

1.0 INTRODUCTION

South Mountain Research & Consulting Services (SMRC) of Bristol, Vermont was contracted by the Lewis Creek Association (LCA) to complete a Phase 1 Geomorphic Assessment for three small tributaries to the Lewis Creek watershed which are unnamed on the USGS topographic maps. The locations of these tributaries are indicated on Figure 1:

- ◆ A tributary draining 2.9 square miles near Prindle Corners (Charlotte) and joining reach M10 of the Lewis Creek main stem (**T1**, identified as Prindle Brook for this study);
- ◆ A tributary draining a 1.02-square-mile subwatershed east of Route 116 in Starksboro and joining reach M16 of the Lewis Creek main stem (**M16S1**); and
- ◆ A tributary draining a 5.21-square-mile subwatershed along Big Hollow Road in Starksboro and joining reach M20 of the Lewis Creek main stem (**T6**, identified as High Knob Brook for this study).

Reaches in these tributary watersheds were previously delineated by the VT Department of Environmental Conservation, Water Quality Division (VTDEC WQD) River Management Section staff and added to the Phase 1 database and Stream Geomorphic Assessment Tool (SGAT) project for Lewis Creek. SGAT-automated Phase 1 steps for these new reaches were completed by the RMS staff; select non-SGAT steps were also completed by the RMS using the Feature Indexing Tool of SGAT (version 4.50) and following the 2006 version of the Phase 1 protocols:

- ◆ Bridges and culverts (Phase 1 Step 5.2);
- ◆ Straightening (Phase 1 Step 5.4);
- ◆ Encroachments: Roads (Step 6.1);
- ◆ Development (Phase 1 Step 6.2).

The current scope of work involved completing the remaining Phase 1 steps and updating the previously-indexed features, using version 4.56 of SGAT and FIT and following the 2007 version of the Phase 1 protocols. Data have been uploaded to the database of stream geomorphic data maintained by the VTDEC WQD, and are summarized in the following report and appendices.

The reader is referred to the separate volume, *Phase 2 Stream Geomorphic Assessment of the Lewis Creek* (SMRC, 2007) for more details of the geology, hydrology, and geomorphology of the Lewis Creek watershed.



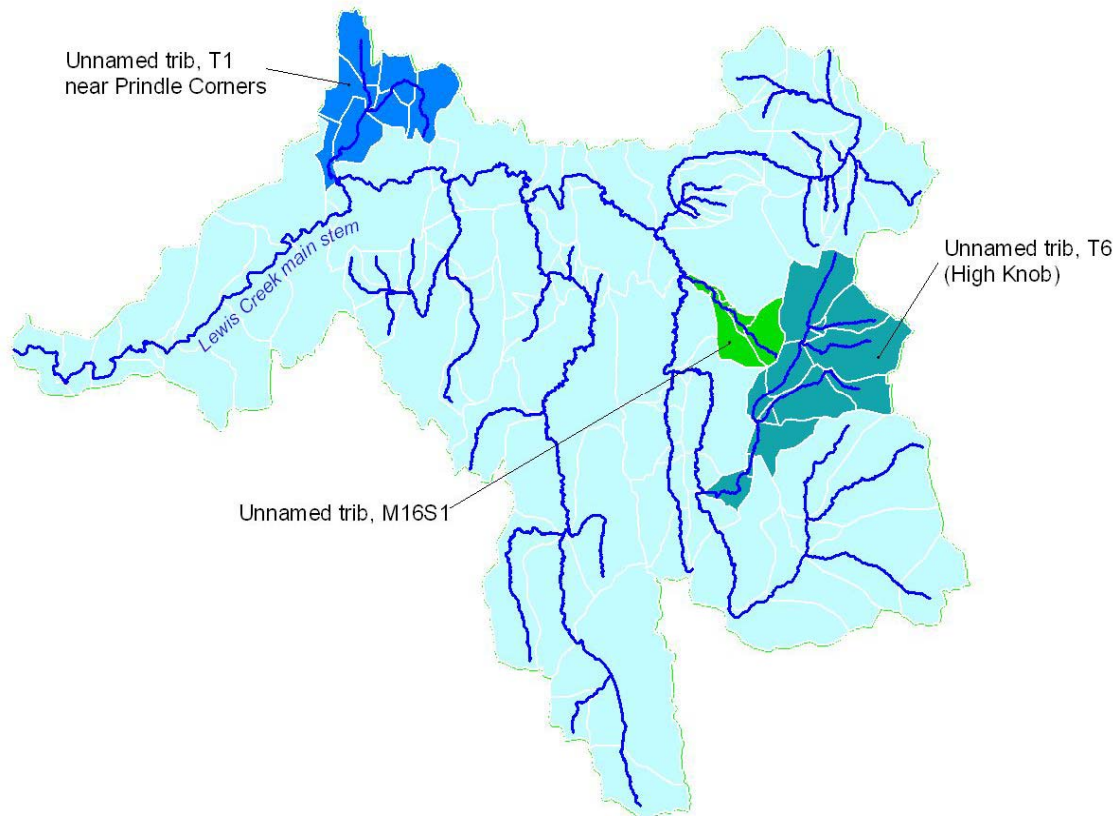


Figure 1. Location of newly-delineated tributary subwatersheds of Lewis Creek watershed, Addison and Chittenden Counties, Vermont..

2.0 GEOGRAPHIC SETTING

The Prindle Brook subwatershed is located in Charlotte and has been delineated into seven distinct reaches (area shaded medium blue in Figure 2).

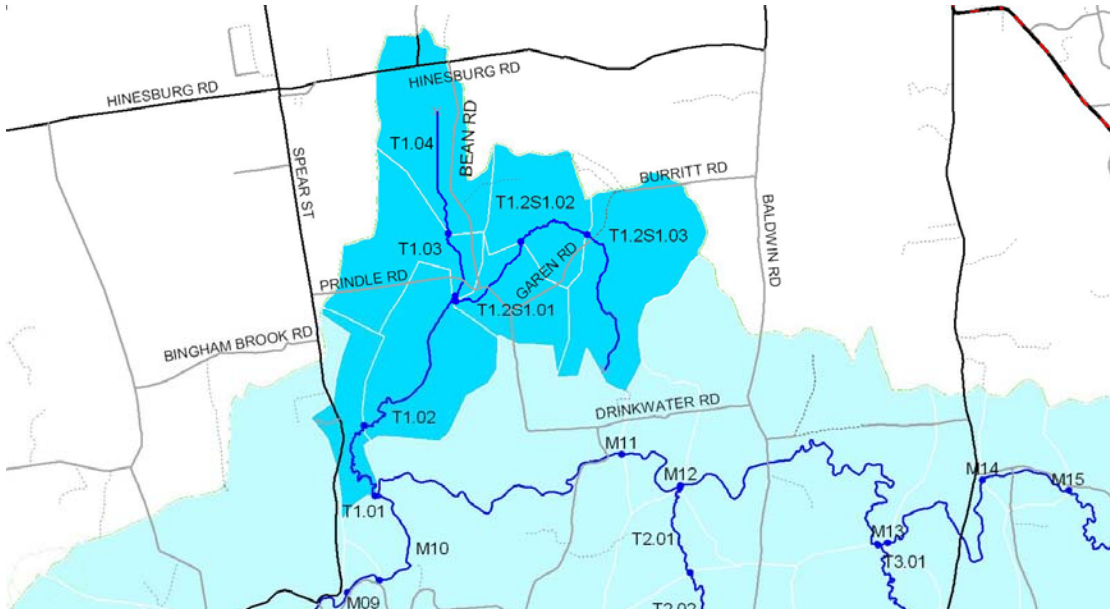


Figure 2. Prindle Brook subwatershed location map.

