

**FLUVIAL GEOMORPHOLOGY ASSESSMENT
MIDDLEBURY RIVER WATERSHED
ADDISON COUNTY, VERMONT
August 2003**



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Prepared for:

Middlebury River Watershed Partnership
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Under contract to:

Addison County Regional Planning Commission
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EXECUTIVE SUMMARY

A fluvial geomorphology assessment of the Middlebury River and its principal tributaries, Middle Branch, South Branch and North Branch, was completed in the Fall of 2002 and Summer of 2003. The 63-square-mile Middlebury River watershed has experienced multiple catastrophic flood events in recent decades, resulting in substantial infrastructure losses, streambank erosion, and in-stream sedimentation. This study was funded by a Federal Emergency Management Agency (FEMA) Project Impact Grant to assess the present geomorphic condition of the river network, to identify local and regional stressors impacting the channel and watershed, and to characterize those reaches at particular risk of future lateral and vertical adjustments. Assessments were also conducted to identify current human land uses in conflict with the river system and delineate particular structures at risk from expected future channel migration.

This study is a companion project to a separate surficial geologic mapping effort presently being conducted in the watershed, also under FEMA Project Impact funding. Combined results of these studies can be used to develop erosion hazard maps to support future planning and zoning decisions by local towns. A second companion project involves surveying riparian buffer widths and characteristics from the confluence with Otter Creek upstream to the Route 7 crossing. Data will be utilized to guide selection of appropriate federal programs (e.g., Conservation Reserve Enhancement Program or Wildlife Habitat Incentives Program) to restore and enhance riparian buffers. Funding for this separate project is being provided through a State of Vermont Department of Environmental Conservation Section 604(b) FY 2002 pass-through grant administered by the Addison County Regional Planning Commission.

The geomorphic condition of the Middlebury River was evaluated using a phased approach of stream assessment, following protocols compiled by the Vermont Agency of Natural Resources (2002).

Phase 1

Phase 1 consisted of historical data gathering, windshield surveys, and remote sensing of available topographic, orthophoto, soils, geologic and landuse mapping coverage. During Phase 1, the 63-square-mile watershed was delineated, and 37 discrete river reaches were defined along the main stem and North, South, and Middle Branches, based on variation in valley confinement, slope, and sinuosity:

- the Lower Watershed from the confluence with Otter Creek to the gorge above East Middlebury village (M01 to M08);
- the Transport Reaches through the gorge from East Middlebury village to Ripton Village (M09 to M12);
- and the Upper Watershed, consisting of:
 - the North Branch (T3.01 to T3.10);
 - the Middle Branch (M13 to M19); and
 - the South Branch (T4.01 to T4.08).

Resulting reaches ranged in length from 1,600 feet to 6,600 feet; the following parameters were quantified for each reach:

- Elevation of downstream reach break (ft above mean sea level)
- Channel Length (ft)
- Channel Slope (ft)
- Channel Width (ft) by reference to VT Regional Hydraulic Geometry Curves (VTDEC WQD, 2001)
- Valley Length (ft)
- Valley Slope (ft)
- Valley Width (ft)
- Sinuosity
- Valley to Channel Width Ratio, or Valley Confinement
- Drainage Area (sq. mi.)

Reaches defined in Phase 1 provide a frame of reference for future restoration and conservation work and additional watershed-based studies, including habitat and natural communities mapping, surficial geologic mapping, and water quality assessments.

Phase 2

Phase 2 protocols are field procedures for rapid geomorphic and rapid habitat assessments. Reach-specific and cross-section data gathered during Phase 2 characterized the present geomorphic condition of the river reach and the dominant process(es) of adjustment. Processes of channel adjustment include:

- **Degradation**, or a drop in stream bed elevations due to sediment erosion;
- **Widening** of the channel due to stream bank collapse, as degradation leads to oversteepened banks;
- **Aggradation**, or build up of stream bed elevations due to sediment deposition;
- **Planform adjustment**, or a substantial change of the stream's flow path in the landscape.

Channel dimensions measured at discrete cross sections in each reach and reach-wide observations of channel form and features were compiled in a Rapid Geomorphic Assessment (RGA) score for each reach. Similarly, reach-based observations relating to in-stream and riparian habitat were compiled in a Rapid Habitat Assessment (RHA) score. Quantitative scores for the RGA and RHA were each correlated to a condition: Reference, Good, Fair, or Poor.

Channel disturbances along the Middlebury River, noted through field reconnaissance and historical data gathering, included:

- Apparent or reported channelization;
- Channel armoring (rip-rap);
- Berming, particularly along reaches M06 and M07 in East Middlebury village;
- Historic floodplain encroachment by Town Roads and Rt.125 (South Branch and Upper Main Stem through the Gorge);
- Reported historic gravel extraction, dredging and berming in East Middlebury village, particularly in response to flood events in 1927 and 1938, with the most recent dredging and berming event being circa 1989;

- Undersized private and public bridges and in-stream culverts, serving as flow constrictors at the bankfull and/or higher magnitude flood events;
- Minimal or negligible riparian buffers along portions of main stem reaches, particularly those associated with current agricultural land use in the Lower Watershed;
- Active stream crossings (fords).

Watershed stressors noted for the Middlebury River, determined from historical data gathering, included:

- Historic (mid-1880s) deforestation of the Upper Watershed leading to historic increased percent imperviousness and sediment mobilization;
- Recent upland development in the Upper Watershed leading to increased percent imperviousness;
- Recent high-magnitude flood events particularly focused on the southeastern portion of the Upper Watershed in 1998 and 2000.

The North Branch reaches in Ripton are in Good to Reference geomorphic condition, due in large part to long-time persistence of forested riparian buffers and minimal floodplain encroachments. Channel-spanning bedrock has also afforded stability to this portion of the watershed. Particularly, the lower-gradient, mid-portions of this watershed would be at risk from upland development, deforestation, or the addition of other regional or local stressors.

The majority of South Branch and Middle Branch reaches (Ripton) are in Poor to Fair geomorphic condition, undergoing substantial lateral adjustments with indications of vertical adjustments, as well. Channel conditions in uppermost reaches of these tributaries appear to have been exacerbated by the recent extreme flood events of 1998 and 2000. While conversion of previously cultivated parcels to fallow land (T4.03 and T4.04) and forest (M13 and M14) is supporting the recovery process in these reaches, they remain particularly susceptible to further degradation from stressors including increased upland development, floodplain encroachment, channelization, increased hydraulic loading from the ski area, removal of riparian buffers, and undersized crossing structures. Lack of grade control in T4.03 and T4.04 increases the likelihood of future adjustments in these reaches.

Lower Watershed reaches ranged from Poor condition through East Middlebury to Fair to Good condition in the broader valley. A long history of channel management (channelization, gravel extraction, dredging and berming) has contributed to the degradation of East Middlebury reaches at this particularly sensitive geographic setting on alluvial fan deposits. Downstream reaches are adjusting to increased sedimentation from streambank erosion in the East Middlebury reaches, as well as to floodplain encroachments by intensive cultivation and associated loss of riparian buffers.

Stable reaches (Channel Evolution Model Stage I and V) are good candidates for conservation to limit potential future stressors to these reaches (such as floodplain encroachment, increased percent imperviousness, or elimination of buffers). Most of the North Branch reaches and South Branch reaches, T4.01 and T4.05 would be considered in this category.

The majority of reaches in the Middle and South Branches and Lower Watershed reaches, M06 and M04, were assessed to be in Channel Evolution Model Stage II or III (actively degrading and/or widening). Stage II and III reaches, in active adjustment, are especially susceptible to future adjustments, particularly those reaches containing no grade controls, those reaches in lower gradient settings with smaller grain sizes (sands and gravels) dominating the stream bed, and those reaches with absent or minimal forested

riparian buffers. Specific Stage II / III reaches in this category include:

- Lower Watershed, Middlebury – M04 and M06
- South Branch, Ripton – T3.03, T3.04, T4.06, and T4.07

Phase 3

Three localities in the watershed were identified for more detailed survey work (Phase 3 assessment) as part of this study:

- A 1996 USGS cross section on approach to the Lower Plains Road bridge in East Middlebury (reach M08) was replicated and referenced to a common datum; comparison of the two cross sections suggests aggradation of the river channel in this location of more than one foot during the past seven years. This result is consistent with Phase 2 determinations that reach M08 is presently dominated by aggradational processes.
- A 1996 USGS cross section on approach to the Route 7 bridge downstream of East Middlebury (reach M06) was replicated and referenced to a common datum; comparison of the two cross sections suggests aggradation of the river channel in this location of nearly one foot during the past seven years. This result is consistent with Phase 2 determinations of aggradation, widening, and planform adjustment in reach M06.
- A 650-foot longitudinal profile, three cross sections and pebble counts were conducted along a sub-reach of the South Branch adjacent to the Robert Frost Interpretive Trail (Ripton, T4.04) to support restoration planning for this sub-reach by the Green Mountain National Forest.

Findings Related to Infrastructure

Seventeen bridges (public and private) or in-stream culverts providing road crossings to the Middlebury River main stem and tributaries were determined to be undersized with respect to the bankfull flow. All crossing structures were undersized when compared to flood prone widths (i.e., corresponding to the ten-year to fifty-year storm). Undersized structures can lead to channel aggradation upstream of the structure and vertical and lateral scour on the downstream side of the channel. Such conditions can, in turn, lead to destabilization of the fill and armoring material supporting the bridge or culvert and to undermining of footings or other structural components. In addition to locally constricting channels, undersized bridges and culverts can cause flood hazards to neighboring properties, serving as the location of debris jams or ice jams during spring runoff events or larger magnitude floods.

Structures currently noted to be at particular risk due to undersized bridge or culvert spans, sharp approach angles of the stream channel, and/or geomorphic setting of the surrounding stream channel, are:

- Dugway Road bridge (T3.03, North Branch, Ripton) – approach angle, undersized span
- Private bridge (T3.04, North Branch, Ripton) – approach angle, undersized span, up to 3 ft lateral undermining of left bank footing
- Private bridge (T3.08, North Branch, Ripton) – undersized span, up to 2 feet lateral undermining of left bank footing
- Baker Bridge (T3.09, North Branch, Ripton) – undersized span, erosion of support fill from overland runoff due to accumulation of stormwaters at this low elevation, excessive vertical and lateral scour at tributary in-stream culvert.
- Private Footbridge (T4.04, South Branch, Ripton) – undersized span, partial collapse of gabion basket footings for bridge.

- Robert Frost Interpretive Trail (T4.04, South Branch, Ripton) – lateral channel migration undermining site marker, debris jam at same location may trigger avulsion or increase lateral channel migration during future flood event.
- Peddlers Bridge Road (M13, Middle Branch, Ripton) – undersized span, approach angle, lateral scour threatens to undermine fill on right bank exit end.
- Armoring along Wagon Wheel Road 400 ft upstream of Wagon Wheel Bridge (M13, Middle Branch, Ripton) – approach angle of river is directed nearly perpendicular to upstream end of armoring at the intersection between rip-rap and native soils.
- Bridge at Wagon Wheel clearing (M16, Middle Branch, Ripton) – undersized span, approach angle, overland runoff is eroding fill at right bank upstream footing, bridge positioned at tight meander (constriction).
- Farm road (M02, Main Stem, Middlebury) – at potential risk from lateral channel migration
- Shard Villa Road bridge (M03, Main Stem, Middlebury) – undersized span, approach angle, bridge positioned at tight meander.
- Three Mile Bridge Road (M05, Main Stem, Middlebury) – possibly at risk from lateral channel migration, compounded by tributary confluence and stormwater runoff.
- Residential structure (M07, Main Stem, East Middlebury) - structure located within 15 feet laterally of present top of right bank, approximately 100 feet upstream of new Grist Mill Bridge; possible risk to structure in the event of higher flood stages with associated streambank erosion or collapse.
- Lower Plains Road Bridge (M08, Main Stem, East Middlebury) – undersized span, undermining of footings noted
- Box culvert on Rt.125 (M11, Main Stem, Ripton) – conveying tributary channel to main stem; vertical scour and slight undermining on exit end, accumulation of cobbles, boulders on entry end to constrict flow.
- Residential and commercial properties (M12, Main Stem, Ripton village) - possible risk if mass wasting on right bank progresses laterally toward the village; warrants monitoring.

Findings Related to Water Quality

Several areas of streambank erosion were identified during the study. In a few cases, channel adjustments had resulted in minor avulsions, where the channel had cut off a meander bend or chosen a new path (e.g., reaches T4.03, M06). Erosion of stream bed and banks, particularly in areas which have historically been farmed, can result in mobilization of phosphorous and excess sediments to the receiving waters.

Streambank erosion can also be aggravated by animal crossings and by four-wheel drive and snowmobile fords, which trample stabilizing vegetation and create weak points in the streambanks and riparian buffer.

Sediment mobilization degrades in-stream habitats for fish and other aquatic insects. In addition, locations of streambank erosion can be correlated to degraded water quality issues. Elevated total phosphorus has been detected historically in the Middlebury River watershed, as well as elevated *E.coli* from possible agricultural or septic sources (Addison County River Watch Collaborative, 2001).

1.0 INTRODUCTION

This report presents an evaluation of the fluvial geomorphology of the Middlebury River and its principal tributaries, Middle Branch, South Branch and North Branch. This region has experienced multiple catastrophic flood events in recent decades, resulting in substantial infrastructure losses, streambank erosion, and in-stream sedimentation. This report has been prepared by South Mountain Research & Consulting (SMRC) of Bristol, Vermont on behalf of the Middlebury River Watershed Partnership under contract to the Addison County Regional Planning Commission. Funding was provided by a Federal Emergency Management Agency Project Impact Grant.

This fluvial geomorphologic study is a companion project to a surficial geologic study being carried out presently in the watershed. Combined results of these studies will be used to develop erosion hazard maps to support future planning and zoning decisions by local towns. Assessments will help to evaluate the sensitivity of given reaches to future stressors and predict the likelihood of lateral and vertical channel adjustments.

A second companion project is a detailed buffer assessment in the lower Middlebury River watershed along the main stem from the confluence with Otter Creek upstream to the Route 7 crossing. This project involves surveying buffer widths along the left and right banks of the river channel using a Global Positioning System (GPS) and noting vegetation types within the buffer and land use in the riparian corridor outside the buffer. These data will be utilized to guide selection of appropriate federal programs (e.g., Conservation Reserve Enhancement Program or Wildlife Habitat Incentives Program) to restore and enhance riparian buffers. Funding for this separate project is being provided through a State of Vermont Department of Environmental Conservation Section 604(b) FY 2002 pass-through grant administered by the Addison County Regional Planning Commission.

2.0 SCOPE OF WORK

Geomorphic and habitat assessments have been conducted for a majority of the 63-square mile Middlebury watershed to identify the current geomorphic condition of the watershed and sub-reaches. Geomorphic conditions have been evaluated with respect to identified human and natural stressors to the watershed, including:

- Deforestation;
- Floodplain encroachment by roads and development;
- Removal of riparian buffers;
- Channelization;
- Gravel extraction;
- Dredging and berming;
- Streambank armoring.

