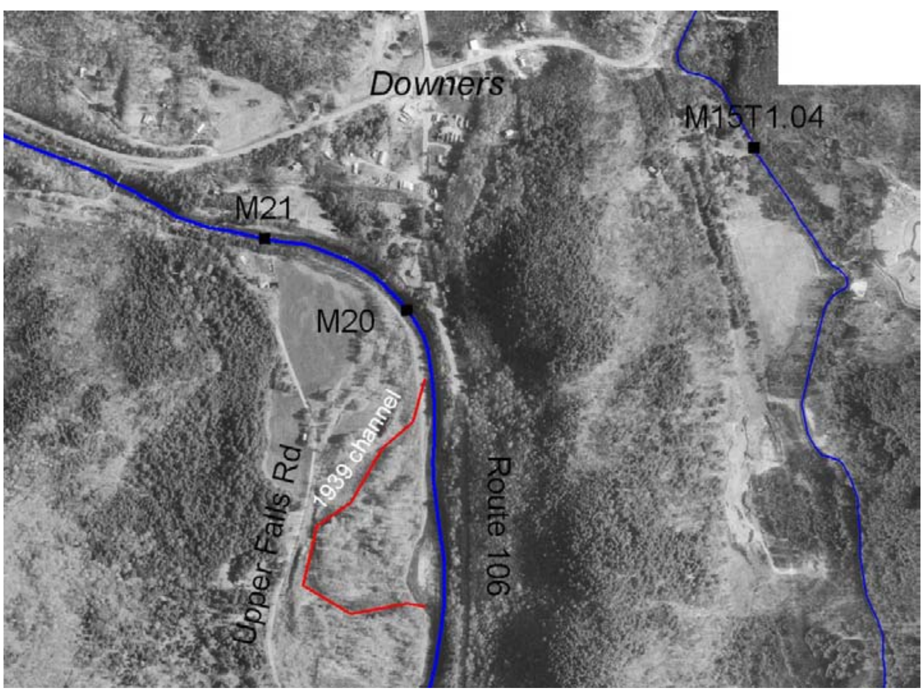

Figure 16. Example of post-1939 channelization of the Black River (Reach M19) between Upper Falls Road and Route 106 upstream (north) of North Springfield Lake, Weathersfield, VT.

4.5.5 Dredging and Gravel Mining History

Channel dredging and in-stream gravel extraction have been undertaken in Vermont streams and rivers (often as part of flood recovery work) with the intention of improving channel flow by removal of sediment bars, woody debris and large boulders. Gravel was sometimes removed from stream beds for commercial use. Often gravel extraction or dredging initiates a cycle of channel incision and/or widening and leads to loss of floodplain connection or downstream aggradation, or both. Results are presented in Appendix K (Step 5 report in the DMS).

Resources reviewed to identify locations of past dredging and/or gravel mining in the Black River main stem and major tributaries included:

- Interview with VT WQD personnel (Nicholson, 2007);
- VTDEC Water Quality Division publication (VTDEC WQD, 1999)
- Field observations during Windshield Surveys (Appendix E);
- Annual town reports

Approximate locations of dredging and gravel mining on the Black River main stem and major tributaries were documented using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database. Impact ratings were assigned to each reach based on the presence or absence, and the frequency and magnitude of dredging / gravel extraction:

Dredging and Gravel Mining Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	Used historically for commercial gravel mining, dredged for flood remediation.
LOW	Used occasionally for annual 50 cubic yards of gravel extraction by landowner.
Not Significant	No gravel mining or post-flood dredging operations.

The following locations of gravel mining / dredging were noted on the Black River main stem, North Branch, Twentymile Stream, Jewell Brook and Branch Brook, with corresponding "High" or "Low" impacts (Table 11).

Table 11. Locations of gravel extraction noted in databases of VTDEC Stream Alteration Engineer (Nicholson, 2007; see also Appendix K).