The M16S1 tributary subwatershed is located in Starksboro and has been delineated into four reaches (area in green depicted in Figure 3). This watershed shares a common boundary with the High Knob Brook subwatershed.

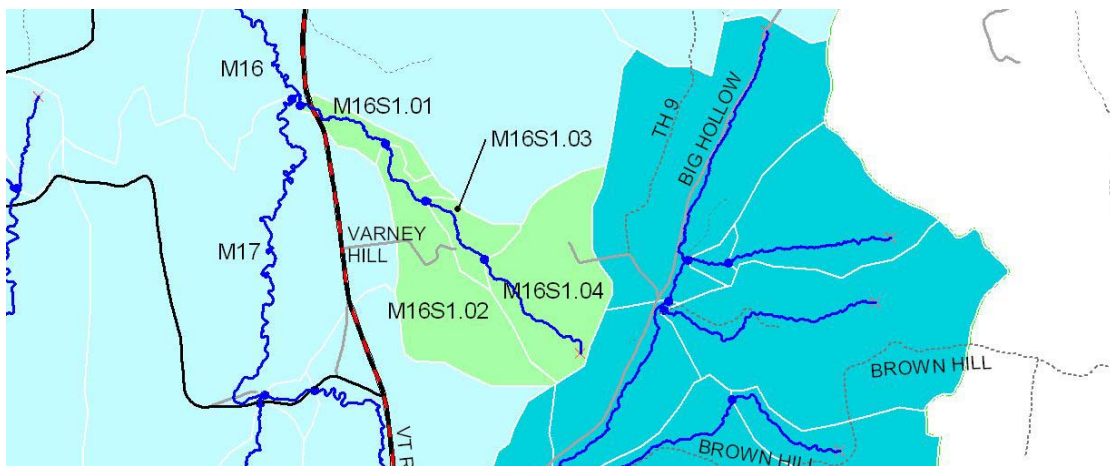


Figure 3. M16S1 subwatershed location map.



The High Knob Brook subwatershed is located in Starksboro and has been delineated into twelve reaches (area shaded medium blue in Figure 4). This watershed shares a common boundary with the M16S1 subwatershed.

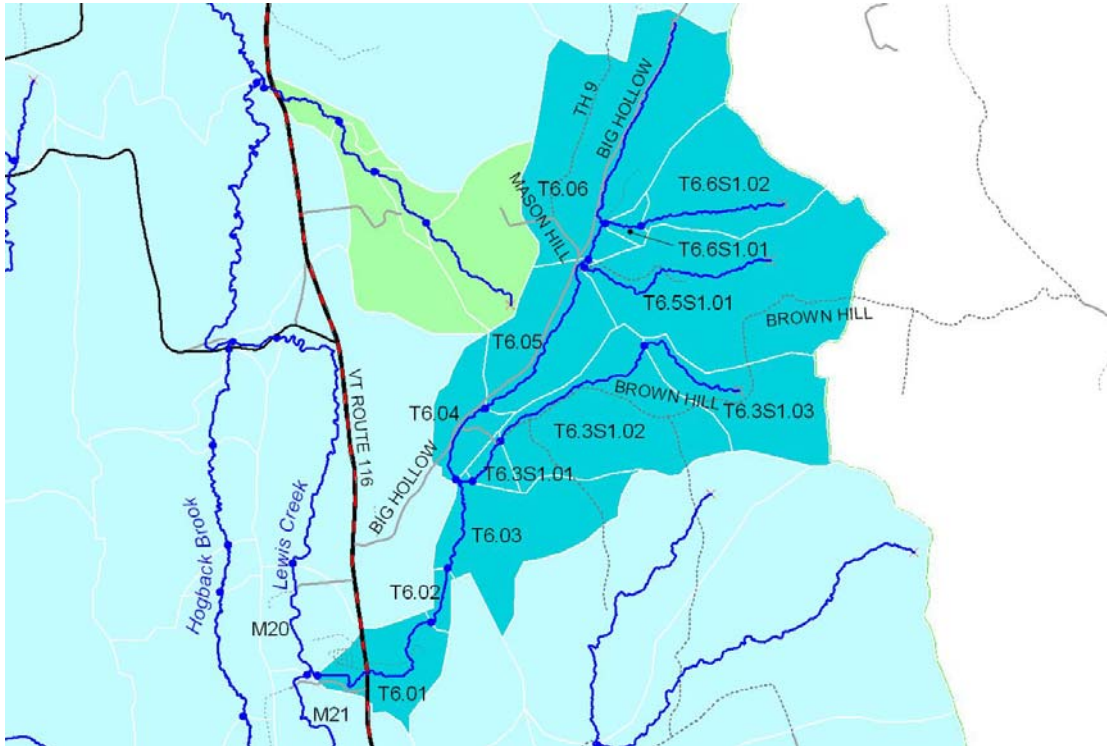


Figure 4. High Knob Brook subwatershed location map.

3.0 ASSESSMENT METHODS

The Phase 1 Stream Geomorphic Assessment of the Lewis Creek tributaries 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 following sections of this report.

Steps 2 through 7 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>.

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.



3.1 Remote-Sensing Resources

Appendix A provides index maps to select resources utilized in remote sensing of the Lewis Creek watershed, including 1:5000 black and white orthophotographs (dated 1995, 1999), USGS topographic maps (various dates), and National Agricultural Imagery Program aerial photography (2003). Additional resources included the historic USGS topographic maps, Natural Resources Conservation Service (NRCS) soil mapping for Addison and Chittenden 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 1942, 1962 and 1974 aerial photographs were also reviewed at NRCS offices in Middlebury, Vermont and [Williston, Vermont](#).

3.2 Windshield Survey, Historical Research and Non-SGAT steps

A windshield survey was conducted in each of the three Lewis Creek tributary watersheds to:

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

Only those portions of the river network easily accessed by vehicle were assessed during the 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 B). Observations were subsequently reduced to pertinent records of Phase 1, Steps 5, 6, and 7.

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 was also 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 1:5000 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.

A Quality Assurance review of the Phase 1 data was performed by River Management Section staff. A record of this QA review and QA response is contained in Appendix C.



4.0 RESULTS

4.1 Reach Delineations

The 23 new reaches of Lewis Creek tributaries were previously delineated by the River Management Section of the VT Water Quality Division on the basis of valley confinement, gradient, and sinuosity, as well as tributary influence (see protocols for further background). Of these 23 new reaches, channel lengths ranged from approximately 1,285 feet (0.24 mile) to 8,482 feet (1.6 miles), with an average length of 4,030 feet (0.76 mile). Reach identifications are presented in Table 1 (see also Step 2 documentation in Appendix D).

Table 1. Phase 1 Reach Delineation of the 23 new reaches on Lewis Creek tributaries.

Tributary	Reach	Town	Channel Length (ft)
Unnamed tributary to Lewis Creek (M16S1)	M16S1.01	Starksboro	3,208
	M16S1.02	Starksboro	2,304
	M16S1.03	Starksboro	2,602
	M16S1.04	Starksboro	4,135
Prindle Brook (T1)	T1.01	Charlotte	3,968
	T1.02	Charlotte	6,282
	T1.03	Charlotte	2,286
	T1.04	Charlotte	3,899
	T1.2S1.01	Charlotte	3,109
	T1.2S1.02	Charlotte	2,785
	T1.2S1.03	Charlotte, Hinesburg	5,010
High Knob Brook (T6)	T6.01	Starksboro	5,649
	T6.02	Starksboro	1,854
	T6.03	Starksboro	3,438
	T6.04	Starksboro	2,907
	T6.05	Starksboro	6,236
	T6.06	Starksboro	8,482
	T6.3S1.01	Starksboro	1,586
	T6.3S1.02	Starksboro	5,845
	T6.3S1.03	Starksboro	3,906
	T6.5S1.01	Starksboro	6,950
	T6.6S1.01	Starksboro	1,285
	T6.6S1.02	Starksboro	4,969

4.2 Reference Stream Typing

Table 2 contains a summary of reference stream types assigned to the 23 delineated tributary reaches of the Lewis Creek. Refer to Appendix D for a summary of Phase 1 Step 2 data for each reach, 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.