Fluvial geomorphology is an interdisciplinary field of science which recognizes river networks as dynamic systems, in a state of continual adjustment. River networks, in absence of natural or human stressors, are theorized to be in a state of dynamic equilibrium. Sediment and water are transported through the system in balance with the given gradients and available sediment sizes, with no net change in average channel dimensions over the time frame of management interest (Lane, 1955). In reality, over time, watersheds are typically exposed to a variety of physical stressors from both natural and human causes (e.g., extreme flood events, fire, deforestation, increased development, channelization, floodplain encroachment, and gravel extraction). A stressor of sufficient type, magnitude, or duration causes the river system to move out of its state of balance and the river channel adjusts by varying its lateral and vertical dimensions (Leopold, 1994; Bull, 1979; Harvey and Watson, 1986). While the stressor to a channel typically lasts a short time (hours to months), channel adjustments in response to the stressor can play out over several years to decades, or longer (Schumm, 1977). Substantial channel-bed and channel-bank erosion can occur during the response period, resulting in mobilization of excess sediment, loss of land, loss of property, and other economic and ecological consequences.

Processes of channel adjustment include:

- **Degradation**, or a drop in stream bed elevations due to sediment erosion;
- **Widening** of the channel due to stream bank collapse, as degradation leads to oversteepened banks;
- **Aggradation**, or build up of stream bed elevations due to sediment deposition;
- **Planform adjustment**, or a substantial change of the stream's flow path in the landscape.

The study of fluvial geomorphology involves observation and measurement of channel dimensions, shapes and features which together indicate the dominant channel adjustment processes active in the system. Based on these observations of channel morphology, combined with historical and anecdotal information, it is possible to infer types and rates of adjustment in the river system in response to past and present stressors. In turn, these data can be evaluated to predict how a river system will respond to future land use choices.

Often, channels progress through these stages of adjustment in a predictable way in response to a stressor (Schumm, 1984; Simon, 1989; Simon and Hupp, 1986). Dominant adjustment processes migrate upstream and downstream within a reach or series of reaches. These channel adjustment processes can also be thought of as migrating through time, since one location in the river network will progress from degradation through widening to aggradation and perhaps planform adjustment, before returning to an equilibrium state. Certain boundary conditions can influence the progression of these channel adjustments. For example, grade controls such as bedrock exposed in the river channel can stop the process of downward channel erosion, or degradation. Structures, such as in-stream metal or concrete culverts can also serve as grade controls.

The present stage of channel adjustment for a given reach or sub-reach can be classified by reference to a channel evolution model (CEM) after Schumm (1984). The reader is referred to the VTANR stream geomorphic assessment protocols for more details (VTANR, 2002). In brief, a reach which is evidenced to be in an equilibrium state, able to effectively mobilize its water and sediment loads, is either in Stage I (pre-disturbance equilibrium) or State V (post-disturbance equilibrium, following adjustment through the intermediate phases). Stage II through IV reaches are in adjustment. A Stage II reach or sub-reach is dominated by degradation, Stage III by widening, and State IV by widening and aggradation.

3.0 BACKGROUND

3.1 Geographic Setting

The Middlebury River watershed is a 63-square-mile unregulated basin located in Addison County, Vermont. It is one of several smaller watersheds which together comprise the larger Otter Creek Basin which drains northward to Lake Champlain (Figure 1). The Middlebury River watershed drains portions of Ripton, Salisbury, Middlebury, Hancock, Lincoln, Goshen and Bristol townships (see Figure 2). However, the main stem channel and major tributary channels (Middle, North and South) are nearly entirely contained within the towns of Ripton and Middlebury.

Table 1.
Township aerial extents, Middlebury River watershed.

Town	Area (sq.mi.)
Ripton	35.5
Salisbury	10.9
Middlebury	10.4
Hancock	3.7
Lincoln	1.7
Goshen	0.5
Bristol	0.03

Total: 62.8 sq. mi.

Land use within the Middlebury River watershed is estimated as 87 % forested, 12 % agricultural fields and cropland, and 1 % urbanized and wetlands (Hill, 2002).

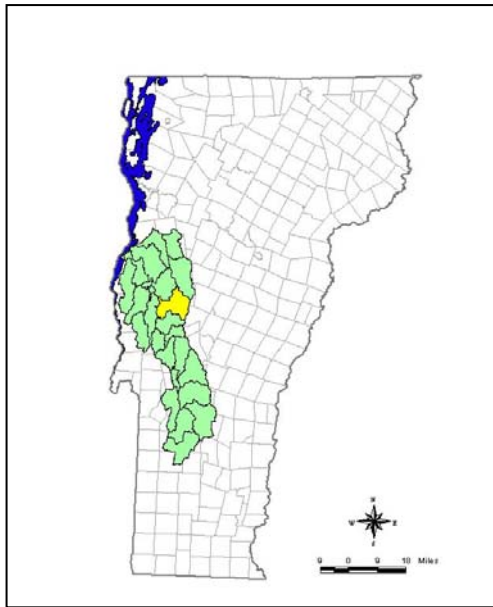


Figure 1. Middlebury Watershed Location within the Otter Creek Basin and Vermont.

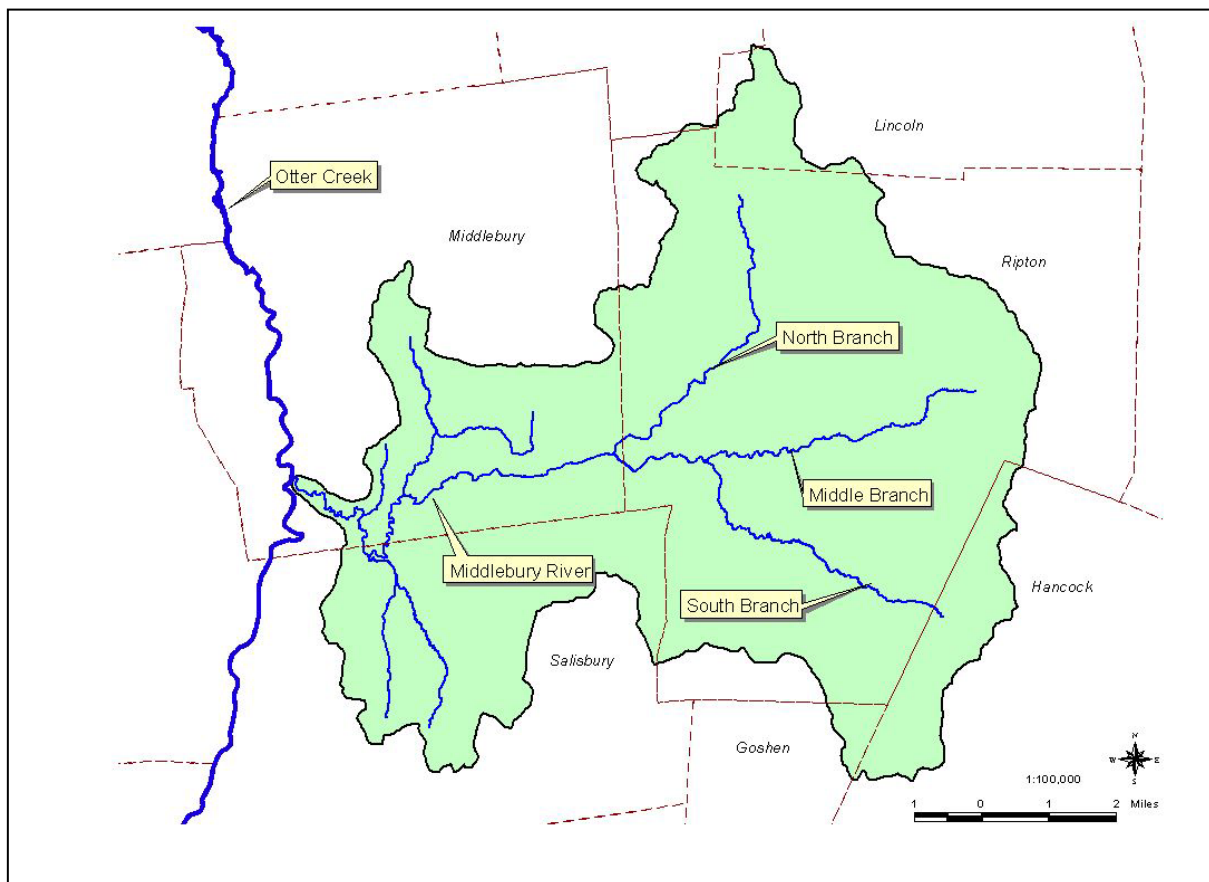


Figure 2. Location of Main Stem and Principal Tributaries, Middlebury Watershed

3.2 Regional Geologic Setting

The Middlebury River watershed spans two major geologic provinces. Headwaters including the entirety of the Middle Branch, North Branch and South Branch tributaries and the upper 1.3 miles of the main stem, are located on the till-blanketed bedrock slopes of the Green Mountains in eastern Middlebury, Ripton, Lincoln, Hancock and Goshen. The remainder of the watershed from the Rt. 125 crossing at the Middlebury Gorge to the confluence with Otter Creek, is located on the broad Champlain Valley. In recent geologic time (from 20,000 to 13,200 years before present) this landscape was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness above the present land surface in the Champlain Valley. As the global climate warmed and the glaciers receded, a large fresh-water lake inundated the Champlain Valley. At its highest stage, Lake Vermont's shoreline was located at the foot of the Green Mountains near the present location of East Middlebury. Isolated bedrock knobs or ridges such as Snake Mountain and Mt. Philo (west and northwest of the Middlebury River watershed) remained at sufficiently higher elevations to be islands poking above the lake surface. Lake Vermont waters receded in stages as natural dams in southern Vermont and New York gave way. From approximately 12,800 to 10,200 years before present, marine waters inundated the valley from the St. Lawrence Seaway as the rate of rise in ocean water levels far exceeded the rate of rise, or isostatic rebound, of the land surface now relieved of its glacial burden. The maximum elevation of these brackish waters is not believed to have extended into the present-day Middlebury watershed (Connally, 1970). Champlain Sea waters had receded from the greater Champlain Valley by approximately 10,000 years before present, as the rate of land rise began to outpace the rate of sea-level rise. River systems, including the Middlebury River, then went to work moving sediments left in the wake of the glaciers, and further eroding the Green Mountains. Our surrounding landscape continues in this erosion phase today (Stewart and MacClintock, 1969; Cronin, 1977; Wagner, 1972; Connally and Calkin, 1972).

3.2.1 Bedrock Geology

The underlying bedrock geology of the watershed influences the Middlebury River in many ways. In general, bedrock geology of the Middlebury River watershed can be grouped into two main categories:

- the PreCambrian and Cambrian crystalline and metamorphosed rocks (e.g., schistose greywacke, phyllites, schist, gneiss) of the north-south trending anticline which forms the Green Mountains at the eastern portion of the watershed; and
- the Cambrian and Ordovician limestones, dolostones and marbles of the Champlain Lowland which comprise the Middlebury synclinorium (Stewart, 1973; Connally, 1970).

The metamorphosed, crystalline rocks are relatively resistant to chemical and physical weathering, while the limestones and other calcitic rocks of the Champlain Lowland are less resistant to erosion. In this way, the bedrock geology of the basin has controlled the regional

topographic setting, with the resistant crystalline rocks forming the steeper slopes of the Green Mountains, and the less-resistant limestones and dolostones forming the broad Champlain Lowlands.

Frequent bedrock exposures in the Upper Watershed control the channel gradients and valley confinement in many of these upper reaches. Channel-spanning exposures of bedrock also offer local grade control, preventing possible downward erosion in the channel in response to regional or local stressors. In similar ways, bedrock exposures along valley walls can control the lateral position of the river channel.

3.2.2 Surficial Geology

The most recent glacial history has influenced the surficial sediments and soil types which are present in the Middlebury watershed today. The Upper Watershed is dominated by thin glacial till deposits overlying bedrock, with alluvial sands, gravels and cobbles found locally in stream corridors. Higher-elevation deposits of outwash (North Branch) and kame moraine (South Branch near Breadloaf) have been noted by previous researchers related to possible stagnating glacial ice in the Upper Watershed (Connally, 1970). At the foot of the Green Mountains are kame terrace deposits of sands, gravels and cobbles which developed at the marginal contact between the glaciers and the mountains. These deposits form the terraces recognizable along the east side of Route 116 extending from East Middlebury to Bristol village and beyond. Some of these deposits may have been subsequently re-worked as beach gravels by wave action in Lake Vermont. At the East Middlebury Village, these deposits have been overlain by fan deposits of alluvial cobbles, gravels and sands where the Middlebury River transitions from the steep slopes of the Green Mountains to the relatively level plains of the Champlain Valley.

Out into the broader Champlain Valley, west of Route 7, the landscape is mostly dominated by clay and silt deposits generated during former occupation by Lake Vermont. This area was in the deeper sections of the lake, farther from the eastern shorelines which were actively receiving runoff from the Green Mountains. Layer upon layer of fine-grained silts and clays were deposited in the quiet lake waters in alternating sequences resulting from annual cycles of spring and summer storm activity followed by winter quiet. Exposures of these varved clays, or rhythmites, were observed during this study by SMRC at a large meander bend along the Middlebury River east of Blake Roy Road. The clay and silt deposits of the Champlain Valley contain frequent large boulders. It is hypothesized that these boulders were contained within or on “rafts” of ice which broke off in large blocks from the edge of the receding ice sheet and floated out into Lake Vermont. As the ice blocks melted, their cargo was released, dropping out to settle in the clay and silt deposits at the bottom of the lake.

3.3 Human Settlement Patterns

Human settlement patterns and land use actions in the Middlebury River watershed have influenced river dynamics, both regionally and locally. Regionally, the balance of water and sediment loads conveyed within a watershed is altered by the density of settlements on the

landscape and its effect on the percent of land area impervious to rainfall. Impermeable (or partially impermeable) surface types associated with development can include roof-tops, pavement, dense gravel-pack roads or driveways, plow-pans created by repeated tilling and compaction of agricultural soils, and compacted forest soils left in the wake of heavy equipment used to harvest timber. Percent imperviousness refers to the proportion of the land surface converted to impermeable or reduced-permeability surfaces. In general, development results in a reduction in total land area remaining pervious to rainfall. Rainfall and snowmelt waters run quickly off the land surface to the nearest swale or stream, if they are not able to infiltrate through the surface soil layers and flow diffusely through the subsurface to the river network. As a result, stormwaters are delivered in higher magnitudes to our stream networks and over shorter durations, leading to a prevalence of “flashy” runoff conditions. Stormwaters diverted overland in this way have high velocities and therefore an increased capability to erode soils and debris from the land surface. Locally, we have altered river dynamics by site-specific actions, including channelization, gravel extraction, dredging, berming, floodplain encroachment, and installation of undersized bridges and in-stream culverts.

Due in part to differences in the geologic and topographic settings, land use within the Middlebury River watershed has varied from the Lower to the Upper Watershed.

3.3.1 Lower watershed

Since their chartered dates of the late 1700s, the lower watershed towns of Middlebury and Salisbury experienced minimal growth until the 1940s. The post-World War II industrial age, as well as post-war college enrollment and hiring at Middlebury College presumably contributed to increased growth beginning in the 1950s.