Project ID	Date	Town	Stream/River	Reach	Description	Phase 1 Impact
N/A	6/19/1997	Weathersfield	North Branch	M15T1.02	"Lots" of Sediment Extracted from Stoughton Pond, Army Corps of Engineers	HIGH
GR-1-0027	10/1/1992	Ludlow	Black River	M33 / M34	Gravel Extraction across from Jewell Brook	HIGH
OR-1-0342	10/1/1996	Ludlow	Jewell Brook	unknown	Gold Dredge, Suction	LOW

In addition, the Ludlow annual report (year ending 1973) indicates "stream cleaning" following the 1973 flood at the following locations which were indexed with a "High" impact: Black River main stem from Ludlow to Cavendish (several locations; M32 – M33); Branch Brook (inferred M36T4.01, T4.02); and Jewell Brook "600' from Dam Site" (inferred M33T3.06).

4.6 Floodplain and Planform Modifications

4.6.1 Berms, Roads, Railroads, Improved Paths (Encroachments)

Berms, roads, driveways, railroads and improved paths located within close proximity to river channels often constrain the lateral movement of the channel and can serve as a berm in the floodplain that reduces or prevents floodplain access by the channel during bankfull or higher-magnitude flood events. Infrastructure within the river corridor is often at risk of fluvial erosion (and inundation) losses during a flood. Moreover, infrastructure present within the corridor may impart risks to downstream communities and lead to downstream channel adjustments. These risks to downstream areas result both from the increased flow velocity and magnitudes resulting from reduced floodplain access and channelization associated with the encroachments, as well as actual physical debris washed downstream in a flood event.

The presence of roads and driveways, railroads, improved paths, and berms was quantified for each short-listed reach in accordance with Step 6.1 of the Phase 1 protocols. Berms were noted from Windshield Surveys of vehicle-accessible portions of these reaches (see Appendix E). Roads, driveways, and improved paths were noted from a review of the 1994 orthophotographs and 2003 aerial imagery available for the watershed (supported by windshield survey observations and GIS coverage of roads; VCGI, 2007). Location of railroads in the watershed was determined from a review of orthophotos, supported by review of GIS coverage available from the VT Center for Geographic Information (TransRail_RR, VCGI, 2007) and historic USGS topographic maps (Claremont – NH, VT, 1957). The Green Mountain Railroad passes through Cavendish, Ludlow and Mount Holly. A former rail line for the Springfield Electric Railroad operated between Springfield and Charlestown, New Hampshire (Springfield Trails and Greenways, 2000). While this line has been converted to a bike and walking path (the Toonerville Trail as of 2000), the base fill for this path was apparently retained; this line was indexed as a railroad in the FIT records and appears as a railroad encroachment in the Phase 1 database (see Appendix L, reaches M02 through M05).

The length of each of these encroaching features within each reach corridor was indexed using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database. The corridor was generated in SGAT (version 4.56), and is provided as an ArcView shape file on the Project CD. Indexing was performed to record whether each encroachment was present along **one side** of the channel at a time or **both sides** of the channel simultaneously. Impact ratings were assigned to each reach based on the presence or absence of these features and the cumulative percent by length of the reach:

Encroachment Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	Berms, roads, railroads or improved paths are present within the river corridor along ≥ 20% of the right and/or left bank.
LOW	Berms, roads, railroads or improved paths are present within the river corridor along ≥ 5% and < 20% of the right and/or left bank
Not Significant	Berms, roads, railroads or improved paths are present within the river corridor along < 5% of the right and/or left bank

Results are presented in Appendix L (Step 6 report in the DMS). An example of corridor encroachments which have constrained the river's ability to laterally adjust (and are associated with channelization) can be seen in reaches M31 and M32 on the Black River main stem in Proctorsville (town of Cavendish) (Figure 17).