Table 2. Phase 1 (Provisional) Reference Stream Types of the 23 new reaches on Lewis Creek tributaries.

Tributary	Reach	Valley Slope (%)	Channel Length (ft)	Channel Slope (%)	Valley Confinement	Provisional Stream Type
Unnamed tributary to Lewis Creek (M16S1)	M16S1.01	2.38	3,208	1.87	NW	C – riffle/pool
	M16S1.02	4.76	2,304	4.34	NC	A – step/pool
	M16S1.03	6.67	2,602	6.15	NC	A – step/pool
	M16S1.04	14.75	4,135	14.27	NC	A - cascade
Prindle Brook (T1)	T1.01	3.44	3,968	2.39	SC	B – step/pool
	T1.02	0.58	6,282	0.48	VB	C – riffle/pool
	T1.03	0.15	2,286	0.13	VB	E – dune/ripple
	T1.04	0.19	3,899	0.18	VB	E – dune/ripple
	T1.2S1.01	0.25	3,109	0.23	VB	C – dune/ripple
	T1.2S1.02	0.56	2,785	0.47	VB	E – dune/ripple
	T1.2S1.03	0.42	5,010	0.40	VB	C – riffle/pool
High Knob Brook (T6)	T6.01	3.50	5,649	3.10	SC	B – step/pool
	T6.02	2.94	1,854	2.70	SC	B – step/pool
	T6.03	1.01	3,438	0.87	VB	C – riffle/pool
	T6.04	0.99	2,907	0.86	VB	C – riffle/pool
	T6.05	1.32	6,236	1.20	BD	C – riffle/pool
	T6.06	1.63	8,482	1.47	SC	B – riffle/pool
	T6.3S1.01	2.39	1,586	2.21	VB	C – riffle/pool
	T6.3S1.02	7.68	5,845	7.36	NC	A – step/pool
	T6.3S1.03	10.27	3,906	9.73	NC	A – step/pool
	T6.5S1.01	11.04	6,950	10.65	NC	A - cascade
	T6.6S1.01	20.91	1,285	17.90	NC	A - cascade
T6.6S1.02	14.04	4,969	13.28	NC	A - cascade	

Table 3 summarizes the generalized stream type categories used to classify reaches; Table 4 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 / channel slopes. Resolution of the 1:24,000 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, where they could not be accessed during windshield surveys. 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 range-finder or taped measurements of channel width and valley width were made, although field-based observations of select reaches supported valley width estimates.



Table 3. Classification of Reach Types (adapted from VTANR protocols, 2007)

Reference Stream Type	Confinement (Valley Type)	Valley Slope
A	Narrowly Confined (NC)	Very Steep (> 6.5%)
A	Confined (NC)	Very Steep (4.0 - 6.5%)
B	Confined or Semi-confined (NC, SC)	Steep (3.0 - 4.0%)
B	Confined or Semi-confined or Narrow (NC, SC, NW)	Moderate - Steep (2.0 – 3.0%)
C or E	Unconfined (NW, BD, VB)	Moderate – Gentle (< 2.0%)
D	Unconfined (NW, BD, VB)	Moderate – Gentle (< 4.0%)

Table 4. 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

None of the delineated Lewis Creek tributary 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 1.44 (see Appendix D).

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.

None of the 23 newly delineated Lewis Creek tributary reaches was identified as a potential alluvial fan site.

4.3.2 Grade Controls

Delineated reaches of the Lewis Creek 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 Lewis Creek 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. A notable example is a section of the upper High Knob tributary in Starksboro (reach T6.06).

Several channel-spanning exposures of bedrock along the delineated main stem and tributary reaches were catalogued as grade controls, as recorded in Appendix D (Step 3 documentation). 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:

- ◆ bedrock mapping data:
 - DiPietro, 1983 – mapping coverage limited to reaches T6.01, T6.02, T6.03, T6.04, T6.05, T6.3S1.01, T6.3S1.02, T6.3S1.03, and T6.5S1.01 of the High Knob tributary watershed;
 - Thompson, et al., 2004 - mapping coverage limited to reaches M16S1.01, M16S1.02, M16S1.03, and downstream end of M16S1.04, in the unnamed tributary watershed;
- ◆ 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>)

The above resources suggest that channel-spanning bedrock is absent from the Prindle Brook watershed reaches. Field investigation would be required to confirm this. Prominent exposures



of bedrock were observed comprising the valley walls of these reaches during the windshield survey.

While reaches M16S1.03 and M16S1.04 were not accessible for direct field observation, bedrock mapping (Thompson, et al., 2004) suggests that channel-spanning bedrock is present in these sections of the unnamed tributary to main stem reach M16. Similarly, channel-spanning bedrock exposures are suggested by bedrock mapping (DiPietro, 1983) in reaches of the High Knob tributary and its tributaries – reaches T6.01, T6.02, T6.3S1.02, and T6.5S1.01. While detailed bedrock mapping did not cover the upstream tributary to High Knob Brook (reaches T6.6S1.01 and T6.6S1.02), and vehicle-accessible field observation was not possible, channel-spanning bedrock is expected in this steep, narrowly-confined tributary.

Dams

Resources reviewed to determine locations of dams included:

- ◆ Vermont Dam Inventory (*EmergencyOther_DAMS* coverage obtained from VCGI);
- ◆ field observations during the windshield survey;
- ◆ orthophotographs, aerial photographs, and topographic maps (current and historic); and
- ◆ 1869 Beers Atlas for Chittenden County; 1871 Beers Atlas for Addison County.

No constructed dams serving as potential grade control structures were identified on the 23 newly-delineated Phase 1 reaches of the Lewis Creek tributaries.

4.3.3 Geologic Materials

Surficial geologic materials were summarized for the Lewis Creek watershed through analysis of soil survey mapping data available from USDA Natural Resources Conservation Service (USDA, 1971). 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 D (Step 3 documentation).

The unnamed tributary to main stem reach M16 originates on the steeper, bedrock-controlled upland slopes which are dominated by a veneer of glacial tills (reach M16S1.04). This tributary then flows over glacial kame terrace deposits, where more erodible sands, gravels and cobbles dominate (reaches M16S1.03, M16S1.02, upstream end of M16S1.01). Near the confluence with the Lewis Creek main stem (downstream half of M16S1.01), sediments of alluvial origin are present (USDA, 1971; Stewart & MacClintock, 1969; Doll, 1970). It is in this downstream-most reach that the tributary transitions from the Green Mountain physiographic province to the Champlain Valley province (Stewart, 1973; Thompson & Sorenson, 2000).

Similarly, the High Knob Brook tributary originates on the till-covered slopes of the Green Mountains (e.g., reaches T6.06, T6.6S1.01, T6.6S1.02, T6.5S1.01, and T6.3S1.03 and T6.3S1.02). Sediments of glacial outwash origin fill the narrow bedrock-controlled valley of the High Knob tributary from the Dugway Lane intersection of the Big Hollow Road downstream to the vicinity of Baldwin Pond (reaches T6.05, T6.04, T6.03 and T6.3S1.01). High Knob Brook then flows south from the vicinity of Baldwin Pond through an area mapped as till-covered bedrock (reach T6.02) before shifting to the west to flow through alternating mapped sequences of glacial



outwash, till, kame terrace and possible deltaic gravels of lacustrine origin before joining the Lewis Creek just downstream of the Tatro Road crossing (Calkin, 1965; Stewart & MacClintock, 1969; Doll, 1970; USDA, 1971). Within this downstream reach T6.01, the High Knob tributary transitions from the Green Mountains to the Champlain Valley (Stewart, 1973; Thompson & Sorenson, 2000).