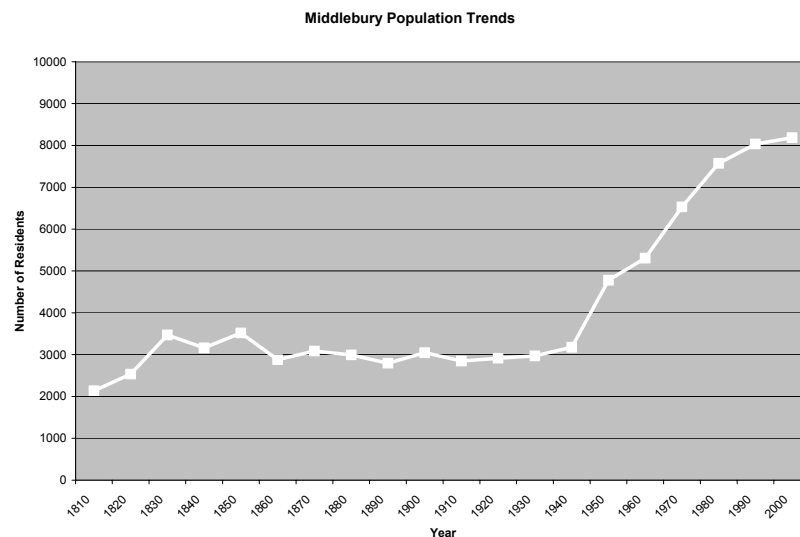


Figure 3. Town of Middlebury population trends.

The portion of Middlebury located within the Middlebury River watershed is largely rural and agricultural, except for the settlement of East Middlebury located at the juncture of the Green Mountain front and the Champlain Valley. Census records are not available for this East Middlebury village, and the statistics for Middlebury township likely do not reflect patterns in the Middlebury River watershed portion of the town. Generally, land use has been agricultural for decades, with a recent trend toward conversion of farm lands to higher density residential or commercial use. The 1871 Beer’s Atlas notes a quarry operated by the Middlebury Marble Company on both sides of the river near the Salisbury town line (Reach M05). Quarry operations do not appear to be active today.

The village of East Middlebury was settled on an alluvial fan deposit which has developed since the retreat of the glaciers more than 10,000 years ago. Valley and river channel slopes become dramatically more shallow at this intersection between the Green Mountains to the east and the broad Champlain Valley to the west (see Figure 4). As a result, the Middlebury River transitions at this point from a transport-driven reach of higher gradients with the ability to carry large cobble- and boulder-sized sediments, to a channel of lesser slope carrying gravels and sands, predominantly. The reduction in stream energy given by the reduction in slope, means that the river is no longer able to carry all of its sediment, and there is a tendency for that sediment to accumulate at the point of transition (i.e., through the village of East Middlebury).

Middlebury River Longitudinal Profile

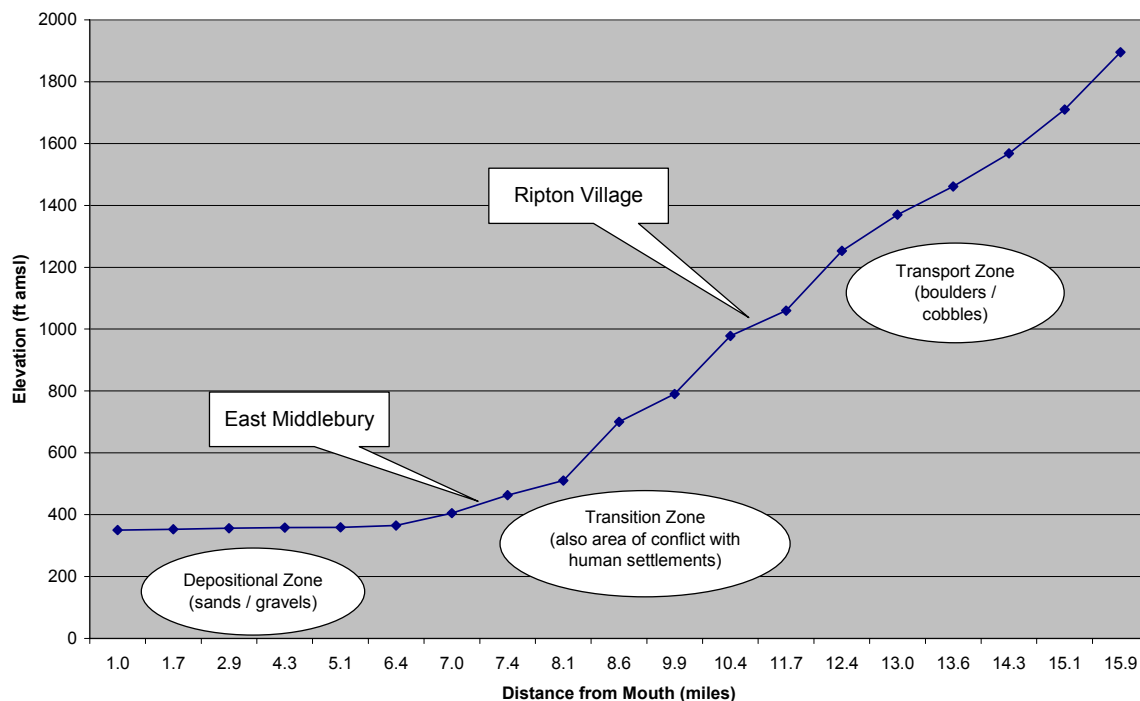


Figure 4. Longitudinal profile of Middlebury River main stem (Reaches M01 to M12) and Middle Branch (Reaches M13 to M19).

Alluvial fans are natural locations for a river to meander and split into multiple, braided channels in response to the reduced stream energy and reduced ability to carry sediment. As happenstance would have it, these are also attractive places to establish communities. East Middlebury has a long history of conflict with the Middlebury River. The community has responded to the river's natural tendency to laterally shift by channelizing and dredging the channel, extracting gravel, berming and armoring (see Section 3.6). Channel management activities are recorded as early as 1870 in the Middlebury annual Town Report.

3.3.2 Upper watershed

Ripton was chartered in 1781 (Ripton town report, 1947). This town has historically had far fewer residents than Middlebury. However, development patterns in this town have had a significant effect on water and sediment loads in the Middlebury River. From review of census data, it is evident that Ripton and the other upland communities, such as Lincoln and Goshen, experienced a substantial immigration of residents beginning in the mid-1880s. This time period roughly coincides with the increase in the lumber trade. Lumber was a booming industry in Northern New England during the mid- to late-1800s, and much of Vermont's forested uplands were stripped of their lumber (Wessels, 1997). The establishment of railroad access to Burlington beginning about 1850 and the ready access to Canadian timber via Lake Champlain, promoted the city to the third largest lumber center in the nation by 1868, behind Albany and Chicago (Amrhein, 1958).

By 1880, 672 people resided in the town of Ripton, and made their living through farming and lumber related industries. "Farm homes dotted the hillsides, and saw mills, shingle mills, butter tub and sash factories had sprung up along the banks of the rivers. These mills, together with lumbering, and [char]coal kilns, kept the men employed the year around." (Ripton town report, 1947). The Beers Atlas from 1871 depicts the location of seven mill dams along the Middle, North and South Branches of the Middlebury River. These are reproduced as Figure 5. Several additional saw mills and shingle mills are noted across the Ripton landscape in this 1871 map. A few foundation remnants of these mills are still found today along the river (reaches T3.05 and M14, e.g.; see Photo 1).

By the late 1890s the lumber industry in Burlington was declining (Amrhein, 1958), and populations in surrounding lumber towns began to decline. Following World War II and emigration coincident with the advent of the industrial age, Ripton's population reached a low of approximately 131 in 1960 (ACRPC web site). Farms, mills and factories were abandoned, and previously cleared farmlands and areas clearcut of their lumber began to revegetate. Comparing aerial photographs from 1942 to orthophotographs dated 1995 (see Appendix B), it is evident that much of the previously cleared landscape in Ripton has since reverted to forest.

As noted in other watersheds across Vermont during the same time frame, widespread deforestation in the Upper Watershed during the mid- to late-1880s would have caused increased water and sediment loads to be mobilized from the Middlebury River watershed. Rainfall which

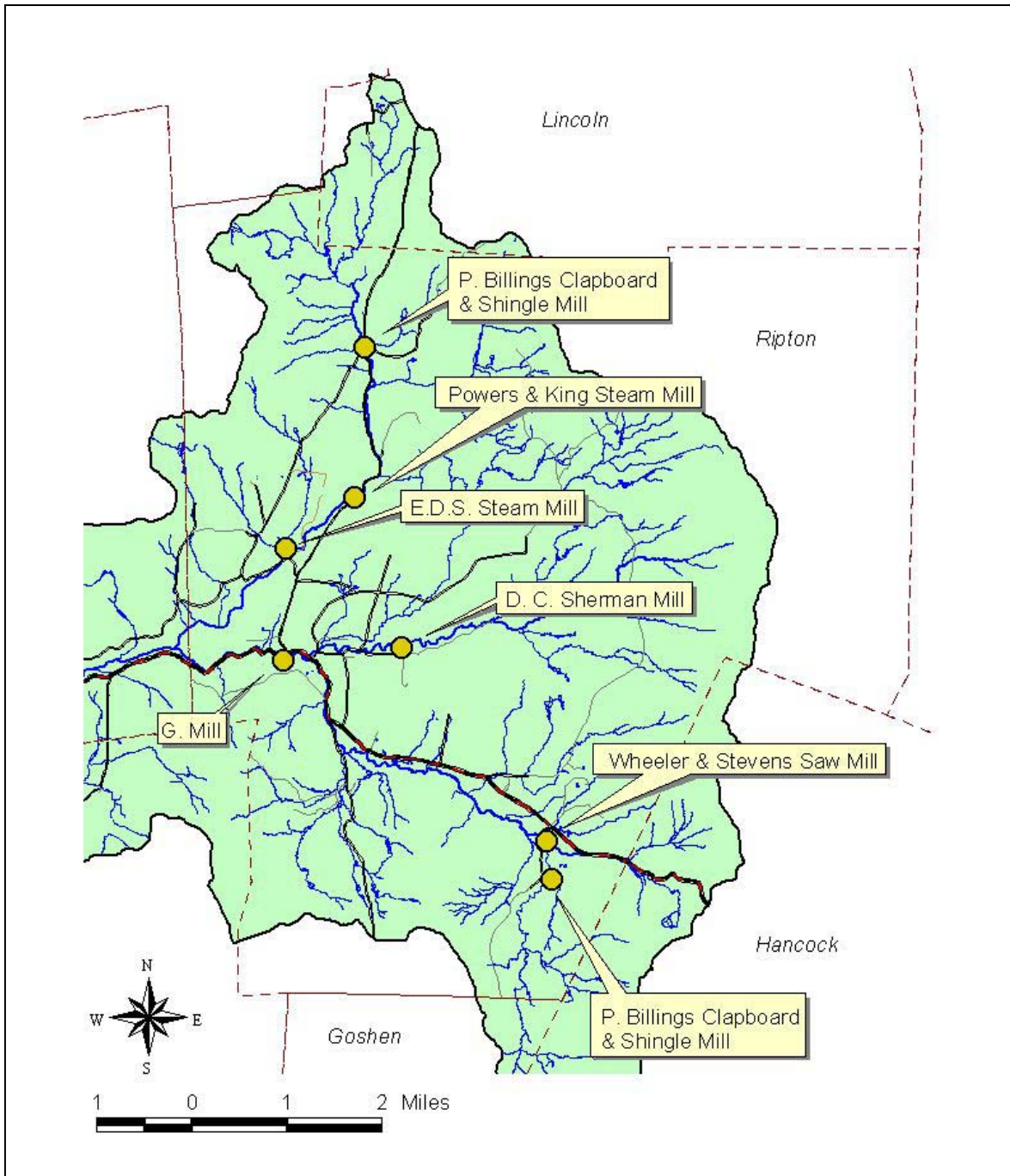


Figure 5. Approximate Location of Mill Dams in Ripton Depicted on 1871 Beers Atlas



Photo 1. Dam across Middle Branch (Reach M14) in approximate location of D.C. Sherman mill dam noted on 1871 Beers Atlas of Ripton, VT. (Warren King pictured)

would previously have been intercepted by tree leaves and branches, and which would have been taken up by tree roots and evapotranspired, instead ran off the land surface. Infiltrative capacities of the soils would have been reduced by compaction of the soils during cutting. And these increased volumes of stormwater runoff would have had increased energies for entrainment of soils and sediments from the land surface, delivering increased sediment loads to the river network. The Lower Watershed likely went through excessive aggradational phases in response to the increased sediment loading. Many abandoned meander bends marking the historic positions of the river are visible along reaches M01 and M02 in the aerial photographs of this region.

Much of the cleared land appears to have been maintained in agricultural use into the early 1900s. As the Upper Watershed began to reforest beginning in the mid-1900s, the water and sediment balance would have again shifted (independent of global climate cycles) back to lesser volumes of runoff and reduced sediment loading. Since the late 1900's, Ripton's population has again began to rise (Figure 6), and the community is establishing itself as a recreational center and bedroom community for those employed in Middlebury, Rutland, and Burlington. Many

residents also telecommute or have established home businesses as facilitated by the Internet and other technological and communication advances. There is a recent trend toward clearing home lots in the forested uplands or converting previously agricultural land to residential use. These development patterns can lead to increased runoff caused by increased impervious surfaces (i.e., more rooftops, driveways, lawn spaces occupying previously forested surfaces). Upland development can also bring more localized stressors to the river channel including additional bridges and culvert crossings undersized with respect to the bankfull or flood widths and floodplain encroachment by roads and structures which reduce the floodplain area available to the river during flood stage. Such floodplain access is a critical need of the river channel to dissipate energies associated with flood stage flows – serving as a kind of pressure release valve for the river.

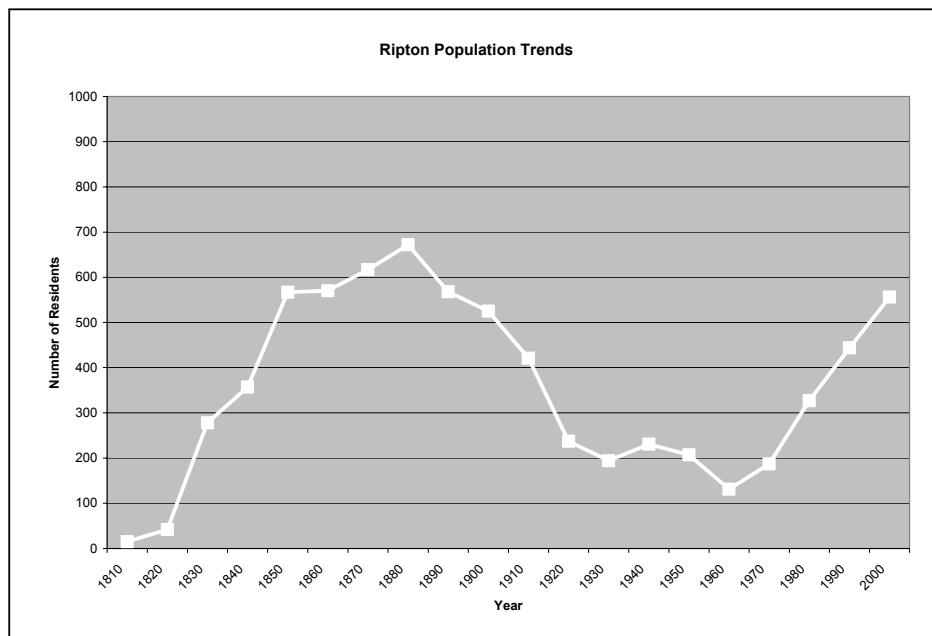


Figure 6. Town of Ripton population trends.