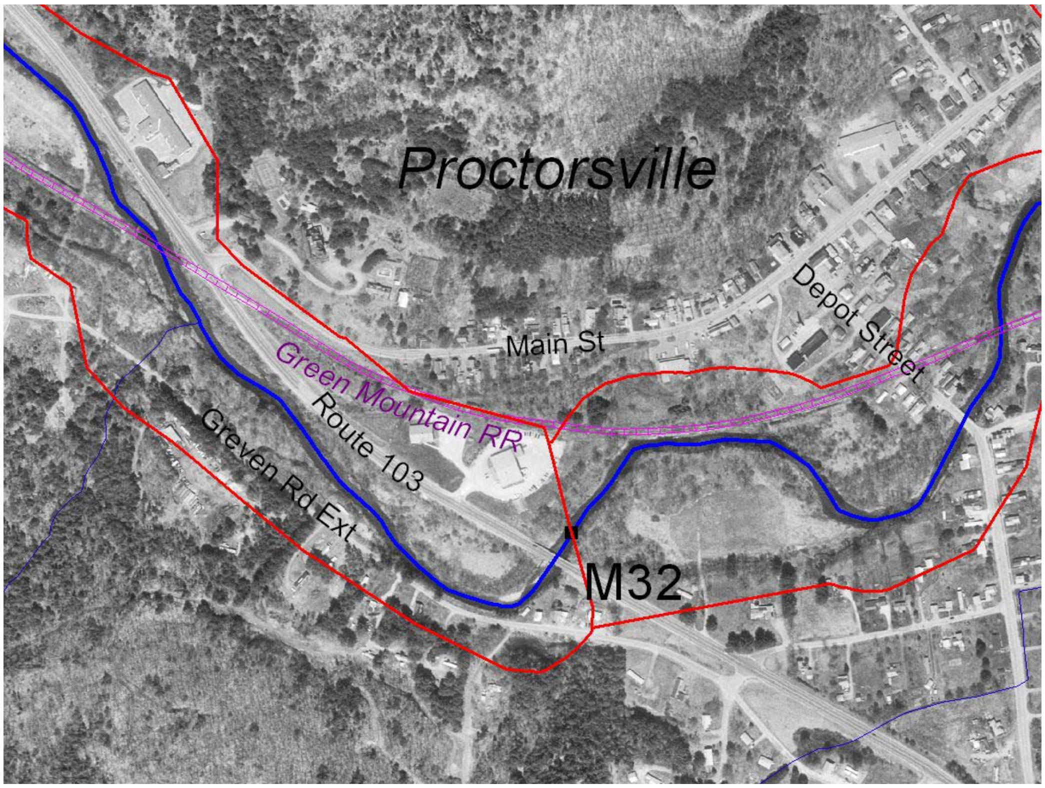

Figure 17. Example of encroachment by roads and railroad along the Black River main stem (Reaches M31, M32) in Proctorsville (Cavendish), VT. Phase 1 / 2 corridor depicted in red.

4.6.2 River Corridor Development

Developments located within close proximity to river channels can also constrain the lateral movement of the channel and may serve as a berm in the floodplain that reduces or prevents floodplain access by the channel during bankfull or higher-magnitude flood events. Buildings, bridges and associated infrastructure within the river corridor is often at risk of fluvial erosion (and inundation) losses during a flood. Also, development present within the corridor may impart risks to downstream communities and lead to downstream channel adjustments. These risks to downstream areas result both from the increased flow velocity and magnitudes resulting from reduced floodplain access and channelization associated with the development, as well as actual physical debris washed downstream in a flood event.

The 1994 orthophotographs and 2003 aerial imagery were reviewed to determine where development has encroached within the corridor surrounding each short-listed reach. Features identified as "development" under Step 6.2 included residential housing; commercial, municipal or industrial buildings; parking areas; cemeteries; airports; campgrounds; and fill material or abutments for bridge or culvert crossings.

The length of channel associated with development in the corridor was indexed using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database. Indexing was performed to record whether development was present along **one side** of the channel at a time or **both sides** of the channel simultaneously. Impact ratings were assigned to each reach based on the presence or absence of these features and the cumulative percent by length of the reach:

Development Impact Ratings (VTANR, 2007)

Impact	Condition
HIGH	Developments are present within the river corridor along ≥ 20% of the right and/or left bank.
LOW	Developments are present within the river corridor along ≥ 5% and < 20% of the right and/or left bank
Not Significant	Developments are present within the river corridor along < 5% of the right and/or left bank

Results are presented in Appendix L (Step 6 report in the DMS). Examples of commercial buildings and residential housing developments encroaching in the floodplain of the Black River are visible in Figure 17. Development of the floodplain is also evident in Ludlow (see Figure 14) and in Springfield on the Black River main stem.