In contrast, the reaches of the Prindle Brook watershed farther to the west in the Champlain Valley are dominated by boulder-clays of lacustrine origin (Stewart, 1965-1966; Stewart & MacClintock, 1969; Doll, 1970). These silts and clays (mapped as Livingston clay; Covington silty clay by USDA, 1971) are hydric in nature and dominate the low-land valley areas between prominent knolls of exposed bedrock (Stewart, 1965-1966).

Additional background on the geology and hydrology of the Lewis Creek is contained in the separate volume, *Phase 2 Stream Geomorphic Assessment of the Lewis Creek* (SMRC, 2007).

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 D (Step 3 documentation). In the High Knob tributary (T6) and the Unnamed tributary (M16S1), 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. In contrast, the reaches of the Prindle Brook in the Champlain Valley have more moderate valley side slopes.

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 D.

4.4 Land Cover and Reach Hydrology

4.4.1 Watershed Land Cover / Land Use

Using SGAT version 4.50, land cover / land use in the Lewis Creek watershed were 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 5 summarizes the land cover / land use in the newly-delineated tributaries of the Lewis Creek. Prindle Brook, in the Champlain Valley, has a higher percentage of agricultural land cover / land use than either the High Knob Brook or the Unnamed tributary (M16S1), which are located primarily on the forested slopes of the Green Mountains.



Table 5. Land cover/ land use in newly-delineated tributaries of the Lewis Creek.

Watershed	Drainage Area (sq mi)	Commercial / Industrial	Residential	Agricultural	Forest / Shrub	Water / Wetland
Lewis Creek	81.1	0%	5%	26%	61%	8%
T1 (Prindle Brook)	2.9	0%	5%	46%	39%	10%
M16S1	1.0	0%	3%	19%	74%	5%
T6 (High Knob Bk)	5.2	0%	5%	6%	85%	4%

Appendix D (Step 4 documentation) 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.

All reaches of the Prindle Brook were assigned “High” impacts for crop and urban percentages ranging from 20.2 to 47.9%. All reaches of the High Knob subwatershed were assigned “Low” impacts, except for T6.6S1.01 and T6.6S1.02 which are remote, forested reaches and had “Not Significant” impacts. The lower two reaches of M16S1 were assigned “High” impacts, while the upper two forested reaches were assigned “Low” impacts.

Historic land cover / land use was visually estimated for the upstream watershed draining to each of the 23 newly-delineated reaches, based on review of 1974 aerial photographs (except for Prindle Brook reaches for which 1942 photos were consulted, as noted in the comments section [Step 7] of the DMS. Historic land cover/land use was similar to “current” (1993) land cover/land use.

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 Lewis Creek and its tributaries. Appendix D 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.

In the Prindle Brook, three reaches were assigned “High” impacts, three were assigned “Low” impacts, and corridor land cover / land use impacts were determined to be “Not Significant” for one reach. Four reaches of the High Knob subwatershed were assigned “High” impacts, including T4.04, T4.05, and T4.06 due to the influence of the Big Hollow Road in the corridor. Four reaches were assigned “Low” impacts and four were assigned a “Not Significant” impact. In the M16S1 tributary subwatershed, the three downstream reaches were assigned “Low” impacts, while the uppermost, forested reach was assigned a “High” impact. This result is due to the influence of the old road within the reach corridor.

The automated methods for analyzing land cover /land use tend to overstate the impacts of transportation networks in these small streams. The land cover land use data set is a pixelated 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.

Historic land cover / land use was visually estimated for the corridor surrounding each of the 23 newly-delineated reaches, based on review of 1974 aerial photographs (except for Prindle Brook reaches for which 1942 photos were consulted, as noted in the comments section [Step 7] of the DMS. Generally speaking, historic land cover/land use in the reach corridors was similar to “current” (1993) land cover/land use - with one exception. The downstream most reach of Prindle Brook (T1.01) was historically cleared for agricultural use, while the current cover is more forested.

4.4.3 Riparian Buffer

The 23 newly-delineated tributary reaches of the Lewis Creek were reviewed on orthophotographs (1995, 1999) and aerial imagery (NAIP, 2003) 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 D (Step 4 documentation). 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).



Most often, buffer widths were reduced due to the presence of roads alongside the channel. Buffer widths were also reduced as a result of development in the urbanized areas and cultivation of fields in agricultural areas. In the Prindle Brook, three reaches were assigned "High" impacts for buffers, two were assigned "Low" impacts, and two were assigned a "Not Significant" rating. In the High Knob Brook, one reach was assigned a "High" impact, three were assigned "Low" impacts, and the remaining forested reaches were assigned a "Not Significant" rating. The lower two reaches of M16S1 were assigned "Low" impacts, while the upper two forested reaches were assigned "Not Significant" impacts.

4.4.4 Groundwater Inputs

Following protocols, groundwater inputs to each Phase 1 delineated reach were estimated as either Abundant, Minimal or None, based 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, hydric soils (NRCS coverage), and Vermont Significant Wetland Inventory mapping. Results are recorded in Appendix D (Step 4 documentation).

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);
- ◆ Vermont Water Supply Division file review on 13 February 2007;
- ◆ Stream Alteration Permit Engineer interview (Brunelle, 2007);
- ◆ field observations during the windshield survey;
- ◆ orthophotographs, aerial photographs, and topographic maps (current and historic);

Dams/ Impoundments

One in-stream impoundment was observed to be located on the 23 Lewis Creek tributary reaches. A 400-foot long and 100-foot wide impoundment extends upstream from a driveway crossing near the mid-point of reach T6.06 on the High Knob Brook. No formal dam structure was apparent (and no such feature was identified on the Vermont Dam Inventory); therefore no dam was indexed at this location under Step 3.2 (grade control). However, elevated fill placement for the driveway crossing over a small-diameter culvert has effectively impounded the High Knob tributary at this location. The approximate drainage area to this location is small – an estimated 0.4 square mile. This impoundment is present on the 1974, 1995 and 2003 aerial photography, but absent on the 1962 and 1942 aerial photos of the region, suggesting that it was formed between 1962 and 1974. The pond is indicated in purple on the 1987 Hinesburg, VT 7.5-Minute USGS topographic map, indicating that it is a feature which appeared in the landscape after the original 1948 publication date of this map and prior to the 1987 publication of the updated map (photo-revised from 1983 aerial photographs). This time span is consistent with a pre-1974, and post-1962 impoundment of the High Knob Brook.



This impoundment on reach T6.06 was classified as a Run-of-River structure, meaning that the flow of water entering the upstream impoundment equals the flow of water leaving the impoundment. (It is possible that the small culvert at the downstream end of the dam conveys water at a lesser rate than water entering the impoundment during high-flow events, thus causing a temporary “storage” effect. However, this structure does not appear to have been constructed as a formal “Store and Release” structure as defined in the protocols). The in-stream impoundment significantly changes the channel geometry and potentially may alter sediment transport dynamics. As such it was assigned a “High” impact under Step 5.1 (see Appendix D). The presence of this in-stream impoundment contiguous to active cattle pasture, suggests that the impoundment serves as an irrigation source for livestock.