3.4 Hydrology

The Middlebury watershed is approximately 63 square miles in size. The basin is ungaged, and the nearest major United States Geological Survey (USGS) station (# 04282500) is located on the Otter Creek near the Rt. 30 crossing in downtown Middlebury (Figure 7).

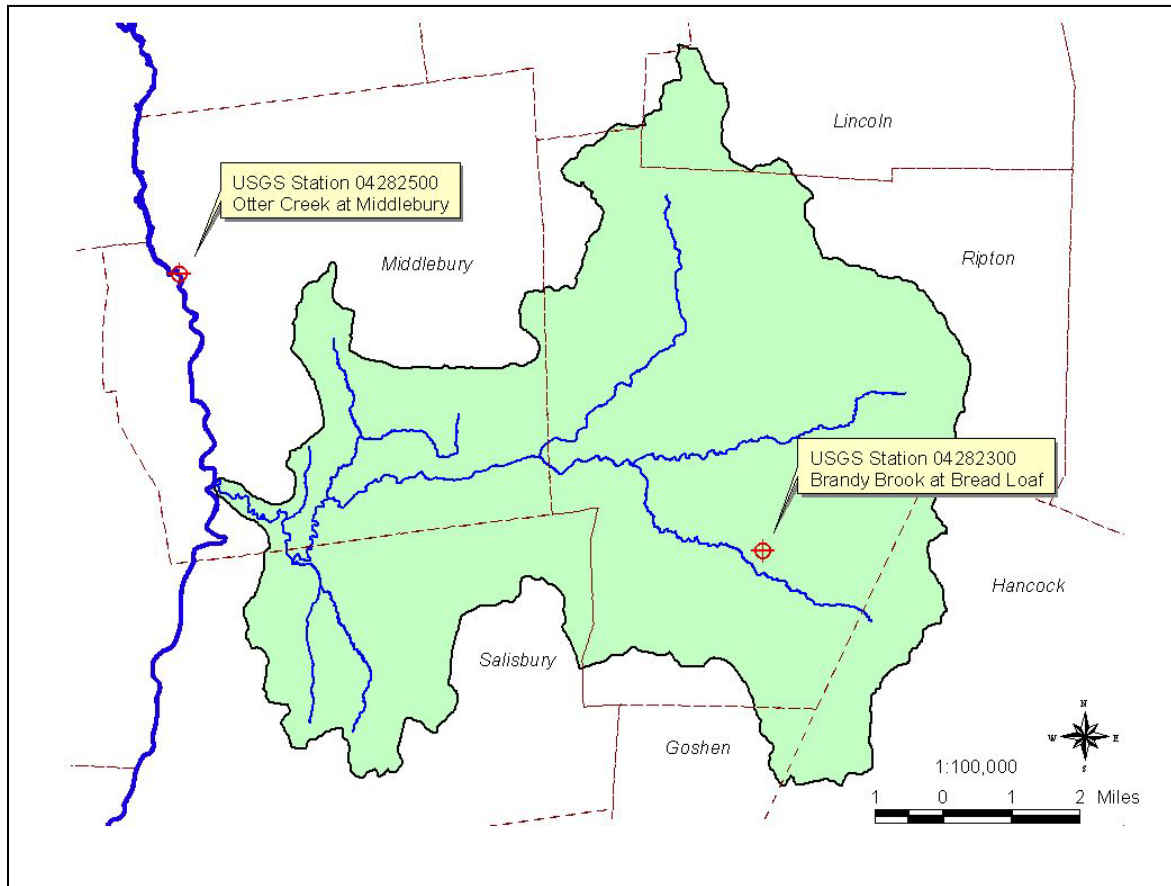


Figure 7. Location of USGS Gaging Stations Near Middlebury River Watershed. Station 04282500 (Drainage Area of 628 sq. mi.) operated from 1904 to 2001; Station 04282300 (Drainage Area of 2.2 sq. mi.) operated from 1963 – 1978.

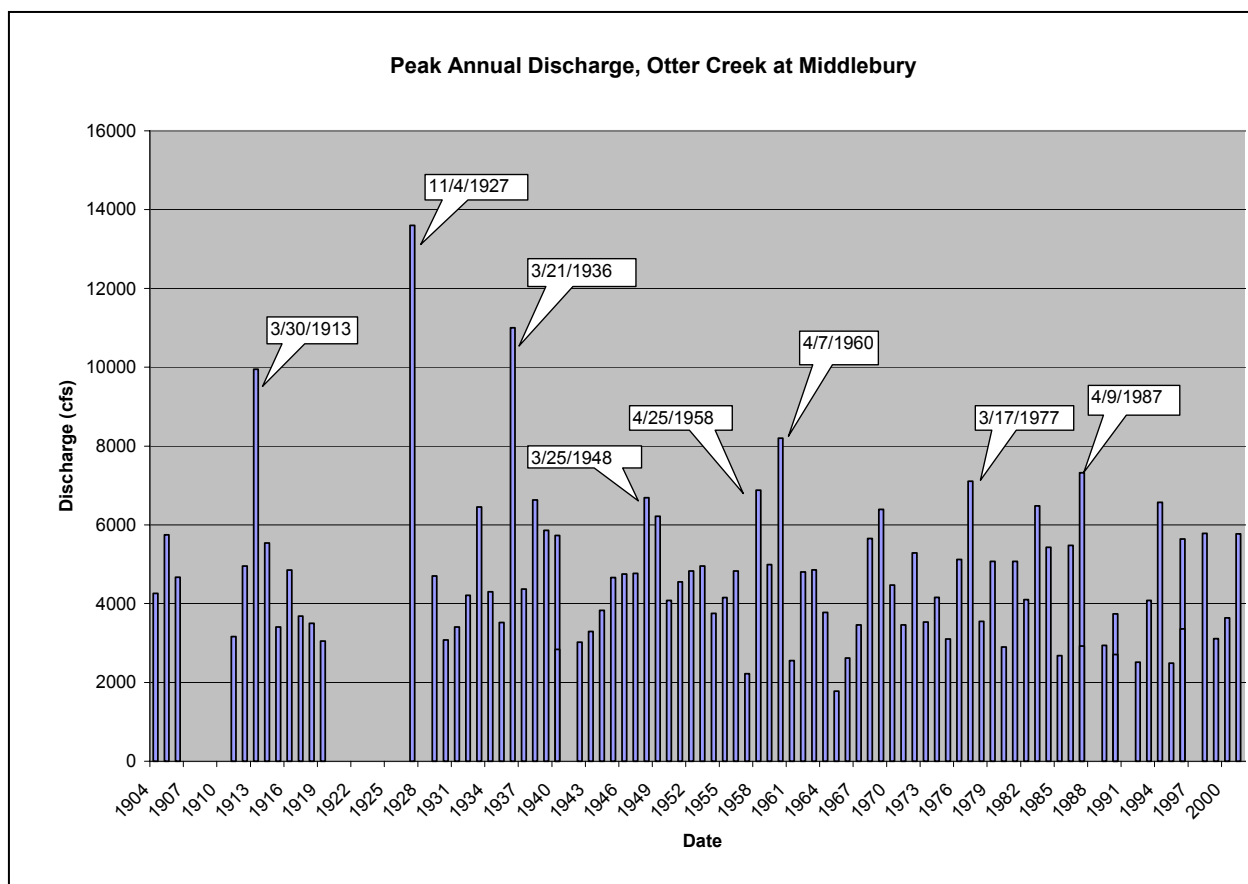


Figure 8. Record of Peak Annual Discharges at USGS Gaging Station #04282500, Otter Creek at Middlebury.

Discharges recorded in Otter Creek (Figure 8) do not necessarily reflect localized or flash floods which have directly impacted the Upper Watershed of the Middlebury River, and in some cases caused substantial flood damage in Ripton, Goshen, Lincoln, and along Rt. 125 leading from Ripton village to East Middlebury. Topographic fluctuations across the watershed are somewhat dramatic as evidenced by the profile of the Middlebury River and Middle Branch leading from the confluence with Otter Creek to the uppermost extent of the watershed (Figure 4). These changes in topography influence weather patterns and the distribution of precipitation over the landscape. During the same storm event, rainfall amounts can be much higher in the Upper Watershed than they are in the Lower Watershed across the Champlain Valley. In addition, the higher elevations tend to receive more snowfall in a given year than the lowlands and the resultant upland snowpack typically is retained for longer into the spring. This equates to a tendency for higher magnitudes and peaks of flow in the Upper Watershed during spring runoff. The Otter Creek at Middlebury receives runoff from a 628 square mile area, including not only upland watersheds such as the Middlebury and Neshobe to the south, but also drainage from low-lying watersheds located in the broad Champlain Valley. Discharge and flood stages tend to fluctuate much more gradually in the Otter Creek valley in response to storm events. Effects of

localized or regional storm events, such as those which have dramatically impacted Ripton in 1989, 1998, and 2000, apparently did not register as large flood events in the Lower Watershed (for example, see Otter Creek flood record, Figure 8).

One small USGS station (#04282300) operated historically in the upper Middlebury watershed at the Rt. 125 crossing of Brandy Brook in Ripton, southeast of Breadloaf (Figure 7). This station recorded peak flows for the 2.2 square mile tributary sub-watershed for a period from 1963 to 1978. A discharge of 546 cubic feet per second (cfs) was also determined from existing data relationships on 16 July 2000 during the flood event that hit the eastern part of the watershed. This year 2002 peak annual flow compared to peak annual discharges ranging from 43 to 236 cfs recorded between 1963 and 1978.

Since no gage exists for the Middlebury River watershed, flood magnitudes must be generally estimated using regional relationships based on watershed size (e.g., Johnson and Tasker, 1974). Flood flows for the Middlebury were estimated as follows in the 1984 FEMA Flood Insurance Study for the Town of Middlebury (Dufresne-Henry, 1984):

Table 2. Estimated flood magnitudes for Middlebury River watershed

(2a) 64.2 sq. mi. drainage area above confluence with the Otter Creek

Storm Frequency	Discharge (cfs)
10-year	3,940
50-year	5,430
100-year	6,060
500-year	7,650

(2b) 46 sq. mi. drainage area above Rt. 7 crossing southwest of East Middlebury

Storm Frequency	Discharge (cfs)
10-year	3,250
50-year	4,720
100-year	5,500
500-year	7,000

3.5 Flooding History

Given the topographic setting of the Middlebury River, the upper watershed in Ripton and Goshen has experienced a different flood history than that of the lower watershed. In general, precipitation cells impact the Upper and Lower watersheds differently, due to the substantial differences in elevation and topography. Table 3 denotes with a “√” those flood events which have impacted the Upper versus Lower portions of the watershed. Flood event summaries were compiled through review of annual town reports for Ripton and Middlebury, USGS discharge

records for the Station on Otter Creek at Middlebury, FEMA Flood Insurance Study reports for Middlebury and New Haven, and anecdotal information. Details of these flood events and historic flood photographs are compiled in Appendix C.

Table 3. Notable flood events in Middlebury River watershed

Flood Date(s)	Upper	Lower	Data Sources
1913	√	√	<i>USGS, 2003; USGS, 1990;</i> <i>VTDEC, 1999, App. 8;</i> <i>Johnson, 1927;</i> <i>Anderson-Nichols, 1986;</i> <i>Dufresne-Henry, 1984;</i> <i>Annual Town Reports, Ripton;</i> <i>Annual Town Reports, Middlebury;</i> <i>Middlebury Zoning Office records;</i> <i>Addison Independent, Oct. 7, 1938;</i> <i>Addison Independent, July 20, 2000;</i> <i>Hanson, 2003; Peabody, 2002</i>
1927	√	√	
1936		√	
1938	√	√	
1947		√	
1958		√	
1960		√	
1976		√	
1984	√		
1989	√	√	
1996, January	√		
1996, June	√		
1998	√	√	
2000	√		

3.6 Restoration and Channel Modification History

Channel management activities were evaluated since these can serve as localized or regional stressors to the river, leading to vertical or lateral channel adjustments. In other cases, (e.g., channel armoring) occurrence of channel management or restoration can be an indicator of active channel adjustments in response to another channel stressor(s) located upstream or downstream.

Appendix D summarizes the major restoration or channel modification events determined from review of annual town reports for Middlebury and Ripton, as well as from newspaper articles, interviews with the Ripton town clerk and other anecdotal accounts. Town road maps for Ripton and Middlebury are also included in Appendix D for reference (ACRPC, 2002).

Annual Town Reports cited channel management and restoration activities particularly following flood events, as well as infrastructure repairs or replacements. Specific locations of these activities were often not noted. As best as could be determined, the location by river reach was noted for these channel management sites.

4.0 ASSESSMENT METHODOLOGY

The geomorphic condition of the Middlebury River was evaluated utilizing stream assessment protocols compiled by the Vermont Agency of Natural Resources. Protocols for Phase 1 consist of historical data gathering, windshield surveys, and remote sensing of available topographic, orthophoto, soils, geologic and landuse mapping coverage. Phase 2 protocols are field procedures for rapid geomorphic and rapid habitat assessments. Reach-specific and cross-section data gathered during Phase 2 identify the present geomorphic condition of the river reach and the dominant process(es) of adjustment. Phase 1 and Phase 2 results permit the user to define the natural and anthropogenic stressors to the watershed over time and the spatial and temporal variability in geomorphic conditions which together have resulted in the present day conditions. The user can then infer possible consequences of land use or watershed management decisions on future geomorphic condition of the watershed to minimize erosion and flooding hazards and to optimize aquatic habitats.

These protocols draw substantially on classification systems advanced from previous work (Rosgen, 1996; Montgomery & Buffington, 1997; Fishenich and Allen, 2000; EPA, 1999; Schumm, 1984; Williams, 1986; Wolman, 1954). Research conducted by Vermont entities has permitted these protocols and classification systems to be customized for Vermont watersheds and geologic settings (Center for Watershed Protection, et al, 1999a; Center for Watershed Protection, et al, 1999b; Center for Watershed Protection, 2000; Barg and Springston, 2001; Barg, 2002).

These are working protocols in the process of being updated through experience gained in implementation at a variety of watersheds state-wide. One newer draft of each of the Phase 1 and Phase 2 protocols has been published since initiation of this study (VTANR, April 2003). In the interest of efficiency and due to budget limitations, not all updates of these evolving protocols could be incorporated in this study.

4.1 Limited Phase 1 Stream Geomorphic Assessment Methods

Ideally, a Phase 1 assessment is conducted in advance of detailed field work to facilitate prioritization of specific reaches or subareas of a watershed for further study (Phase 2 and perhaps Phase 3 survey work). For this study, however, Phase 2 field data were being collected for a majority of the watershed at the same time as the Phase 1 was completed. Therefore, a limited Phase 1 was conducted with a primary focus on supporting Phase 2 work in the basin with calculation of reach-based channel length, slope and sinuosity as well as valley widths and confinement ratios.

The limited Phase 1 was completed following protocols in the April 2002 draft (VTANR, 2002). The reader is referred to these protocols for more detailed descriptions of methodology. Specifically, Steps 1 through 4 of the protocols were completed, using ArcViewTM Extension: *Stream Geomorphic Assessment Tools* (C.L. Davis Associates, March 2002).