4.6.3 Depositional Features

The short-listed reaches were reviewed on 2003 aerial photography and 1994 orthophotography for presence of depositional features including point bars, side bars, mid-channel bars, vegetated islands and tributary-confluence bars. Where possible, observations of depositional features during Windshield Surveys also informed data development in Step 6.3. Presence and type of depositional bars were noted in the Phase 1 database. A "High" impact rating was assigned for numerous bars; "Low" for some bars; and "Not Significant" for typical point bars but no mid-channel or other bars noted. Results are presented in Appendix L (Step 6 report in the DMS).

Many of the tributary reaches were small in size and forested; therefore, resolution of the aerial photography was insufficient for viewing in-channel depositional bars. "No Data" was selected for these reaches under Step 6.3.

4.6.4 Meander Migration / Channel Avulsion

Aerial photography was reviewed for indications of recent lateral channel adjustments including meander extension and migration, flood chutes, bifurcations and braiding, neck cutoffs and avulsions. In addition to the 1994 and 2003 photographs, aerial photographs from 1939 and 1977 were reviewed at the Natural Resource Conservation Service offices in White River Junction. Evidence of lateral channel adjustments was also determined through review of limited historical records (town annual reports; Minsinger, 2003).

Presence of lateral adjustments was indexed using FIT and uploaded to the Phase 1 database. An impact rating was assigned – "High" for frequent occurrences; "Low" for a few occurrences;

and "Not Significant" for no significant lateral adjustments evident from the comparison of available photograph coverage. Results are presented in Appendix L (Step 6 report in the DMS).

Many of the tributary reaches were small in size and forested; therefore, resolution of the aerial photography was insufficient for identifying occurrences of lateral adjustments. "No Data" was selected for these reaches under Step 6.4.

A notable historic avulsion occurred on the Black River main stem in the town of Cavendish during the 1927 flood. Waters of the Black River were historically impounded behind the dam at the top of Cavendish gorge. A secondary dike, or levee structure, was present along the north side of the impoundment along the southern margins of the Cavendish village. This earthen dike was outflanked by flood waters of the 1927 flood, and a quarter-mile long channel avulsion bypassed the Cavendish Gorge and eroded approximately 2 million tons of sediment down to bedrock leaving a channel 150 feet deep and 600 feet wide. Several buildings and a long section of the road were washed away (Minsinger, 2003). Historic photographs depicting the erosion and flood damage are available for viewing on the Perkins Landscape Change Program website (see References, Section 7.0, for a website link).

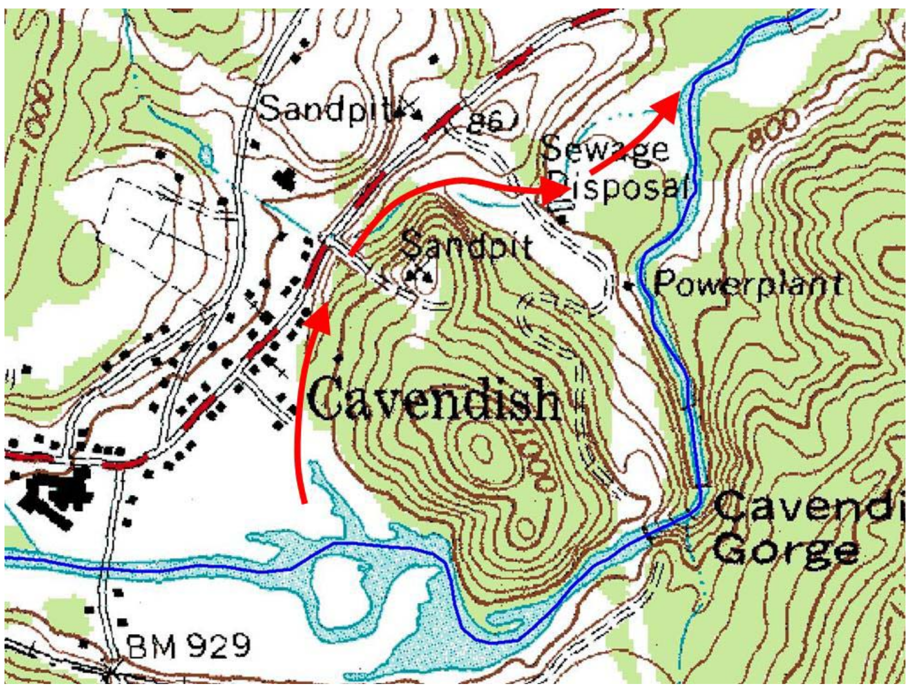

Figure 18. Approximate path of channel avulsion on the Black River main stem during the 1927 flood (from Reach M29 to M27), Cavendish, VT.