A past impoundment of the High Knob Brook in reach T6.06 was also revealed from historic aerial photo review near the downstream end of the reach just upstream of the T6.6S1.01 confluence. This past impoundment extended approximately 650 feet upstream of the Dugway Lane crossing of the brook. This impoundment was apparently short-lived (possibly related to beaver activity). It appeared on the 1974 photograph but was absent on the 1942, 1962, 1995 and 2003 photos, and was absent on the 1948 (photoinspected 1983) topographic map. In these other photographs, this section of the brook had a similar appearance to present day – a sinuous planform through apparent wetlands. Since this impoundment is not present today, it was not indexed; however, a note regarding the past presence of this impoundment was added to the Comments section (Step 7) of the DMS.

One constructed dam / reservoir was noted within the High Knob tributary watershed, on a small, non-delineated tributary to reach T6.5S1.01. Impoundment effects of this dam and/or catastrophic dam failure may influence the High Knob tributary. According to the Vermont Dam Inventory, the Clifford dam is approximately 208 feet long and 13 feet high and was constructed for recreational purposes in 1971, as designed by the Natural Resources Conservation Service; it is a Hazard Class 3 dam under jurisdiction of the VT Department of Environmental Conservation. The 5-acre impoundment immediately upstream of the dam is noted in purple shading on the 1987 Hinesburg, VT 7.5-Minute USGS topographic map (see Figure 5), indicating that it is a feature which appeared in the landscape after the original 1948 publication date of this map and prior to the 1987 publication of the updated map (photo-revised from 1983 aerial photographs). This time span would be consistent with a 1971 construction date. The impoundment is visible on the 1974 aerial photographs, but absent on the 1962 and 1942 photographs. The Vermont Dam Inventory also notes that this dam is owned by the Town of Starksboro. However, the Starksboro Town Clerk indicated that the dam (located off Stokes Hill Road) is owned by Art and Susan Clifford and is used privately for recreation (Estey, 2007). Since the dam / impoundment is not located on one of the 23 delineated reaches, it was not indexed using FIT under either Step 3.2 (grade controls) or Step 5.1 (impoundments). However, a note pertaining to its presence was added to the comment section (Step 7) of the DMS for reach T6.5S1.01.



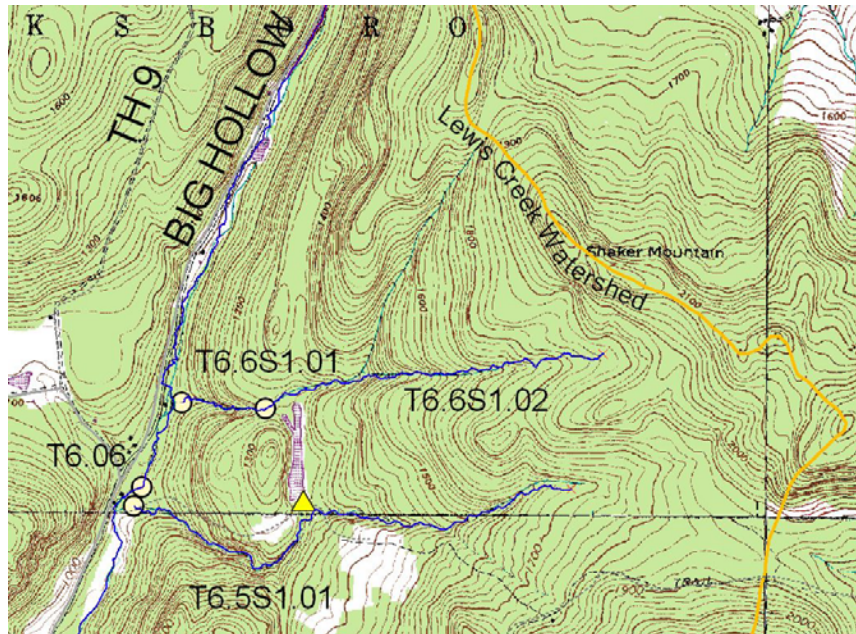


Figure 5. Clifford dam site (yellow triangle) located on a small tributary draining to reach T6.5S1.01 in the High Knob watershed, Starksboro, VT. (Base map: Hinesburg, VT 7.5-Min. USGS topographic map, 1948, photorevised 1987 from 1983 aerial photos).

Flow Diversions or Water Withdrawals

No formal flow diversion sites were identified within the 23 newly-delineated Lewis Creek tributary reaches.

No direct surface water withdrawal sites for drinking water use were identified within the 23 Phase 1 tributary reaches, from a review of Surface Water Source Protection Areas on file with the VT Water Supply Division (records reviewed 13 February 2007). No water withdrawal sites for other purposes were evident from field-based observations or resources reviewed.

There are two public water supplies whose Source Protection Areas extend across the Lewis Creek tributaries, and which may be recharged in part from surface water which infiltrates from the tributaries. Notes to this effect were included in the comments section (Step 7) of the Phase 1 database under relevant reaches. These include:

- ◆ Starksboro Village Water Coop (WSID #5005) – which consists of a spring source at the upstream extent of a Lewis Creek tributary draining via the Baldwin Pond and ultimately joining Lewis Creek in reach M19. The Source Protection Area for this spring extends up to the southwest side of the High Knob Brook in reaches T6.03 and T6.04.
- ◆ Brookside Mobile Home Park water system (WSID #5006) – which consists of multiple drilled bedrock wells located along the north side of the High Knob Brook. The Source Protection Area for this well extends across a broad area including reach T6.01 of the High Knob Brook.



4.5.2 Bridges and Culverts

Locations of bridge and culvert crossings were indexed on the Lewis Creek tributary reaches. The number of crossing structures and the length of channel inferred to be impacted by each structure is recorded for each reach in Appendix D. 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)

Bridge and culvert impacts for each of the 23 reaches was determined to be “Not Significant”.

4.5.3 Bank Armoring / Revetments

Locations of bank armoring and revetments on the 23 tributary reaches were documented under Phase 1 Step 5.3. Data were populated from a variety of sources, including:

- Field observations during the windshield survey (see Appendix B);
- Review of orthophotos (1995, 1999) and aerial imagery (2003);
- Interview with VT WQD Stream Alteration Engineer (Brunelle, 2007).

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 (see Appendix D):

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

Bank armoring and revetment impacts for each of the 23 reaches was determined to be “Not Significant”. However, the Phase 1 reaches were not 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 some reaches. Field-based assessment of reaches would yield a more comprehensive evaluation of bank armoring and revetments. It is possible that impact ratings would change 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:

- ◆ Field observations during the windshield survey (see Appendix B);
- ◆ Comparison of historic aerial photographs (1942, 1962, 1974) to more recent photographs (1995 orthophotographs, 2003 aerial imagery);
- ◆ Interview with NRCS personnel in the Middlebury office on (Lossmann, 24 August 2007) and Williston office (Alves, 2007);
- ◆ Interview with VT WQD Stream Alteration Engineer (Brunelle, 2007);

Approximate locations of channel straightening on the Lewis Creek tributaries were documented using the Feature Indexing Tool of SGAT and uploaded to the Phase 1 database (previously indexed straightening by the River Management Section was reviewed and updated based on the newly-available historic photographs and Windshield Survey evidence). Impact ratings were assigned to each reach based on the percentage of inferred straightening (see Appendix X):

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

Channelization was prevalent in the reaches of the Prindle Brook due to the past history of cultivation and pasturing, and due to the hydric soils and wetland conditions. Except for the downstream reach T1.01 (which was "Not Significant") all Prindle Brook reaches were assigned a "High" impact for channelization.

Minimal straightening was observed in the Unnamed tributary to M16; a short section is inferred near the Route 116 crossing at the downstream reach (supported by historic aerial photo review). Reach M16S1.01 was assigned a "Low" impact, while straightening in the remaining reaches was considered "Not Significant".