The Limited Phase 1 study was conducted by Shannon Hill of Waitsfield, Vermont, for the entire 63-square mile watershed (see Appendix A). The Phase 1 process delineated the watershed and defined discrete river reaches along the main stem and eight tributaries: Upper Watershed tributaries North Branch, Middle Branch, and South Branch; and Lower Watershed tributaries: Beaver Brook, Tributary to Beaver Brook, Halnon Brook, Tributary to Halnon Brook, and unnamed Tributary to Middlebury River. These lower watershed tributaries were delineated to support a separate streambank erosion study being conducted in the basin under Federal 2002 Clean Water Act Section 604(b) funding.

Reaches were defined based on variation in valley confinement, slope, and sinuosity. The Phase 1 process results in a standardized method for identification of reaches and location of land features relative to the river system. In addition, Phase 1 provides a frame of reference for future restoration and conservation work and additional watershed-based studies (e.g., habitat and natural communities mapping, surficial geologic mapping, and water quality assessments).

4.2 Phase 2 Stream Geomorphic Assessment Methods

Rapid Geomorphic Assessments (RGAs) and Rapid Habitat Assessments (RHAs) were conducted as per the April 2002 draft of Phase 2 Stream Geomorphic Assessment protocols (VTANR, 2002). In the case of the North and South Branches, assessment work made occasional use of cross section data gathered in 2002 and 2001, respectively, by the US Forest Service, Rochester office (Beck, 2002; see Appendix E).

Specific features and present channel positions (typically, left bank) were located using a Garmin™ eTrex Vista global positioning system (GPS) unit. Pictures were recorded with an Olympus™ D-520 zoom, 2.0-megapixel digital camera.

4.3 Phase 3 Stream Geomorphic Assessment Methods

Three localities in the watershed were identified for more detailed survey work as part of this study:

- Upstream of the Lower Plains Road bridge in East Middlebury (Reach M08);
- Upstream of the Rt. 7 bridge crossing southwest of East Middlebury (Reach M06);
- A 650-foot stretch of the South Branch adjacent to the Robert Frost Interpretive Trail.

A laser level and direct-read rod with laser receiver attachment were utilized to survey cross sections and a longitudinal profile following procedures contained in the Phase 3 Stream Geomorphic Assessment protocols (VTANR, 2003). Pebble counts were conducted at the cross sections following methods of Wolman (1954).

5.0 PHASE 1 AND 2 ASSESSMENT RESULTS

5.1 Limited Phase 1 Stream Geomorphic Assessment Results

The Middlebury River main stem, its three major tributaries (North, Middle, and South Branches) and five minor tributaries were delineated into reaches, based on characteristics of valley confinement, valley slope and channel sinuosity. Main-stem reaches are identified with an “M”. North Branch reaches with a “T3” and South Branch reaches with a “T4”. The Middle Branch was considered an extension of the main stem of the Middlebury River for purposes of identifying reaches. Resulting reaches ranged from 1,600 feet to 6,600 feet in length (see Figure 9).

For each reach, the following parameters were quantified, as per VTANR Protocols (2002):

- Elevation of downstream reach break (ft above mean sea level)
- Channel Length (ft)
- Channel Slope (ft)
- Channel Width (ft) by reference to VT Regional Hydraulic Geometry Curves (VTDEC WQD, 2001)
- Valley Length (ft)
- Valley Slope (ft)
- Valley Width (ft)
- Sinuosity
- Valley to Channel Width Ratio, or Valley Confinement
- Drainage area (sq. mi.)

Phase 1 results are summarized in Appendix A. Detail parameters are provided in the VTANR River Management Section Phase 1 and 2 database (Microsoft Access©) included with this report (Appendix K).

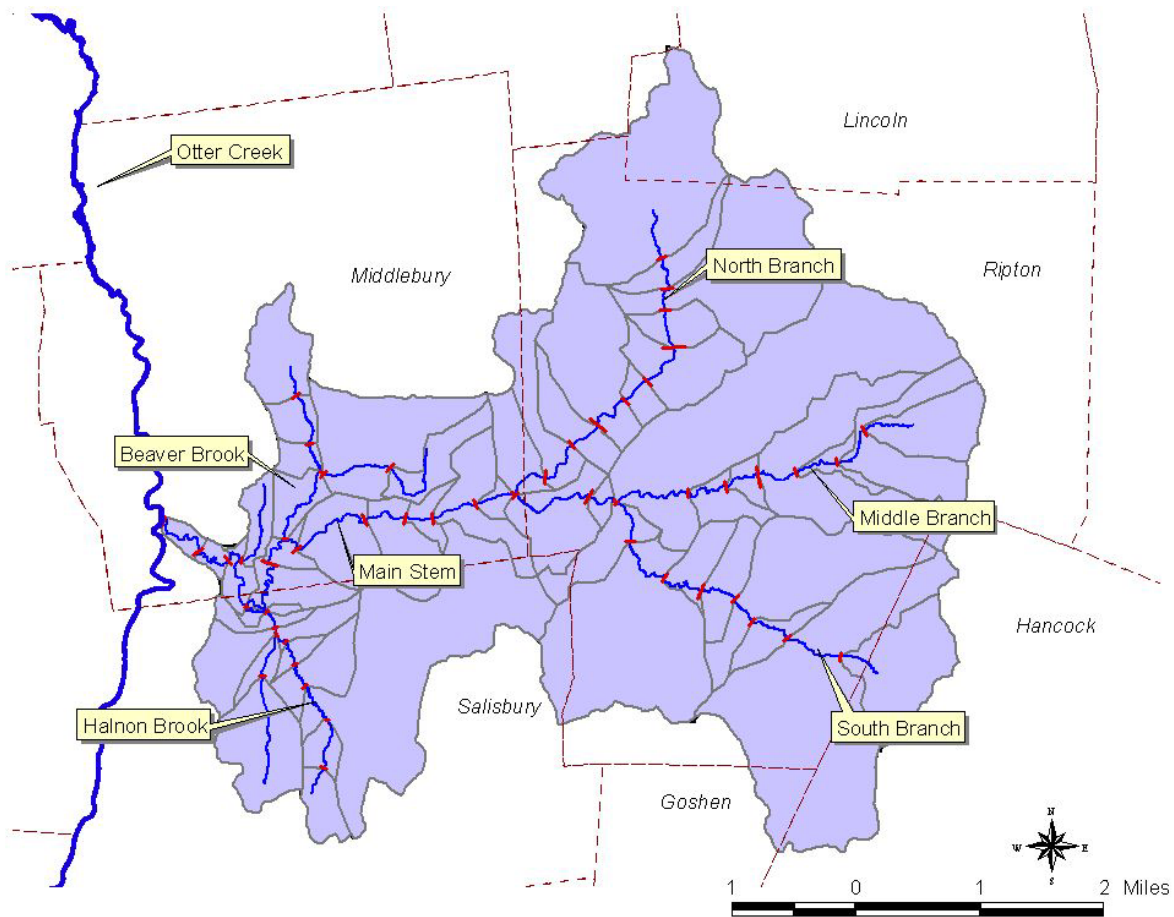


Figure 9. Reach and reach-based sub-watershed delineation for the Middlebury River watershed.

5.2 Phase 2 Stream Geomorphic Assessment Results

Phase 2 assessment results are summarized below for each major portion of the Middlebury River watershed (see Figure 10):

- the Lower Watershed from the confluence with Otter Creek to the gorge above East Middlebury village (M01 to M08);
- the Transport Reaches through the gorge from East Middlebury village to Ripton Village (M09 to M12);
- and the Upper Watershed, consisting of:
 - the North Branch (T3.01 to T3.10);
 - the Middle Branch (M13 to M19); and
 - the South Branch (T4.01 to T4.08).

Detailed results of each major sub-watershed are presented in the following sections, beginning with the Upper Watershed.

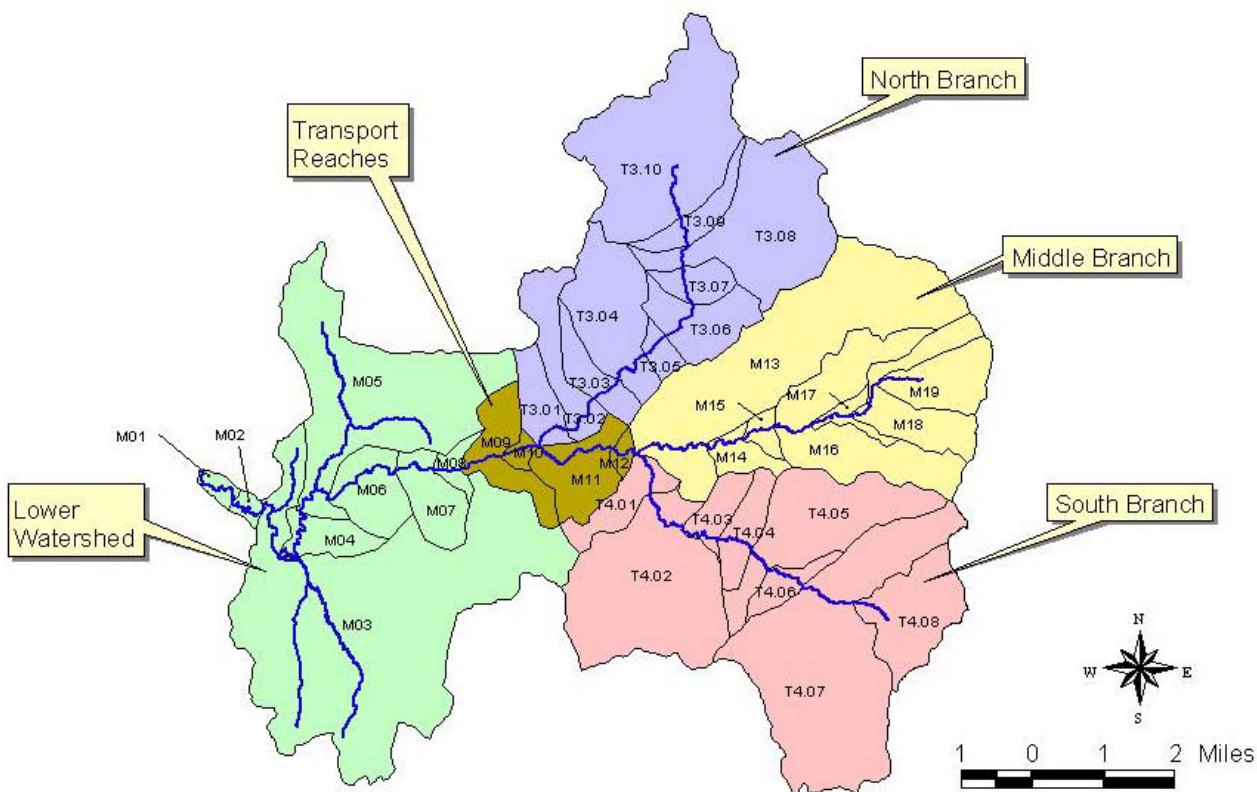


Figure 10. Major sub-watersheds of the Middlebury River watershed.

Phase 2 assessment results are tabulated in Appendix E. Major channel features are noted on orthophotograph base maps of each reach, as presented in Appendix F.

Channel dimensions measured at discrete cross sections in each reach, along with observations of channel form and features were compiled in a Rapid Geomorphic Assessment (RGA) score for each reach. Similarly, reach-based observations relating to in-stream and riparian habitat were compiled in a Rapid Habitat Assessment (RHA) score. The reader is referred to VTANR protocols for more details (VTANR, 2002). As per VTANR protocols, the quantitative scores for the RGA and RHA are each correlated to a condition, ranging from Reference to Poor, based on the following ranking:

Condition	Score
Reference	0.85 – 1.0
Good	0.65 – 0.84
Fair	0.35 – 0.64
Poor	0.00 – 0.34

5.2.1 Upper Watershed

North Branch (T3.01 to T3.10)

The North Branch drains approximately 14 square miles (or 22 %) of the Middlebury River watershed. North Branch reaches are generally narrowly confined between moderately steep valley walls, although reaches T3.06, T3.07, and T3.08 occupy a somewhat broader valley and have more flood plain access. Channel slopes range from less than 2 % in these middle reaches to greater than 2 % in the remaining reaches. The most downstream reach approaching the confluence with the main stem has a steep slope (greater than 4 %).

Good frequency of vertical grade control is offered in the downstream half of the North Branch by channel-spanning bedrock (and in a few possible instances, by channel-spanning boulder lines). (see Field Notes in Appendix F and Figure 15).

Geomorphic conditions of North Branch reaches ranged from Good to Reference, as summarized below in Table 4. Localized overwidening and channel braiding around two large, well-vegetated (forested) mid-channel bars were noted at the transition from reach T3.01 to reach T3.02 where channel gradient was locally reduced. These localized conditions contributed to the reduction in Rapid Geomorphic Assessment (RGA) score from Reference to Good. In mid-Branch reaches T3.06 to T3.08, more widespread aggradation, overwidening and planform change were noted associated with locally reduced buffer widths and relative scarcity of trees in the riparian corridor, floodplain encroachment by Lincoln Road, and channel constrictions at both bankfull and flood discharges caused by undersized private and public bridges. These mid-Branch reaches have shallower slopes and a somewhat broader stream valley – which are also favorable settings for development and placement of roads. Some older, well-vegetated armoring was noted along the right bank adjacent to Lincoln Road and locally on both banks at bridge crossings.

Minimal floodplain encroachment by roads or development was noted along North Branch reaches. In general, well-developed riparian buffers exist along the channel, estimated at greater than 100 feet in width in all but a few locations along the right bank (facing downstream) of middle reaches, T3.06 and T3.07. These buffers appear to have been maintained along the North Branch channel for several decades back to at least 1942 (see Figure B.1 in Appendix B).

RHA scores ranged from Good to Reference and generally correlated to Geomorphic conditions (Table 4). Embeddedness of larger particles by fines was generally less than 25 %; filling of pools was minimal. Good diversity of flow depths and velocities was observed. Some recruitment of large woody debris was evident, although the general lack of streambank erosion meant that snags, large woody debris, and undercut banks were not present to contribute a diversity of epifaunal substrates.

Table 4. Summary of Phase 2 results for North Branch reaches

Reach	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq. mi.)	Stream Type	RHA Condition	RGA Condition	CEM Stage	Left Buffer Condition	Right Buffer Condition
T3.01	3028	4.1	14.04	A3-S/P	0.79 Good	0.90 Ref	I	> 100 ft	> 100 ft
T3.02	3736	2.6	13.37	B3-R/P	0.75 Good	0.73 Good	I	> 100 ft	> 100 ft
T3.03	2402	2.5	12.34	B3-S/P to R/P	0.85 Ref	0.88 Ref	I	> 100 ft	> 100 ft
T3.04	3678	2.6	11.69	B3-S/P to R/P	0.90 Ref	0.84 Good	I	> 100 ft	> 100 ft
T3.05	2096	2.2	9.77	B3-R/P	0.89 Ref	0.88 Ref	I	> 100 ft	> 100 ft
T3.06	3646	1.8	9.50	C3-R/P	0.79 Good	0.75 Good	I	> 100 ft	50-100 ft
T3.07	2951	1.0	8.41	C4-R/P	0.77 Good	0.77 Good	I	> 100 ft	50-100 ft
T3.08	1837	1.4	7.92	C3-R/P	0.73 Good	0.75 Good	I	> 100 ft	> 100 ft
T3.09	2460	2.9	4.81	B2-S/P	0.88 Ref	0.86 Ref	I	> 100 ft	> 100 ft
T3.10	3899	2.2	4.24	C3-PB	0.88 Ref	0.90 Ref	I	> 100 ft	> 100 ft

Abbreviations:

S/P = Step/Pool; R/P = Riffle/Pool; PB = Plane Bed; Ref = Reference

CEM Stage (Schumm, 1977, 1984): I=Stable; II=Degrading; III=Widening; IV=Stabilizing; V=Stable

Middle Branch (M13 to M19)

The 5.5 mile length of the Middle Branch drains approximately 11.6 square miles (or 18.5 %) of the Middlebury River watershed. Nearly half of this drainage area is gained in the downstream reach M13 with the confluence of Sparks Brook. This confluence occurs upstream of the Billings Bridge on the Peddlers Bridge Road. It should be noted that the USGS 7.5 Minute Topographic Map (East Middlebury, 1944, photoinspected 1983) depicts this confluence to be downstream of the Billings Bridge, contrary to field observation.