4.6.5 Meander Geometry

Those reaches classified as unconfined C or E stream types were reviewed for their meander geometry following Phase 1 protocols (Steps 6.5 and 6.6). Reaches with meander wavelength (MWL) ratios that are significantly more or less than 10 to 14 channel widths, and meander belt width (MBW) ratios greater or lesser than 5 to 8 channel widths, were highlighted as an indication that they may be out of equilibrium or otherwise disturbed or manipulated, presumably from human-induced channel or watershed stressors.

Impact ratings were assigned where estimated meander geometry ratios fell outside of these expected ranges (see Appendix L). Appendix M presents a more detailed discussion of the meander geometry assessment for the selected Black River watershed reaches, and a review of data outliers and the assignment of impacts.

Sixty (60) of the short-listed reaches were identified (in Step 2) as C or E stream types (following exclusion of impoundments, lakes, ponds, and wetlands). Twenty-four of these 60 reaches were exempted from evaluation of meander geometry due to one or more of the following conditions (see Appendix M for discussion):

- presence of bedrock channel constraints (as revealed by digital bedrock mapping and/or field observations);
- channel slopes in excess of 2%; or
- reach lengths less than the reference MWL.

Of the remaining 36 reaches, all but 7 were determined to be greater than 50% straightened (in Step 5.4). In these reaches (following protocols), the value of the reference channel width (Step 2.8) is substituted for both the MBW and MWL. This substitution then forces the MBW and MWL ratios to a value of "1" and a corresponding impact rating of "High" for Step 6.5 and 6.6, respectively. (See Table M-2 in Appendix M for an identification of reaches with greater than 50% straightening).

Of the 7 reaches for which meander geometry was measured, all seven had a measured MBW ratio or MWL ratio outside of the range of expected values considered by VTANR protocols, necessitating assignment of "Low" or "High" impacts under Steps 6.5 and 6.6 (see Appendix L).

4.7 Bed and Bank Windshield Survey

Windshield surveys were conducted in the Black River watershed to:

- characterize stream channel conditions at vehicle accessible points in support of stream typing (Phase 1 Step 2, Section 4.2 of this report);
- note erosion conditions including length and height; and
- identify the potential for debris or ice jams.

Four windshield surveys were conducted in the Summer of 2006 and the Spring / Summer of 2007 (see Table 12, below). Photo logs and notes recorded during windshield surveys are contained in Appendix E.

Table 12. Record of Windshield Surveys conducted in the Study Area

Dates of Windshield Survey	Personnel	Locations
20 July 2006	K. Underwood M. Caduto, VTDEC K. Dolan, VTDEC	Multiple Watershed Locations (Orientation)
29 May 2007	K. Underwood B. O'Shea	Upper Main Stem, Branch Brook, North Branch Black River
7 June 2007	B. O'Shea	Twentymile Stream; Main stem Black River
13 June 2007	B. O'Shea	Jewell Brook

A cataloguing of various field conditions along the Black River main stem was also reported by the Black River Action Team in 2005 (BRAT, 2005). BRAT floated portions of the Black River main stem from the Branch Brook confluence north of Ludlow downstream to Proctorsville; a section from Downers through Perkinsville; and a section from North Springfield downstream to the confluence with the Connecticut River. Observations of BRAT were used to support indexing of select features in this Phase 1 Stream Geomorphic Assessment, as noted in the comments section (Step 7) of the Phase 1 database (see Appendix N).

4.7.1 Bank Erosion

Where reaches could be accessed through Windshield Surveys, locations of stream bank erosion were recorded and indexed using the Feature Indexing Tool. Data were uploaded to the DMS and an impact rating was generated based on the percentage (by length) of the reach impacted by right bank and/or left bank erosion.