Generally, straightening in the High Knob Brook was limited to the main valley along Big Hollow Road. Evidence for past straightening was most obvious on the 1942 photographs. Agricultural clearing of the corridor and watershed landscape was more extensive in this era, as compared to the 1960s, 1970s and 1990s aerial photographs. The High Knob tributary appears to have been channelized along the eastern, forested wall of the valley. Another notable example of channelization occurred within reach T6.06 near the Dugway Lane intersection of the High Knob



Brook. The current planform (and the apparent planform on photographs from 2003, 1995, 1974, and 1962 is actually along the west side of Big Hollow Road for an approximate length of 650 feet – different than the planform indicated by the Vermont Hydrography Dataset (VHD). The current planform is indicated in light blue on Figure 6, superimposed on the 2003 base photograph.

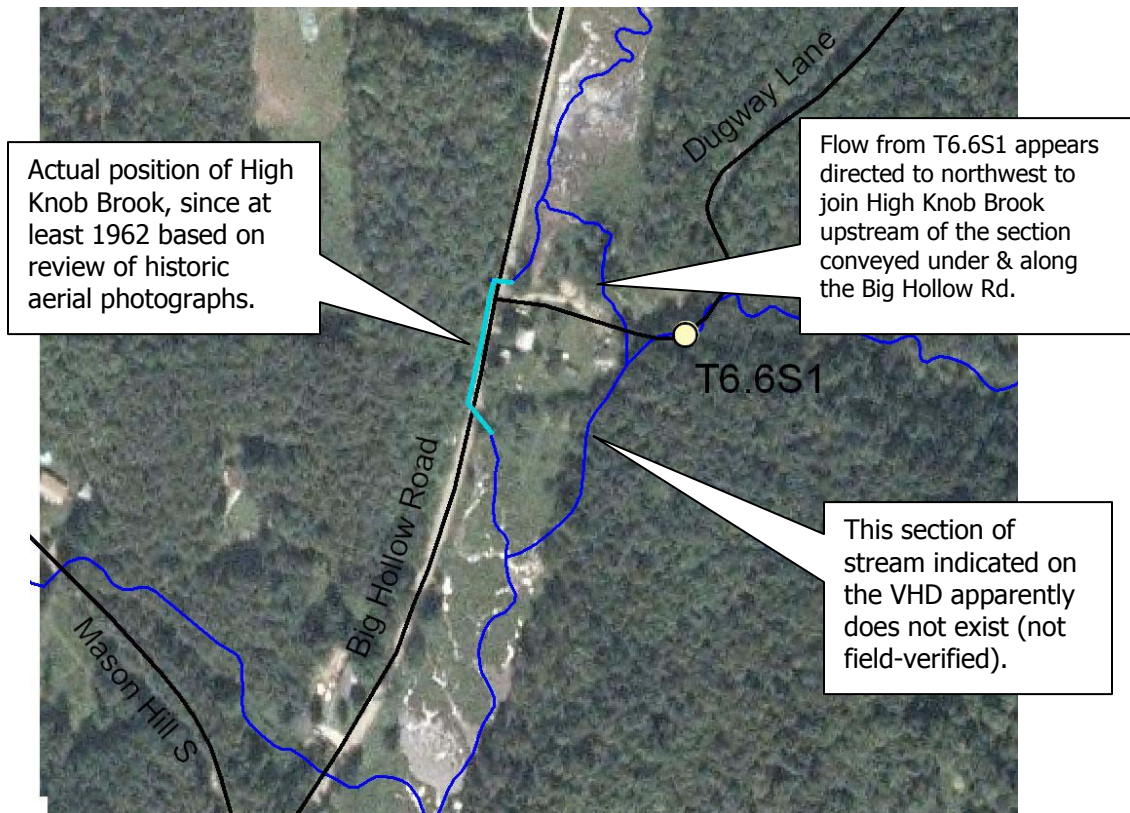


Figure 6. Apparent pre-1962 channelization of High Knob Brook along the Big Hollow Road, reach T6.06.

Reaches along the Big Hollow Brook (T6.04, T6.05, T6.06) and reach T6.3S1.01 were assigned "High" impacts for channelization. Straightening was determined to be "Not Significant" for the remaining reaches of the High Knob subwatershed.

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.



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.

Resources reviewed to identify locations of past dredging and/or gravel mining in the Lewis Creek tributaries included:

- ◆ VTDEC Water Quality Division publication (VTDEC WQD, 1999);
- ◆ field observations during the windshield survey (Appendix B);
- ◆ Interview with VT WQD Stream Alteration Engineer (Brunelle, 2007).

No evidence for gravel extraction / dredging was revealed by the above resources in the 23 tributary reaches of the Lewis Creek.

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. Presence of berms was reviewed during windshield surveys of vehicle-accessible portions of these reaches (see Appendix B). Roads, driveways, and improved paths were noted from a review of the 1995 / 1999 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.

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 4.50), 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 $\geq 20\%$ of the right and/or left bank.
LOW	Berms, roads, railroads or improved paths are present within the river corridor along $\geq 5\%$ 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

In the Prindle Brook watershed, the downstream reach T1.01 was assigned a "High" impact due to presence of an old gravel road that appears to have accessed a former gravel pit (based on features noted on the USGS topographic map). Encroachments in all other reaches of the Prindle Brook were determined to be "Not Significant".

An old forest road, more recent driveways and Route 116 were noted as encroachments along the M16S1 subwatershed reaches. The uppermost reaches were assigned a "High" impact; the downstream two reaches were assigned a "Low" impact.

In the High Knob subwatershed, driveways, Big Hollow Road and more remote forest roads were noted as encroachments. Three reaches were assigned "High" impacts; two were assigned "Low" impacts, and seven of the more remote, forested reaches were assigned a "Not Significant" rating.

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 1995/1999 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 $\geq 20\%$ of the right and/or left bank.
LOW	Developments are present within the river corridor along $\geq 5\%$ 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

Developments within the corridor were determined to be "Not Significant" in all of the Prindle Brook subwatershed reaches.

In the M16S1 subwatershed, a "Low" impact was assigned to reach M16S1.02 due to the presence of residential buildings; developments within the corridor were considered "Not Significant" for the remaining reaches.

Five of the High Knob reaches (along Big Hollow Road, Brown Hill Road, and Freedom Acres Road) were assigned "Low" impacts for development in the corridor. The remaining reaches were assigned "Not Significant" ratings.

4.6.3 Depositional Features

The short-listed reaches were reviewed on 2003 aerial photography and 1995/1999 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 the windshield survey also informed data development in Step 6.3. Presence and type of depositional bars were noted in the Phase 1 database (see Appendix D). 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.

Depositional features were considered "Not Significant" for the Prindle Brook reaches. These reaches are generally low-gradient reaches dominated by cohesive soils and wetland characteristics.

In the M16S1 subwatershed, a "Not Significant" rating was assigned to the downstream reach, M16S1.01. Because the upstream reaches were not readily accessible, and their size and dominance of forest cover prevented observation of channel features on the 1:5000 orthophotographs, a "No Data" rating was assigned to these reaches.

Similarly, in the upper reaches of the High Knob subwatershed, several reaches were assigned a "No Data" rating. Where the channel was able to be viewed, a "Low" impact (T6.01, T6.05) or "Not Significant" impact (T6.06) was assigned. A large sediment deposit (mid-channel bar) immediately upstream of Freedom Acres Road culvert crossing is causing bifurcated flow in reach T6.01. Large concrete block headers have been used to stabilize the crossing. This reach contains a localized decrease in gradient which could be contributing to sedimentation, along with the undersized (less than bankfull width) culvert span. Active sand and gravel quarries are also located upstream. A large sediment bar ("delta") is present at the confluence of the High



Knob tributary and Lewis Creek (which has increased in size between observation dates: July 2002 and November 2006). Multiple flood chutes, debris jams, and mid-channel bars of sand and fine gravel were also observed in the downstream 100 feet of the High Knob Brook at this confluence on 7 November 2006.