Middle Branch reaches become progressively steeper in slope with distance upstream from the confluence with South Branch at Ripton Village. Channel gradients range from 2.8 % (M13) to more than 5 % at the upstream extent (M19). In general, Middle Branch reaches flow through a narrow valley setting, which becomes semi- to narrowly-confining in the headwaters. The somewhat broader valley setting of M13 and M14 have allowed for historic residential and agricultural settlement. Mill dams were depicted on the Beers Atlas (1871) along mid-reaches, and remnants of a concrete and timber dam in a location of bedrock-controlled channel were noted in reach M14 (see Appendix F). In recent years much of the riparian corridor along M13 and M14 has reverted to forest. The upland areas of the Middle Branch sub-watershed presently appear to be utilized for low-density recreation and logging activity.

Vertical grade control is essentially absent in the Middle Branch sub-watershed, except for two locations of channel-spanning bedrock in the lower portion of reach M14 (see Field Notes in Appendix F and Figure 15). Therefore, channel degradation has the potential to migrate through the majority of the reach, unchecked.

Geomorphic conditions of Middle Branch reaches ranged from Fair to Poor (see Table 5, below). Channel adjustments appear system-wide in nature. The channel is entrenched and appears to have lost connection with its floodplain along the upstream quarter of reach M13 (see reach results in Appendix E). Comparison of cross section dimensions to those predicted by regional hydraulic geometry curves (see Appendix H) and to results for a cross section conducted in this same general location by representatives of the Green Mountain National Forest (Beck, 2002), suggest that field measurements by SMRC were somewhat in error. The bankfull elevation appears to have been too low, with a resulting narrower than expected bankfull width. However, even allowing for adjustment to a higher bankfull elevation, the channel is entrenched at this location. Areas of entrenched conditions within reach M13 each are coincident with channel encroachment by residential development along the left bank and possible channelization associated with an old road crossing. Further downstream from this segment, the channel is dominated by aggradation and planform adjustment (flood chutes and channel avulsions). Localized scour was noted at bridge crossings and in-stream culverts, particularly the in-stream culvert crossing of Peddlers Bridge Road (see Figure 11). Five bridge crossings exist along reach M13, estimated to be constrictors at the bankfull flow stage or higher flood magnitudes, based on the bankfull widths surveyed during this study (see Appendix G and Figure 16).



(a)



(b)

Figure 11. In-stream culvert on Peddlers Bridge Road crossing of Middle Branch, Reach M13 – (a) upstream approach depicts culvert width (16 ft) undersized with respect to the measured bankfull width (40.5 ft) – (b) constriction of flow through the culvert has lead to vertical scour on the downstream end of the culvert, as well as excessive lateral scour along the right bank of the stream channel which has migrated upstream and poses risk to the integrity of the fill material surrounding the culvert.

Channel disconnection with the floodplain is also evident along reach M17. Remaining reaches are in Fair condition dominated by aggradation, widening and planform adjustment.

Minimal floodplain encroachment by roads or development was noted along Middle Branch in upstream reaches, M16 through M19. In general, well-developed riparian buffers exist along this portion of the channel, estimated at greater than 100 feet along both the left and right banks. These buffers appear to have been maintained along the Middle Branch channel for several decades back to at least 1942 (see Figure B.1 in Appendix B).

Habitat conditions ranged from Fair to Good along the Middle Branch (Table 5). While mass wasting and streambank erosion are tending to liberate large woody debris and detritus, creating diversity of flow patterns and abundant epifaunal substrates for aquatic habitats, substantial aggradation along many reaches is resulting in localized embeddedness and filling of pools. In lower reach, M13, relatively narrower buffer widths and floodplain encroachment by roads and residential development have locally reduced vegetative canopies and vegetative diversity along streambanks.

Table 5. Summary of Phase 2 results for Middle Branch reaches

Reach	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq. mi.)	Stream Type	RHA Condition	RGA Condition	CEM Stage	Left Buffer Condition	Right Buffer Condition
M13	6961	2.8	11.62	C3b-R/P	0.72 Good	0.55 Fair	IV	50-100 ft	50-100 ft
M14	3912	3.0	5.99	B4-S/P	0.61 Fair	0.34 Poor	III/IV	> 100 ft	> 100 ft
M15	2902	3.1	5.55	C4b-R/P to S/P	0.60 Fair	0.58 Fair	IV	50-100 ft	> 100 ft
M16	3259	3.3	5.33	B3-S/P	0.69 Good	0.34 Poor	III	> 100 ft	> 100 ft
M17	3609	3.9	2.66	F3- S/P	0.72 Good	0.36 Fair	II	> 100 ft	> 100 ft
M18	4382	4.2	2.42	B4a- S/P	0.76 Good	0.55 Fair	III	> 100 ft	> 100 ft
M19	4091	5.1	1.04	B4a- S/P	0.72 Good	0.49 Fair	III	> 100 ft	> 100 ft

Abbreviations:

S/P = Step/Pool; R/P = Riffle/Pool; PB = Plane Bed; Ref = Reference

CEM Stage (Schumm, 1977, 1984): I=Stable; II=Degrading; III=Widening; IV=Stabilizing; V=Stable

South Branch (T4.01 to T4.08)

The South Branch drains approximately 16.2 square miles (or 26 %) of the Middlebury River watershed. In general, South Branch reaches are confined between moderately steep valley walls. However, in a topographic pattern similar to the North Branch, mid-Branch reaches, T4.03, T4.04, T4.05, and T4.06 occupy less narrow valley settings and have floodplain access (where channel incision has not locally caused disconnection with the floodplain). Channel slopes range from less than 2 % in these middle reaches to greater than 2 % in the remaining reaches. The upstream-most reach (T4.08) at the headwaters of South Branch, has a steep slope (6.88 %).

Channel-spanning bedrock offers vertical grade control in downstream reaches T4.02 just below the Goshen Road bridge and in T4.01 beneath and just upstream of the Old Town Road bridge (see Field Notes in Appendix F and Figure 15). In the upstream reach, T4.08, water cascades over a 30-ft section of exposed bedrock. However, such grade control is not present in the majority of the South Branch sub-watershed.

Geomorphic conditions ranged from Poor to Good. No reference reaches were identified along the South Branch. The upstream reaches T4.08, T4.07 and T4.06, rated Fair and were dominated by widening, planform change and aggradation. These channel adjustment processes were evidenced by occurrence of enlarged, unvegetated point bars and mid-channel bars, presence of low-level scouring along both banks, occasional mass failures with fracture lines along the top of banks, leaning and falling trees, and large debris jams. Also, measured bankfull widths in reaches T4.05, T4.04 and T4.03 were much greater than predicted by regional hydraulic geometry curves produced from stable, reference streams (VTDEC Water Quality Division, 2001; see Appendix H). Imminent disconnection of the channel with its floodplain was noted in a few sections of reach T4.06, downstream of the Brooks Road bridge.

Disequilibrium of the channel appears systematic in nature through these upper reaches, although instability may have been exacerbated locally by undersized public (former Brooks Bridge) and private bridges in reach T4.07. This portion of the South Branch was considerably less forested and actively farmed several decades ago, by reference to the 1942 aerial photographs. Evidence of decades-old berming was noted along a substantial length of the left bank through T4.07, upstream of the Brooks Road bridge.

The Middlebury Snow Bowl ski area operates at the uppermost reaches of the South Branch watershed, and portions of the area's ski slopes drain into the watershed. Ski areas can serve as stressors for a watershed, increasing runoff due to increased percent imperviousness of cleared slopes relative to naturally forested slopes and due to increasing runoff from artificial snowmaking. According to Mr. Howard Kelton, past manager of the Snow Bowl, (Chal interview, 11 July 2003), artificial snow was not manufactured on Snow Bowl slopes until the late 1980s. Snow-making is, however, limited in scope (only a few trails) and limited in duration (initiated only to adequately cover the trail surface to maintain skiing during warm spells). Water used for snow-making is extracted from the natural runoff from Lake Pleiad (Chal

Schley, interview). The current condition of these upper reaches may also be the result of recent catastrophic floods, particularly the 2000 year flood, which resulted from a sustained accumulation of thunder storm cells over this portion of the Upper Watershed. The Brooks Road bridge (reach T4.07) and the Goshen Road bridge over a tributary to the South Branch (reach T4.02) were destroyed in this flood event. Wooden bridge fragments were noted immediately downstream of a crossing over reach T4.07. It is possible that a crossing structure at this location may have also been lost during the 2000 flood.

Geomorphic condition of the South Branch recovers in reach T4.05. The upstream half of the reach flows through a well developed forest with riparian buffers greater than 100 feet on the left and right corridors. Near the downstream end of this reach the South Branch enters an area of historically agricultural use. This area has gone fallow and is beginning a process of forest recovery. However, the long agricultural history and relative absence of riparian buffers appears to have contributed to the current state of disequilibrium through these reaches. Reaches T4.04, T4.03, and portions of T4.02 are in Poor to Fair geomorphic condition, dominated by planform changes, widening and aggradation. T4.04, adjacent to the Robert Frost interpretive trail, has the lowest RGA score relative to neighboring reaches. Several sets of steep riffles were noted throughout this reach, and may be related to the substantial aggradation evidenced by mid-channel bars and large unvegetated point bars with steep faces and mixed sediment sizes throughout. However, degradation may be active in the reach, as results of one cross section indicated imminent disconnection with the floodplain. Reaches T4.04 and T4.03 have undergone substantial lateral adjustments since the late 1970s, as evidenced by comparison of the current channel (surveyed by GPS, July 2003) and 1995 channel position (orthophotos base) with the 1972 topographic map for this region and the 1974 aerial photographs. An approximate rendering of past channel positions (aerial photographs not orthorectified) is presented in Figures 12a and 12b. A neck cutoff has occurred post 1995 and pre-2001 mid-way along reach T4.03 (Figure 12a). This channel avulsion carved a nearly 140-foot new channel bypassing approximately 490 feet of meander. Sediments were mobilized downstream, contributing to aggradation noted in downstream reaches.

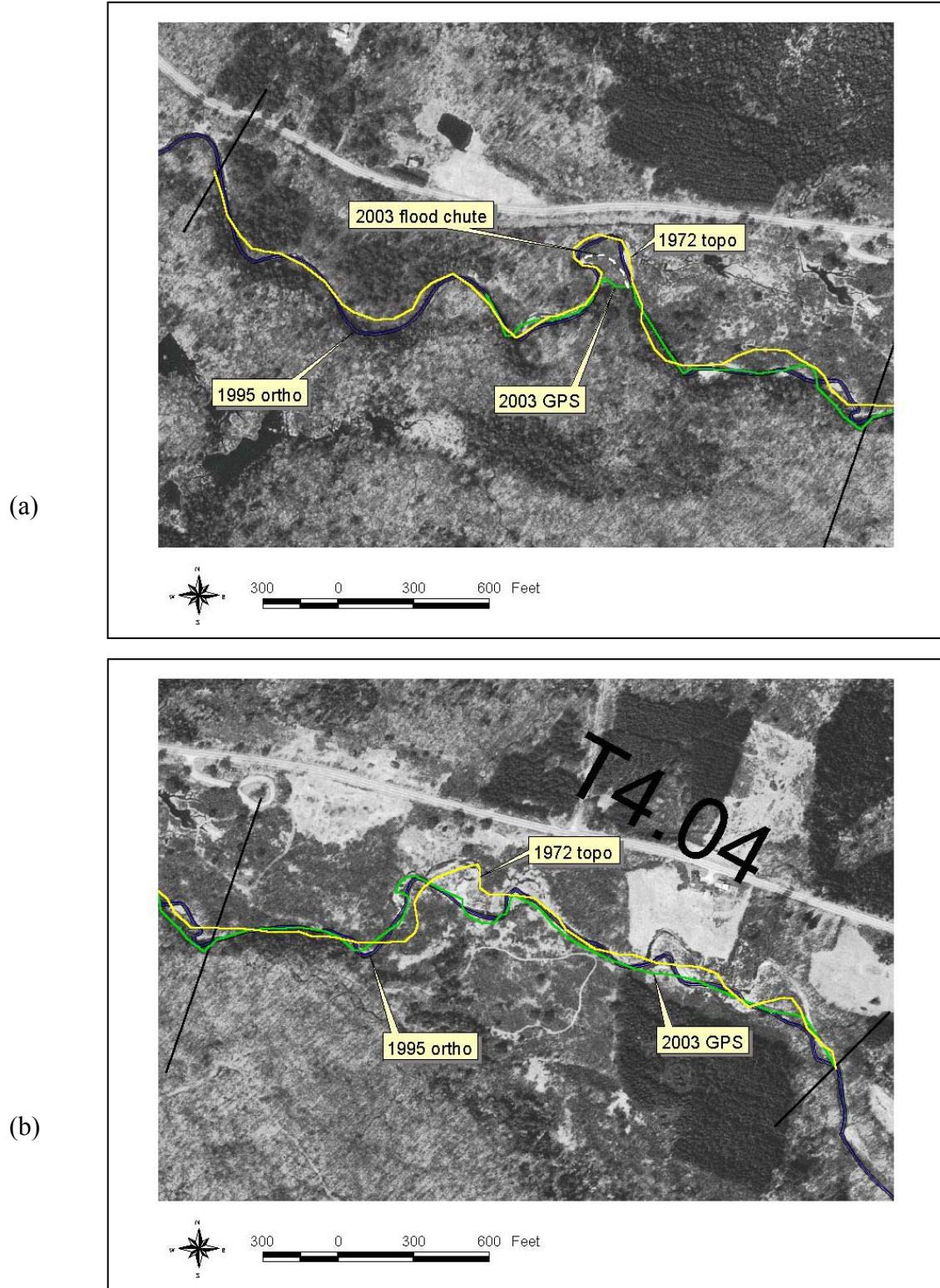
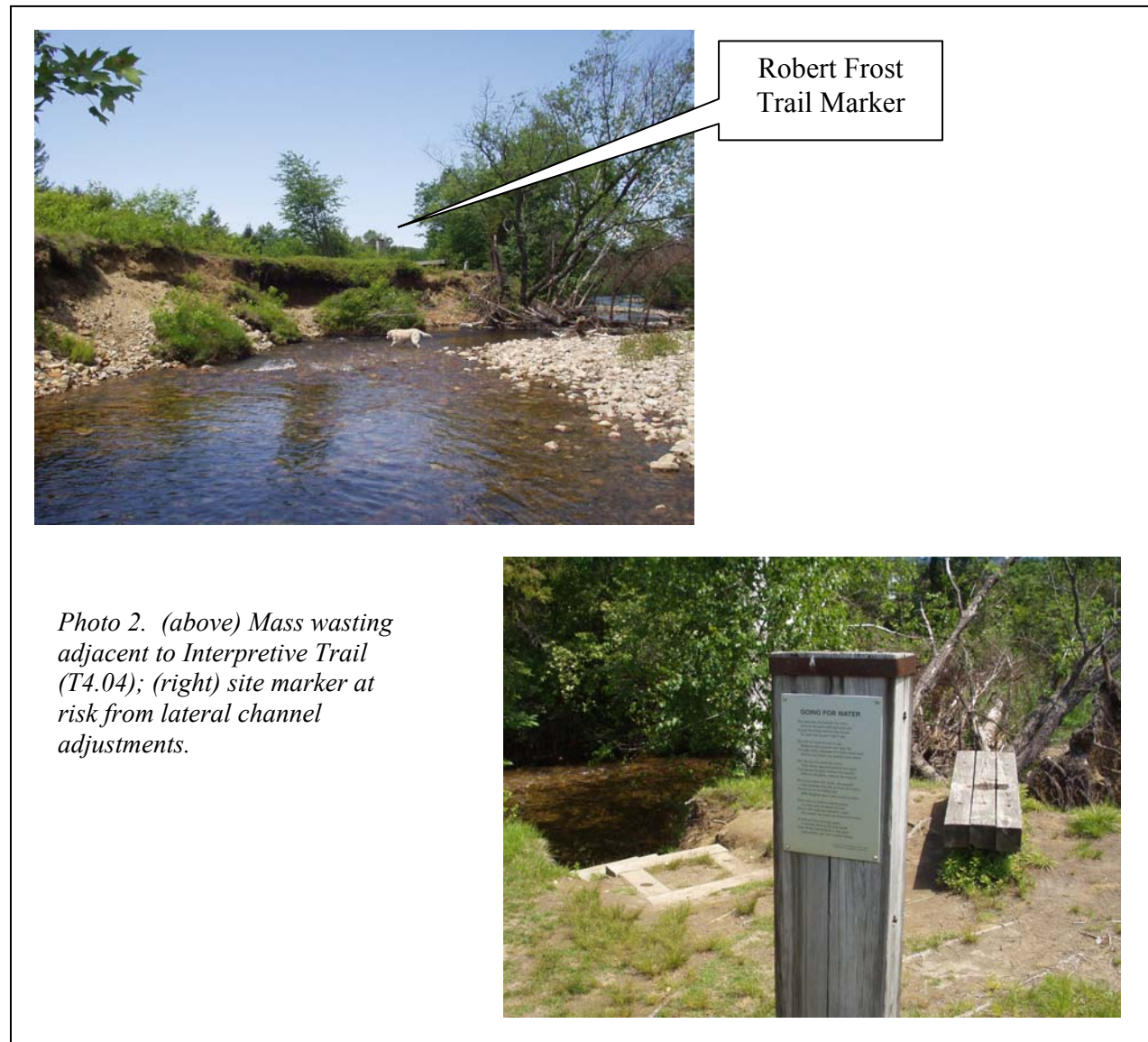