Bank Erosion Impact Ratings (VTANR, 2007)

Impact	**Condition**
HIGH	Bank erosion observed along ≥ 20% of the right and/or left bank.
LOW	Bank erosion observed along ≥ 5% and < 20% of the right and/or left bank
Not Significant	Bank erosion observed along < 5% of the right and/or left bank

Step 7.1 results are included in Appendix N. Not all short-listed reaches could be accessed during windshield surveys; bank erosion impact ratings were classified as "Not Evaluated" for those reaches. Also, none of the reaches was accessed in its entirety; estimated lengths of erosion are likely less than actual lengths. Field-based assessment of reaches will yield a more comprehensive evaluation of bank erosion. It is possible that bank erosion impact ratings would change following consideration of field-based estimates of bank erosion.

4.7.2 Debris and Ice Jam Potential

Available resources were reviewed for known sites of debris jams and ice jams on the Black River and selected major tributaries. This review relied on:

- observations during windshield surveys;
- the online Ice Jam Database maintained by the Ice Engineering Group at the Cold Regions Research and Engineering Laboratory (CRREL, 2007);
- the online flood database maintained by the National Climatic Data Center (NCDC) Storm Event Database.

Features along each of the reaches that could suggest the potential for debris jams were noted, including undersized bridges or culverts, sharp meander bends (greater than 90 degrees), wide and shallow channel sections with depositional bars, and presence of woody debris.

A "High" impact rating was assigned for reaches with a known, recorded history of ice or debris jams. A "Low" impact was assigned for reaches with features suggesting the potential for jams, but for which no record of previous jams was found. A "Not Significant" impact rating was assigned for reaches with no recorded history of jams and no features suggesting the potential for jams. Step 7.2 results are summarized in Appendix N; ice jam database records are presented in Appendix O.

5.0 DATA ANALYSIS

5.1 Impact Scores

As presented in previous sections, impact scores were assigned to each short-listed reach under Phase 1 Steps 4 through 7 which evaluated various parameters under the broader categories of Land Use, Instream Modification, Floodplain Modification, and Bed and Bank Survey (see Table x). A "Not Significant" rating is equivalent to a score of zero; a "Low" impact is assigned a score of 1; and a "High" impact is given a score of 2. The maximum total impact score for a given reach is 32, or 2 points assigned for each of the parameters listed in Table 13.

Table 13. Phase 1 Parameters Comprising Impact Scores (VTANR, 2007)

Impact Category	Phase 1 Step #	Description
Land Use	4.1	Watershed Land Cover / Land Use
	4.2	Corridor Land Cover / Land Use
	4.3	Riparian Buffer Width
Instream Modification	5.1	Flow Regulations / Water Withdrawals
	5.2	Bridges & Culverts
	5.3	Bank Armoring / Revetments
	5.4	Channel Straightening
	5.5	Dredging / Gravel Mining History
Floodplain Modification	6.1	Berms & Roads
	6.2	River Corridor Development
	6.3	Depositional Features
	6.4	Meander Migration/ Channel Avulsion
	6.5	Meander Belt Width Ratio
	6.6	Meander Wavelength Ratio
Bank and Bank Survey	7.2	Bank Erosion – Relative Magnitude
	7.3	Debris & Ice Jam Potential

The highest Total Impact Score assigned to a Black River watershed reach was 21 - out of a possible 32 (see Appendix P). Based on Phase 1 data alone, land uses account for a majority of the impact score assigned to Black River reaches overall (see DMS, Step 8: Summary of Categorical Impacts); floodplain modifications are the next most influential category on the overall impact score for Black River watershed reaches.

Through field-based investigations, it will be possible to more comprehensively index certain parameters – including, bank armoring, bank erosion, berms, bridge & culvert crossings, depositional features, and migration features. It is likely that Total Impact Scores will be revised following Phase 2 updates.

Table 14 lists the reaches on the Black River main stem and four major tributaries with the top five Total Impact Scores.

Table 14. Reaches with Highest Impact Scores on Black River main stem and Select Major Tributaries.