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 1995/1999 and 2003 photographs, aerial photographs from 1942, 1962 and 1974 were reviewed at the Natural Resource Conservation Service offices.

Presence of lateral adjustments was indexed using FIT and uploaded to the Phase 1 database (see Appendix D). 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.

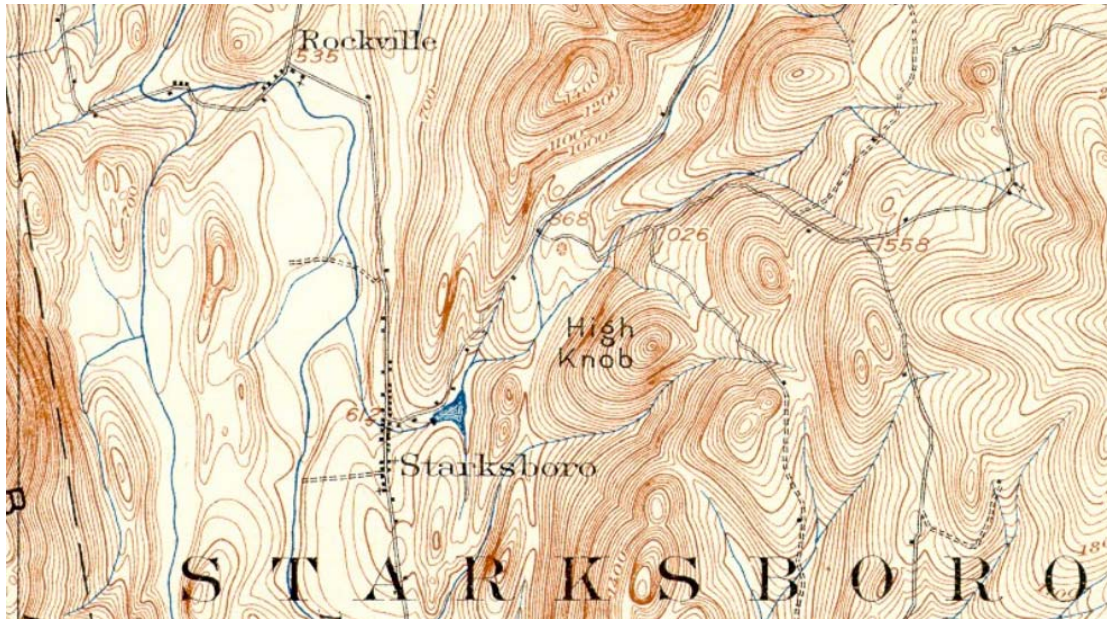
Meander migration was considered “Not Significant” for the Prindle Brook reaches.

In the M16S1 subwatershed, a “Not Significant” rating was assigned to the downstream reach, M16S1.01. Because the upstream reaches were not readily accessible, and their size and dominance of forest cover prevented observation of channel features on the 1:5000 orthophotographs, a “No Data” rating was assigned to these reaches.

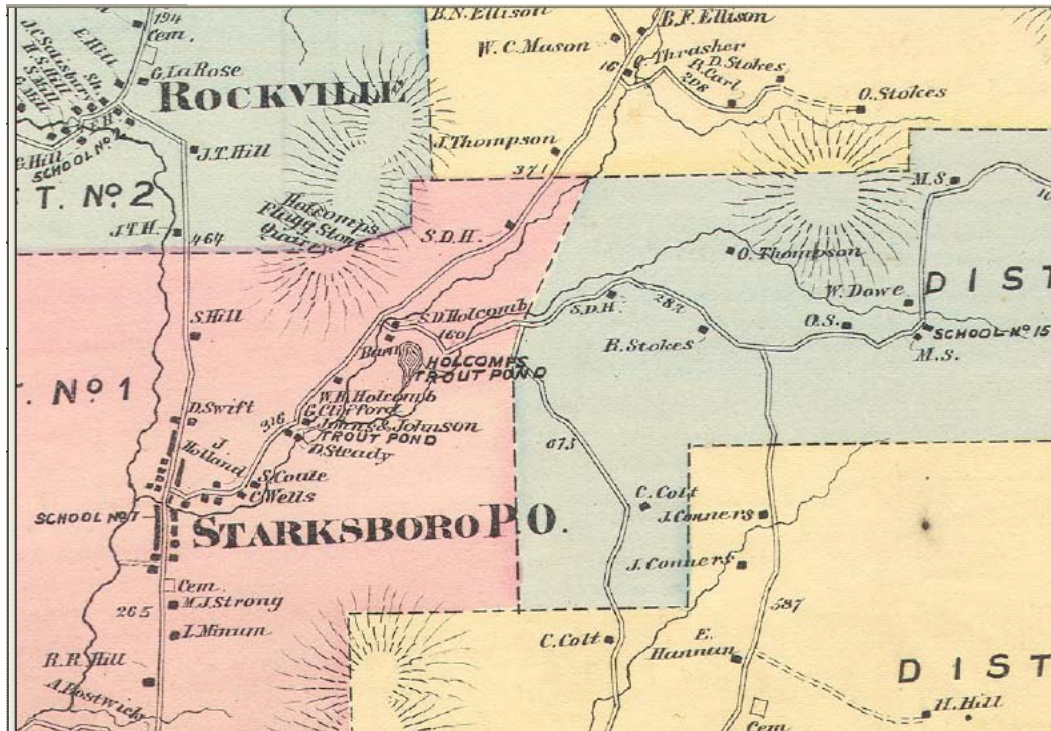
In the High Knob subwatershed, most of the reaches were remote, such that a “No Data” value was assigned. Of those reaches which could be viewed, one was assigned a “Not Significant” rating (T6.06) and two were assigned a “Low” impact (T6.01 and T6.05). A possible small avulsion site was noted through the forested mid-section of reach T6.05 - as viewed from Big Hollow Road. As previously noted, flood chutes and a channel-bifurcation were observed in reach T6.01.

One curious finding in the High Knob tributary was noted during review of historic maps. According to the 1905 USGS Middlebury, VT 15-Mintue topographic map and the 1871 Beers Atlas for Addison County (Starksboro), the High Knob tributary previously continued along the Big Hollow Road, drained via the Baldwin Pond, through Starksboro village and joined the Lewis Creek main stem in reach M19 (see Figure 7). These early map publications may have been in error. This is a smaller tributary flowing through somewhat remote territory that would have been difficult to field survey at the time these maps were produced. Or perhaps the High Knob tributary did actually flow in this other planform at one time. If so, it is not known whether the current planform resulted from a sudden avulsion (perhaps the 1927 flood or the 1938 flood), or as a result of channel manipulation in the early to mid-1900s. The available resources consulted in this Phase 1 assessment did not indicate either a historic avulsion or channel modification in this location. In absence of specific data, neither an avulsion nor channel modification was indexed during this Phase 1.





Middlebury, VT USGS 15-Minute Topographic Quadrangle map 1905 (surveyed 1903, reprinted 1943)



Beers Atlas of Addison County, 1871

Figure 7. Historic maps depict different planform of the High Knob Brook in the late 1800s and early 1900s.



4.6.5 Meander Geometry

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 to indicate that they may be out of equilibrium or otherwise disturbed or manipulated, presumably from human-induced channel or watershed stressors.