Figure 12. History of lateral channel migration, Reaches T3.03 (a) and T3.04 (b), South Branch, Ripton.

Reaches T4.04 and T4.03 are the subject of a restoration project being undertaken by the Green Mountain National Forest (Beck, 2002). Phase 3 geomorphic assessments were conducted in support of this restoration project as part of this Middlebury River watershed study, and are presented in Section 6.3. Infrastructure including a footpath bridge over the South Branch and site marker stations of the Robert Frost interpretive trail are at risk from lateral and vertical channel migrations through these reaches (Photo 2).



Perhaps due to the bedrock grade control afforded in lower reaches T4.02 and T4.01, the geomorphic condition of the South Branch recovers somewhat prior to its confluence with the Middle Branch above Ripton Village. The channel gradient begins to steepen through these reaches while the valley walls narrow to become semi-confining. Several mass failures of

streambank material were noted through T4.02 where the channel impinges on the valley wall. Despite floodplain encroachment along the right bank by Rt. 125 and the occasional residential development, and despite a bridge span expected to constrict the bankfull flow event (Old Town Rd. Bridge), reach T4.01 exhibited limited signs of channel adjustment. A step pool structure dominated by boulders and cobbles is evident in the channel bed through this reach.

Table 6. Summary of Phase 2 results for South Branch reaches

Reach	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq. mi.)	Stream Type	RHA Condition	RGA Condition	CEM Stage	Left Buffer Condition	Right Buffer Condition
T4.01	3643	2.1	16.24	B3-S/P	0.80 Good	0.66 Good	I	> 100 ft	50-100 ft
T4.02	4623	2.1	15.51	C3b-R/P	0.80 Good	0.56 Fair	III	> 100 ft	> 100 ft
T4.03	4134	0.8	11.49	F3-R/P	0.69 Good	0.43 Fair	III/IV	> 100 ft	> 100 ft
T4.04	3141	1.0	10.98	C4-PB	0.58 Fair	0.24 Poor	III/IV	50-100 ft	> 100 ft
T4.05	2165	1.4	10.32	C4-R/P	0.66 Good	0.68 Good	V	> 100 ft	50-100 ft
T4.06	3331	1.7	7.86	B4c-R/P	0.75 Good	0.50 Fair	III/IV	> 100 ft	> 100 ft
T4.07	4515	2.7	7.43	C4b-R/P	0.69 Good	0.50 Fair	III	50-100 ft	> 100 ft
T4.08	2267	6.9	1.61	A3-S/P	0.69 Good	0.45 Fair	III	> 100 ft	50-100 ft

Abbreviations:

S/P = Step/Pool; R/P = Riffle/Pool; PB = Plane Bed; Ref = Reference

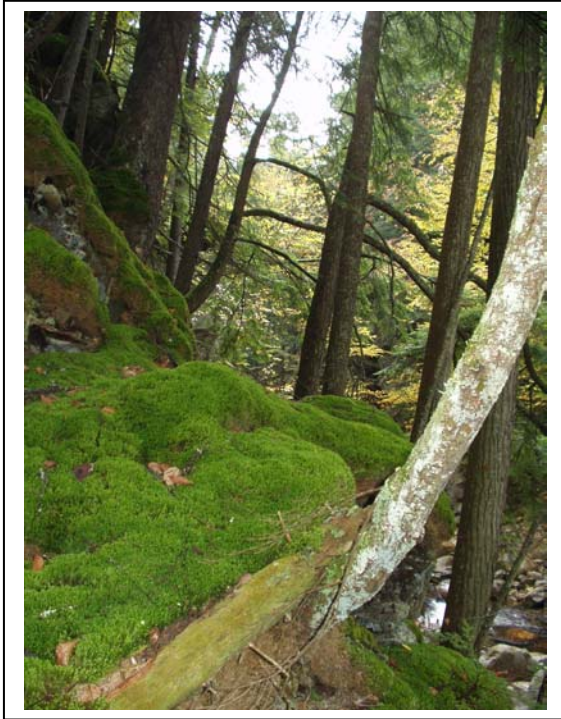
CEM Stage (Schumm, 1977, 1984): I=Stable; II=Degrading; III=Widening; IV=Stabilizing; V=Stable

Habitat conditions along the South Branch varied from Fair to Good. Reach T4.04 exhibited the lowest RHA score, largely due to absence of a forested buffer, limited canopy cover, streambank erosion and substantial aggradation. Plane bed structure dominated through this reach with the associated loss of pool and flow diversity.

5.2.2 Transport Reaches

The Transport Reaches are defined as reaches M09, beginning just upstream of the Rt. 125 crossing above East Middlebury village, to M12 through the village of Ripton. The small sub-watersheds draining directly to reaches M09 through M12 comprise an area of only 2.4 square miles (approximately), or 3.8 % of the Middlebury River watershed (see Figure 10). Primarily these reaches serve to transport water and sediment from the Upper Watershed down through the Middlebury Gorge to the Lower Watershed.

Downstream Transport Reaches, M09 and M10, are narrowly confined between steep valley walls; channel gradients are steep (5.3 % and 3.1 %, respectively). These reaches comprise the Middlebury Gorge and are particularly remote from vehicular access owing to the very steep talus and bedrock slopes. This “steep, narrow-walled mountain gorge... with cascades and falls and very tight technical channels” is rated a Class V white water, “suitable only for expert closed boaters with experience on very steep streams” (VTANR, 1992).



Reach M10 and the majority of reach M09 were not assessed for geomorphic and habitat conditions during this study, due to the limited access. Anecdotal accounts from Middlebury River Watershed Partnership volunteers and published accounts demonstrate that this portion of the main stem is largely controlled (vertically and laterally) by bedrock. Also, the reach is remote from development or other infrastructure which could potentially be in conflict with the river.

Above the Gorge, the upstream extent of Reach M10 and the downstream portion of Reach M11 near the confluence of the North Branch are in a steep valley setting with many boulder and channel-spanning bedrock controls (see Appendix F). The landscape in this area is dominated by hemlock with occasional birch and thick moss carpeting a thin till veneer over shallow bedrock (Photo 3).

Photo 3. Moss-covered valley wall at confluence of North Branch.

The majority of Reach M11 shares a narrow steep valley with Rt. 125 (Photo 4). Several hundred feet of rip-rap line the left bank of the river along this main road. Culverts convey stormwater runoff and tributaries from the left corridor under Rt. 125 to the stream channel.



(a)



(b)

Photo 4. Middlebury River along Rt. 125 (Reach M11) at base flow conditions in October 2002 (a) and during flood conditions in June 1996 (b) – view upstream.

Other than this floodplain encroachment by the road, riparian corridors are quite wide and well forested through Reach M11. Floodplain encroachment and channel armoring have contributed to somewhat degraded conditions along Reach M11, and floodplain disconnection along much of the reach.

Continuing upstream into Reach M12, increased residential and commercial development along the right bank, has lead to floodplain encroachment. Lack of buffer vegetation and channel armoring are prevalent along the right bank. A series of several steep riffles were evident. A mass failure located along the right bank was observed to increase substantially in length and height between November 2002 and July 2003 (see Appendix F for location).

Vertical grade controls in reaches M11 and M12 are offered by boulders and channel-spanning bedrock (M11 and M12) as well as the concrete bottoms of a double box culvert at the Rt. 125 crossing at Lower Ripton village (M12).

Habitat conditions through the Transport Reaches ranged from Fair (M12) to Good (M11). Lack of buffer along large sections of the right bank and floodplain encroachment by the road and residential development have resulted in reduced canopies and minimal vegetative cover along the right bank. Based on topographic settings and review of aerial photographs, conditions of Gorge reaches M09 and M10 are expected to be similar to those of North Branch reaches T3.01 and T3.02 which ranked in the Good range for habitat. Habitat conditions may be compromised somewhat by the steepness of grade, leading to reduced diversity of flow conditions and epifaunal substrates.

Table 7. Summary of Phase 2 results for Main Stem Transport Reaches

Reach	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq. mi.)	Stream Type	RHA Condition	RGA Condition	CEM Stage	Left Buffer Condition	Right Buffer Condition
M09	3596	5.3	44.31	(Ph.1) A-S/P	NM	NM	NM	> 100 ft	> 100 ft
M10	2872	3.1	43.31	(Ph.1) B-PB	NM	NM	NM	> 100 ft	> 100 ft
M11	6722	2.8	29.12	F3-S/P	0.78 Good	0.76 Good	II / III	50-100 ft	> 100 ft
M12	2478	3.3	28.01	B3-S/P	0.54 Fair	0.43 Fair	II	> 100 ft	25-50 ft

Abbreviations:

S/P = Step/Pool; R/P = Riffle/Pool; PB = Plane Bed; Ref = Reference; NM = Not Measured
CEM Stage (Schumm, 1977, 1984): I=Stable; II=Degrading; III=Widening; IV=Stabilizing; V=Stable

5.2.3 Lower Watershed

The Lower Watershed is comprised of reaches M01 (at the confluence with Otter Creek) to M08 (above the East Middlebury Village). This portion of the Middlebury River watershed is approximately 18.5 square miles in area (or 29.4 %) of the watershed. Lower Watershed reaches M01 through M05 occupy the broad valley setting of the Champlain Valley physiographic

province. Reaches M06, M07 and M08 are positioned on the alluvial fan deposits at the transition between the Green Mountains and the Champlain Valley. Channel slopes range from less than 0.1 % in the downstream reaches to greater than 2 % in the transition reach, M08, for example.

The Lower main stem flows generally westward from Middlebury Gap to the Otter Creek. However, at reaches M03 and M04, the river diverts to the south into the town of Salisbury to make its way around shallow bedrock. A low waterfall of channel-spanning bedrock forms a vertical grade control mid-way along reach M03 (see Photo 5; Appendix F).



Photo 5. Channel-spanning bedrock exposure west of Shard Villa Road (Reach M03). Such exposures of bedrock provide grade control to the river, preventing the stream from lowering its bed elevation.

Geomorphic condition along the Lower Watershed reaches ranged from Fair to Good (Table 8). Along alluvial fan reaches M08, M07 and M06 the river has a natural tendency to become braided, as the channel gradient decreases abruptly, stream power decreases, and larger sediments conveyed through the gorge drop out. A long history of channel management in East Middlebury Village has included channelization, repeated dredging and berming, as well as armoring through reaches M08, M07, and M06. The Middlebury Town Report from 1871 references labor and materials expended on the “breakwater in East Middlebury”. In 1947-1948, gravel was extracted from the river bed to form the pavement base for Ossie Road north and west of Goodro Lumber (Appendix D).

Table 8. Summary of Phase 2 results for Lower Watershed reaches

Reach	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq. mi.)	Stream Type	RHA Condition	RGA Condition	CEM Stage	Left Buffer Condition	Right Buffer Condition
M01	5040	0.06	62.82	C5-R/D	0.68 Good	0.65 Good	V	5 - 25 ft	5 - 25 ft
M02	4119	0.07	62.65	F4-R/P	0.54 Fair	0.59 Fair	IV	5 - 25 ft	5 - 25 ft
M03	6107	0.03	62.51	F5-R/D	0.60 Fair	0.56 Fair	IV	25 - 50 ft	5 - 25 ft
M04	7507	0.01	52.00	C4- R/P	0.58 Fair	0.36 Fair	III	25 - 50 ft	25 - 50 ft
M05	4220	0.1	51.38	C4- R/P	0.61 Fair	0.60 Fair	IV	50-100 ft	25 - 50 ft
M06	6899	0.6	46.43	C4-PB	0.52 Fair	0.33 Poor	III	> 100 ft	25 - 50 ft
M07	3176	1.8	45.42	B2c-S/P	0.58 Fair	0.59 Fair	IV	50-100 ft	50-100 ft
M08	2043	2.3	44.56	B2-S/P	0.74 Good	0.91 Good	IV	> 100 ft	5 - 25 ft

Abbreviations:

S/P = Step/Pool; R/P = Riffle/Pool; PB = Plane Bed; R/D = Ripple/Dune; Ref = Reference
CEM Stage (Schumm, 1977, 1984): I=Stable; II=Degrading; III=Widening; IV=Stabilizing; V=Stable

Berms were reinforced and extended from reach M07 into the upstream extent of M06 as recently as 1989 (see Appendix D and Appendix F). Several sets of channel-spanning bedrock in reach M08 have likely contributed to vertical stability in this reach. However, extensive berming and channel armoring along reaches M08 and M07 appear to have translated erosive energies downstream to reach M06. A large meander bend has developed south of Goodro Lumber, with mass wasting along a 440 foot length of channel, ranging from 16 to 20 feet high (see Photo 6).