Score	Main Stem	North Branch	Twentymile Stream	Jewell Brook	Branch Brook
21	M32 M33				
20	*No reaches with this score.*				
19	M19 M30 M31		M26T2.01		
18	M34 M36	M15T1.05 M15T1.06			M36T4.01
17	M03 M47	M15T1.08 M15T1.09			M36T4.02 M36T4.03

5.2 Algorithm-Derived Reach Condition and Sensitivity

For each of the short-listed reaches, a provisional geomorphic condition, dominant adjustment process and reach sensitivity were assigned by an algorithm developed by the VTDEC River Management Program (Phase 1 Step 9, Appendix Q). Impact ratings assigned in Phase 1 Steps 5 through 7 and the stream type assigned in Step 2 are utilized as inputs in this algorithm (see protocols for further discussion). Reach conditions and sensitivity determinations generated by the algorithm are provisional and are not substantiated by field measurements.

6.0 RECOMMENDATIONS

Phase 1 results have helped to prioritize reaches for further field-based assessment. Twenty-three reaches are recommended for Phase 2 Stream Geomorphic Assessment, as listed in Table 15. This list was compiled by a project steering committee comprised of representatives from SMRC, the VT Water Quality Division, and the Southern Windsor County Regional Planning Commission. A general priority ranking for each reach is also presented in Table 15.

In general, these reaches tend to have the highest identified provisional impact scores, and thus are expected to demonstrate higher degrees of channel adjustment and sensitivity based on their topographic and geomorphic setting and provisional identification of past and current watershed and channel disturbances. Other considerations included proximity to reach(es) with a high impact score, and potential for restoration or conservation projects that could support a reduction in sediment and nutrient mobilization and/or mitigation of fluvial erosion hazards.

Table 15. Reaches Recommended for Phase 2 Field-Based Assessment

Tributary	Reach	Length (ft)	Provisional (Phase 1) Stream Type	Impact Score	Priority
Black River main stem	M30	8,101	C-dune/ripple	19	1
	M31	3,741	C-riffle/pool	19	1
	M32	12,000	C-riffle/pool	21	1
	M33	7,849	C-riffle/pool	21	1
	M34	2,161	C-riffle/pool	18	1
	M35	1,713	Bc-riffle/pool	12	1
	M36	4,713	C-riffle/pool	18	1
	M26	1,815	C-riffle/pool	14	2
	M27	3,999	C-riffle/pool	16	2
	M19	7,697	C-riffle/pool	19	2
North Branch	M15T1.05	6,365	C-dune/ripple	18	1
	M15T1.06	6,547	C-dune/ripple	18	1
	M15T1.07	2,740	C-riffle/pool	12	1
	M15T1.08	2,488	C-riffle/pool	17	1
	M15T1.09	3,664	C-riffle/pool	17	2
	M15T1.10	2,400	C-riffle/pool	16	2
	M15T1.11	1,138	C-step/pool	15	2
Twentymile Stream	M26T2.05	5,400	C-riffle/pool	14	1
	M26T2.06	9,808	C-dune/ripple	13	1
	M26T2.07	4,926	C-riffle/pool	10	1
	M26T2.08	3,634	C-riffle/pool	9	1
Branch Brook	M36T4.01	3,228	C-riffle/pool	18	1
	M36T4.02	2,074	C-riffle/pool	17	2

Given the size of the Black River watershed and due to budgetary constraints, only a subset of the 341 watershed reaches was fully assessed in this Phase 1 study. Steps 5 through 7 (following baseline delineation in SGAT) were not able to be completed for many of the Major Tributaries and Minor Tributaries of the watershed. Based on Windshield Survey observations and feedback from the public received in outreach meetings (June 2007), sediment erosion issues are prevalent on many of these smaller tributaries. Depositional bars were noted on the Black River main stem at the confluence of several tributaries, including Patch Brook, Reading Pond Brook, Tinker Brook, and Seaver Brook. Phase 1 should be completed on the remaining Major Tributaries and the Minor tributaries, particularly those with high road and development densities.

Evaluation of these smaller tributary reaches would be aided by Bridge and Culvert Assessments at crossing structures (following Appendix G of VTANR protocols).

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