According to protocols, a MBW ratio less than 5 or a MWL ratio higher than 14 “may indicate that the stream has become straighter and steeper, possibly degrading its bed and losing access to its floodplain”. A MBW ratio greater than 8 or a MWL ratio less than 10 “may indicate that the stream, possibly due to an increase in fine sediment, has started to aggrade and become more sinuous, decreasing its channel slope as it migrates laterally (VTANR, 2007).” Impact ratings are assigned where MBW or MWL ratios fall outside of these expected ranges as a way to focus on the potential disequilibrium of these reaches, and as a means to prioritize these reaches for further field-based study.

Impact ratings assigned for the MBW and MWL ratios are as follows (VTANR, 2007):

Meander Belt Width (MBW) Ratio Impact Ratings

Impact	Condition
HIGH	MBW ratio is < 3 or >10
LOW	MBW ratio is ≥ 3 and < 5 or > 8 and ≤ 10
Not Significant	MBW ratio is ≥ 5 or ≤ 8
Not Applicable	For certain stream types

Meander Wavelength (MWL) Ratio Impact Ratings

Impact	Condition
HIGH	MWL ratio is < 6 or >16
LOW	MWL ratio is ≥ 6 and < 8 or > 14 and ≤ 16
Not Significant	MWL ratio is ≥ 8 or ≤ 14
Not Applicable	For certain stream types

By VTANR protocols, calculations of MBW and meander wavelength MWL and their respective ratios to channel width are completed only for “C or E riffle-pool or ripple-dune reference stream types in narrow (NW) and unconfined (BD and VB) valleys in Step 2.10”. Eleven of the 23 Lewis Creek tributary reaches were identified (in Step 2) as C or E stream types (Table 6):

Table 6. Lewis Creek tributary reaches classified as C or E stream types.

Unnamed Trib (M16S1)	Prindle Brook (T1)	High Knob (T6)
M16S1.01	T1.02 (S)	T6.03
	T1.03 (W)	T6.04 (S)
	T1.04 (W)	T6.05
	T1.2S1.01 (S)	T6.06 (E)
	T1.2S1.02 (W)	
	T1.2S1.03 (S)	



All but three of these 11 reaches were exempted from evaluation of meander geometry under Steps 6.5 and 6.6. Three reaches were dominated by wetland hydrology (designated by a "W" in the above table). One reach (T6.06) was exempted (E) due to presence of lateral bedrock controls which resulted in a reference valley width that was less than the reference (predicted) meander belt width for a channel of that size (based on Williams, 1986 – equation 32). Four reaches were determined (in Step 5.4) to be greater than 50% straightened (designated with an "S" in the above table. 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.

Thus, meander geometry was measured in three of the eleven reaches (M16S1.01, T6.03, and T6.05). Meander sets utilized in measurements of MBW and MWL were documented in ArcView™ shape files (*Step6_5.shp* and *Step6_6.shp*, respectively; see project CD). MBW and MWL were quantified in GIS using the measuring tool, and the measured values were entered in the DMS. Consistent with protocols, these values represent the average of measurements from at least three sets of meanders per reach.

Of the three reaches for which meander geometry was measured, all were assigned an impact for either MBW, MWL, or both.

- ◆ **Review of the MBW ratios:** All 3 reaches had impacts assigned for a MBW ratio lower than the expected range (M16S1.01 and T6.03 were "High" impacts; T6.05 was assigned a "Low" impact). These findings would suggest that these reaches may be influenced by channel or floodplain modifications that have lead to a straighter and steeper channel. Further field-based evaluation would be warranted to determine if these reaches have undergone channel incision or other channel adjustments in response to their altered geometry.
- ◆ **Review of the MWL ratios:** One of the three reaches (M16S1.01) had a MWL ratio within the expected range and was assigned a "Not Significant" impact. The other reaches were assigned a "Low" impact. One reach (T6.05) had a measured average MWL ratio very slightly higher than expected (T6.05) – a ratio of 14.1 as compared to the expected range of 8 to 14. The other reach (T6.03) had a measured average MWL ratio lower than the expected range, suggesting that the reach may be undergoing some change or disturbance that would lead to a lengthening of the channel and lessening of the channel gradient, such as increased sediment loading. Somewhat contrary to expected conditions, this reach also had a MBW ratio that was lower than predicted (suggesting channel shortening and channel steepening). This finding may suggest overlapping stressors in this channel – for example, channel disturbance such as straightening combined with increased sedimentation rates from upstream reaches. A case of apparent MWL / MBW ratio contradiction may represent a reach which is transitional - in the process of adjusting in response to past disturbances.



4.7 Bed and Bank Windshield Survey

A windshield survey was conducted on 26 July 2007 in the Lewis Creek tributary watersheds 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 floodplain and channel modifications, where observed (Steps 5 and 6)
- ◆ note erosion conditions including length and height (Step 7.1); and
- ◆ identify the potential for debris or ice jams (Step 7.2).

Photo logs and notes recorded during the windshield survey are contained in Appendix B. Phase 1 assessments were also supported by field observations during Phase 2 assessments at the confluence of each tributary with the Lewis Creek main stem (2004-2006).

4.7.1 Bank Erosion

Where reaches could be accessed through the windshield survey, 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 $\geq 20\%$ of the right and/or left bank.
LOW	Bank erosion observed along $\geq 5\%$ and $< 20\%$ of the right and/or left bank
Not Significant	Bank erosion observed along $< 5\%$ of the right and/or left bank

Not all reaches could be accessed during Windshield Surveys; bank erosion impact ratings were classified as "No Data" 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 would yield a more comprehensive evaluation of bank erosion. It is possible that impact ratings would change considerably following consideration of field-based estimates of bank erosion.

Erosion was considered "Not Significant" for the accessible Prindle Brook reaches. These reaches are generally low-gradient reaches dominated by cohesive soils and wetland characteristics. The downstream two reaches were not accessible and were assigned a "No Data" rating.

In the M16S1 subwatershed, a "Not Significant" rating was assigned to the downstream reach, M16S1.01. A "No Data" rating was assigned to the remaining reaches.

Similarly, in the upper reaches of the High Knob subwatershed, several reaches were assigned a "No Data" rating. Where the channel was able to be viewed, a "Not Significant" rating was assigned.



4.7.2 Debris and Ice Jam Potential

Available resources were reviewed for known sites of debris jams and ice jams on the Lewis Creek tributaries. This review relied on:

- ◆ observations during the windshield survey; and
- ◆ the online Ice Jam Database maintained by the Ice Engineering Group at the Cold Regions Research and Engineering Laboratory (CRREL, 2007).

Features along each of the reaches that could suggest the potential for debris jams were also 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. This rating applied to High Knob reach T6.01, where debris jams were observed near the confluence with Lewis Creek in November of 2006. Also, a “High” impact was assigned to reach M16S1.01. A USGS gage formerly operated on this reach near the Route 116 crossing. The Ice Jam Database maintained by CRREL notes previous ice jams impacting the gage in the late 1960s and early 1970s (three separate occurrences).

A “Low” impact was assigned for reaches with features suggesting the potential for jams, but for which no record of previous jams was found. This rating applied to three reaches of the Prindle Brook and to five reaches of the High Knob Brook each containing in-stream culvert crossings.

A “Not Significant” impact rating was assigned for remaining reaches with no recorded history of jams and no features suggesting the potential for jams, unless the reach was largely inaccessible in which case a “No Data” value was assigned.



5.0 DATA ANALYSIS

Text

5.1 Impact Scores

text

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 (Table x and Appendix E). 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 specific reaches for further field-based assessment. Specific reaches recommended for Phase 2 Stream Geomorphic Assessment are listed in Table x. In general, these reaches tend to be the ones with the highest identified provisional impact scores. These reaches are expected to demonstrate higher degrees of channel adjustment and sensitivity based on their topographic and geologic setting and provisional identification of past and current watershed and channel disturbances.

Table x.

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