Photo 6. Mass wasting along outside of meander bend at upstream extent of Reach M06. This section of the river is immediately downstream of a long stretch of channel berming and armoring. Stream energies translated through the armored reach are now impacting this downstream river reach.

This mass failure site initiates at the downstream extent of rip-rap along the left bank (facing downstream). This meander has shifted approximately 225 feet in less than 30 years, equating to an average lateral migration rate of 7.5 feet per year. As reviewed on historic aerial photographs and topographic maps, the downstream portion of Reach M06 has also undergone substantial lateral adjustments in the last 30 years (see Figure 13). Particularly following the flood events of 1998 and 2000, the river has undergone substantial channel avulsions.

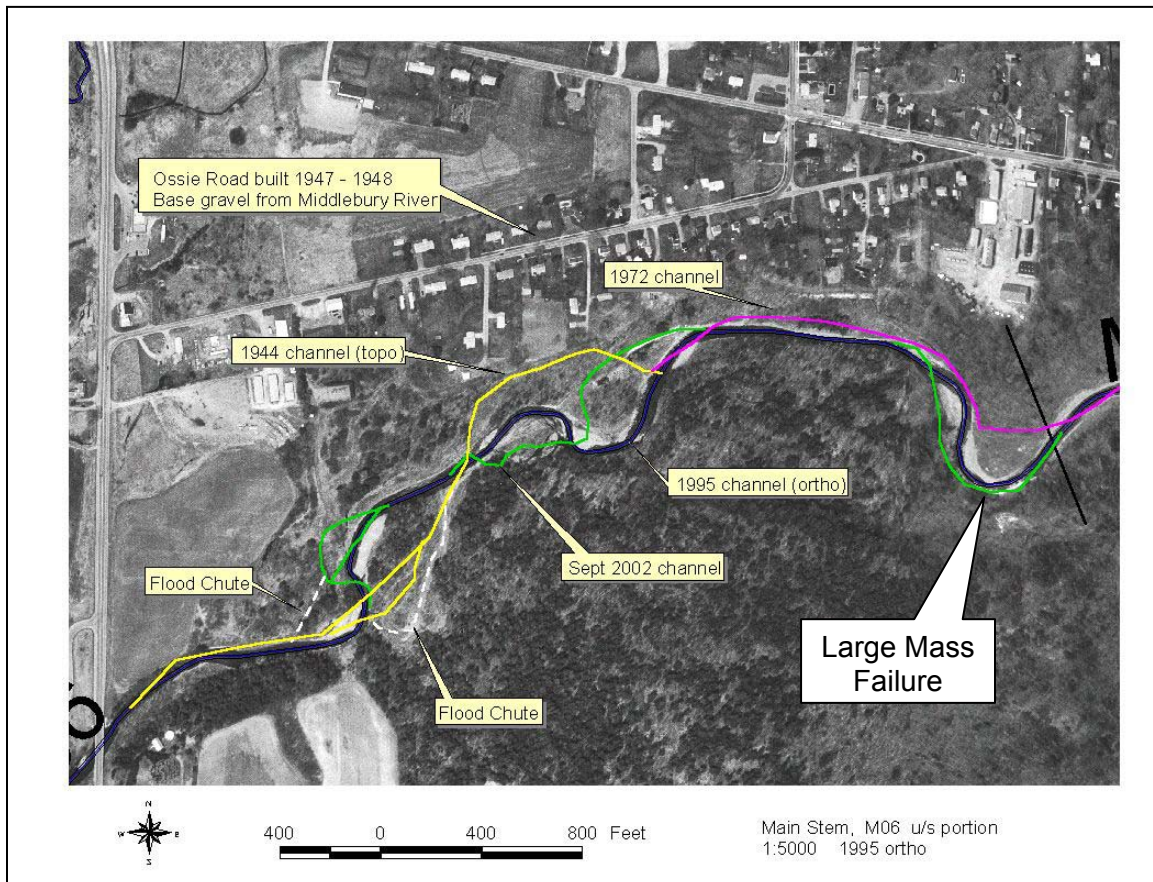


Figure 13. History of lateral channel migration, Reach M06, Main Stem, East Middlebury.

Streambank erosion and recent channel avulsions, particularly in reach M06, have mobilized substantial sediment loads downstream of the Route 7 crossing. Reaches M05 through M02 are dominated by aggradation, widening, and planform adjustments. In part, these conditions are in response to upstream instabilities. However, undersized bridges, limited channelization and reduced or absent riparian buffers have contributed to downstream channel conditions (see Photo 7).



Photo 7. Less than 5-foot riparian buffer along a portion of Reach M04 Buffer is dominated by grasses which provide little root-binding capacity to streambank soils and negligible shade to the river channel.

5.2.4 Summary of Phase 2 Assessment Results

Geomorphic conditions within the Middlebury River watershed are summarized in Figure 14. Generally, North Branch reaches appear to be in good condition, with several reaches suitable for conservation. The steepness of gradient, frequency of bedrock and boulder grade controls, as well as the relative lack of stressors from floodplain encroachment and channel management activities (see Table 9) have likely contributed to stable conditions in this upper tributary watershed.

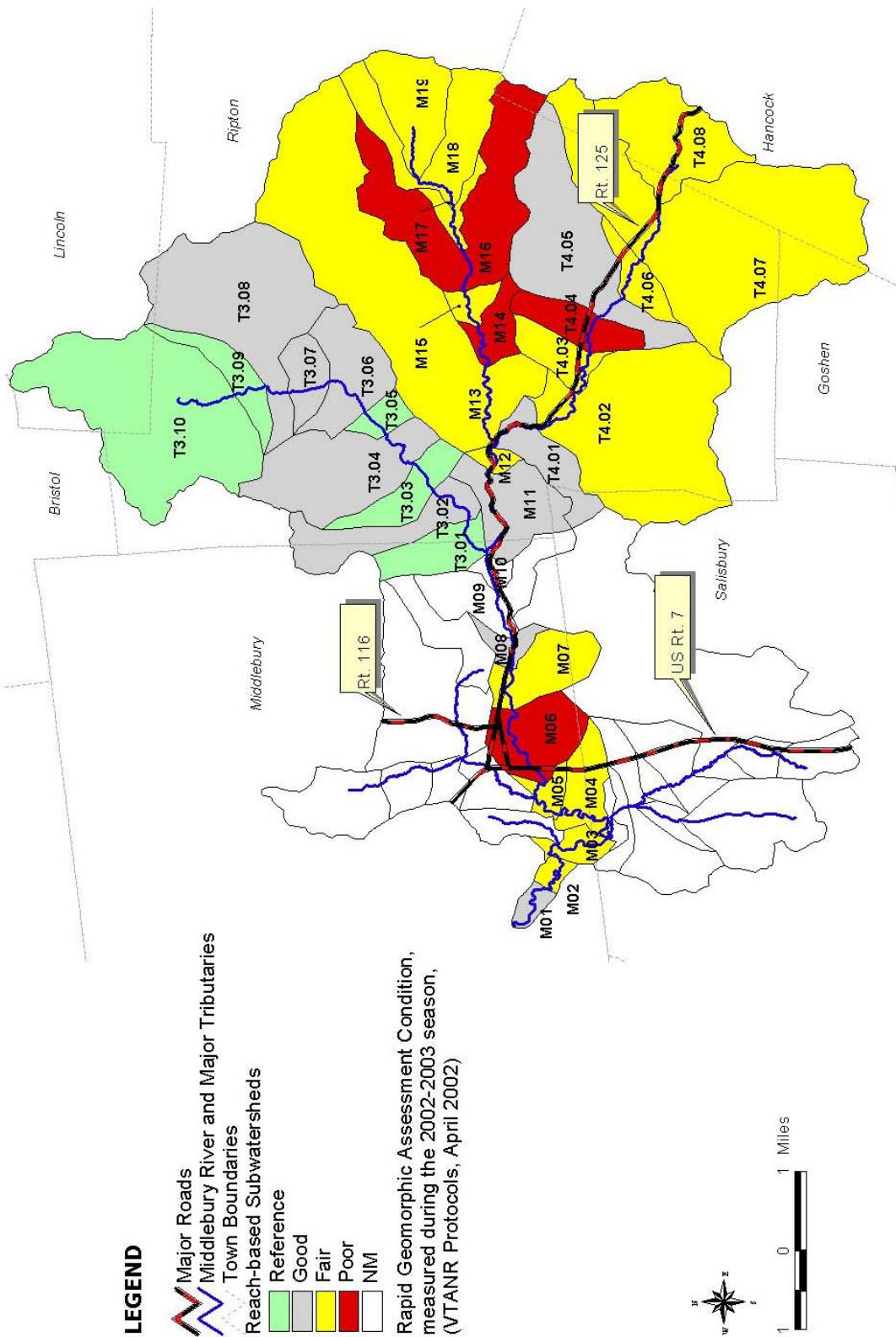


Figure 14. Reach-based Geomorphic Condition Phase 2 Stream Geomorphic Assessment Results, 2002-2003, Middlebury River Watershed

Table 9. Summary of Reported and Field-observed Potential Channel Stressors by Reach, Middlebury River Watershed

Reach	Vertical Grade Control	Channelization	Dredging	Berming	Bank Armoring	Revetments	Gravel Extraction	Undersized Bridges	Fords	Beaver Activity	Floodplain Encroachment	Segments of Minimal Riparian Buffer
Lower Watershed												
M01		√	√		√							√
M02		√			√			√			√	
M03	Bedrock	√			√			√			√	√
M04		√			√				√	√		√
M05		√			√			√	√		√	√
M06		√	√	√	√		√	√				√
M07		√	√	√	√		√	√			√	√
M08	Bedrock	√	√	√	√		√	√			√	√
Transport Reaches												
M09	Boulder, Bedrock											
M10	Bedrock											
M11	Bedrock				√					√		√
M12	Bedrock, Culvert	√			√	√	√	√		√		√
Middle Branch												
M13	Culvert	√		√	√		√	√		√		√
M14	Bedrock, Dam				√			√				
M15		√			√					√		√
M16		√		√	√			√	√	√		√
M17												
M18												
M19	Culvert							√				
North Branch												
T3.01	Boulder											
T3.02												
T3.03	Boulder							√				
T3.04	Bedrock							√				
T3.05	Bedrock							√				
T3.06		√			√			√		√		√
T3.07		√			√			√		√		√
T3.08					√			√		√		√
T3.09					√			√		√		√
T3.10								√	√			
South Branch												
T4.01	Bedrock	√			√			√		√		√
T4.02	Bedrock	√			√			√		√		√
T4.03						√			√			
T4.04		√	√	√				√	√			√
T4.05		√							√			√
T4.06												
T4.07		√		√	√			√	√	√		√
T4.08	Bedrock	√			√					√		√

South and Middle Branch reaches have experienced more regional and local stressors from deforestation in the mid-1800s, with active farming and lack of buffers persisting in the riparian corridor through at least the early 1960s. These upland tributaries have also been subject to floodplain encroachment by residential development and roads. Fewer locations of stabilizing bedrock or boulder grade controls exist in these tributary watersheds (see Figure 15). Also, anecdotal accounts suggest that the 2000 flood was concentrated on the southeastern portion of the watershed, more than over the North Branch portion of the watershed. The majority of reaches in the Middle and South Branches were rated in Fair to Poor geomorphic condition.

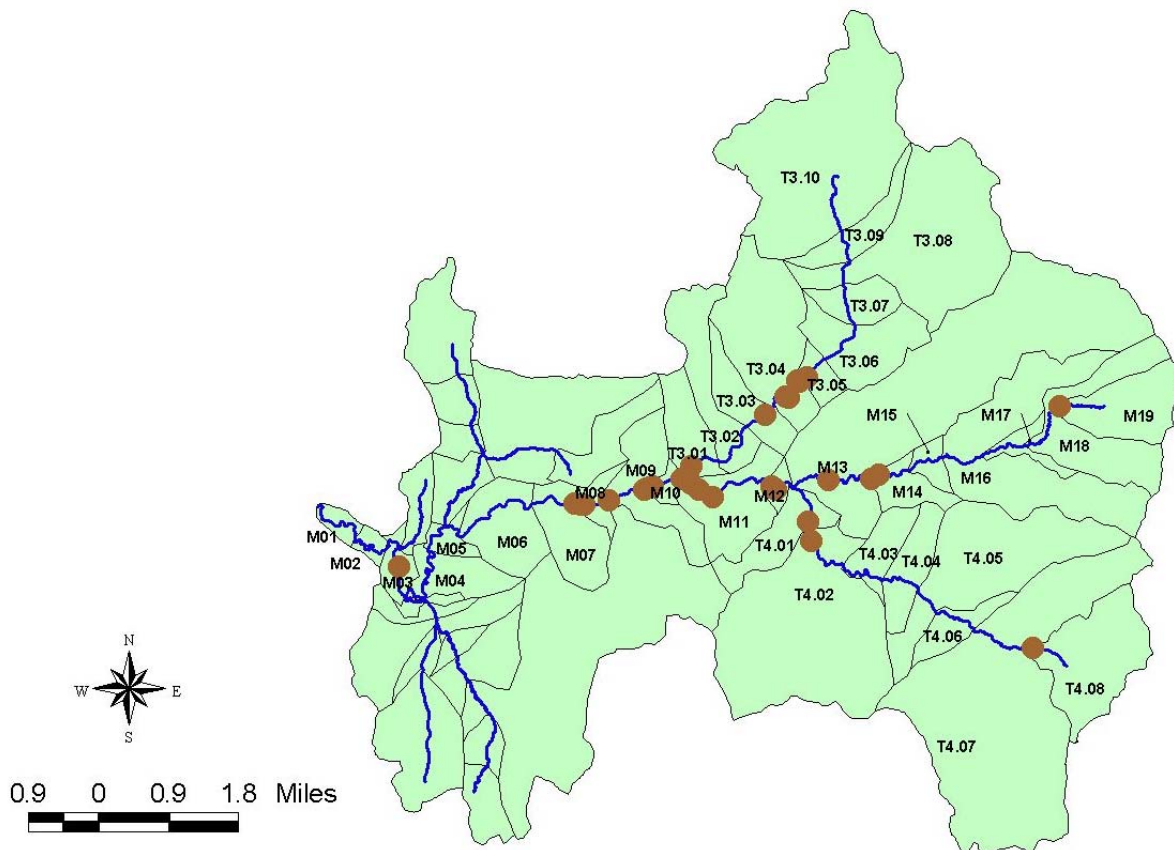


Figure 15. Location of boulder, bedrock and structural grade controls in the Middlebury River watershed.

Downstream of the Transport Reaches which were in Good condition, the majority of the Lower Watershed channel was in Fair to Poor geomorphic condition. Stressors in the Lower Watershed contributing to channel disequilibrium likely include channel management activities (channelization, dredging and berming, armoring, etc.) particularly through East Middlebury reaches M06, M07, and M08, undersized bridges (see Figure 16, Appendix G), lack of riparian buffers, and localized floodplain encroachment by roads (Table 9).

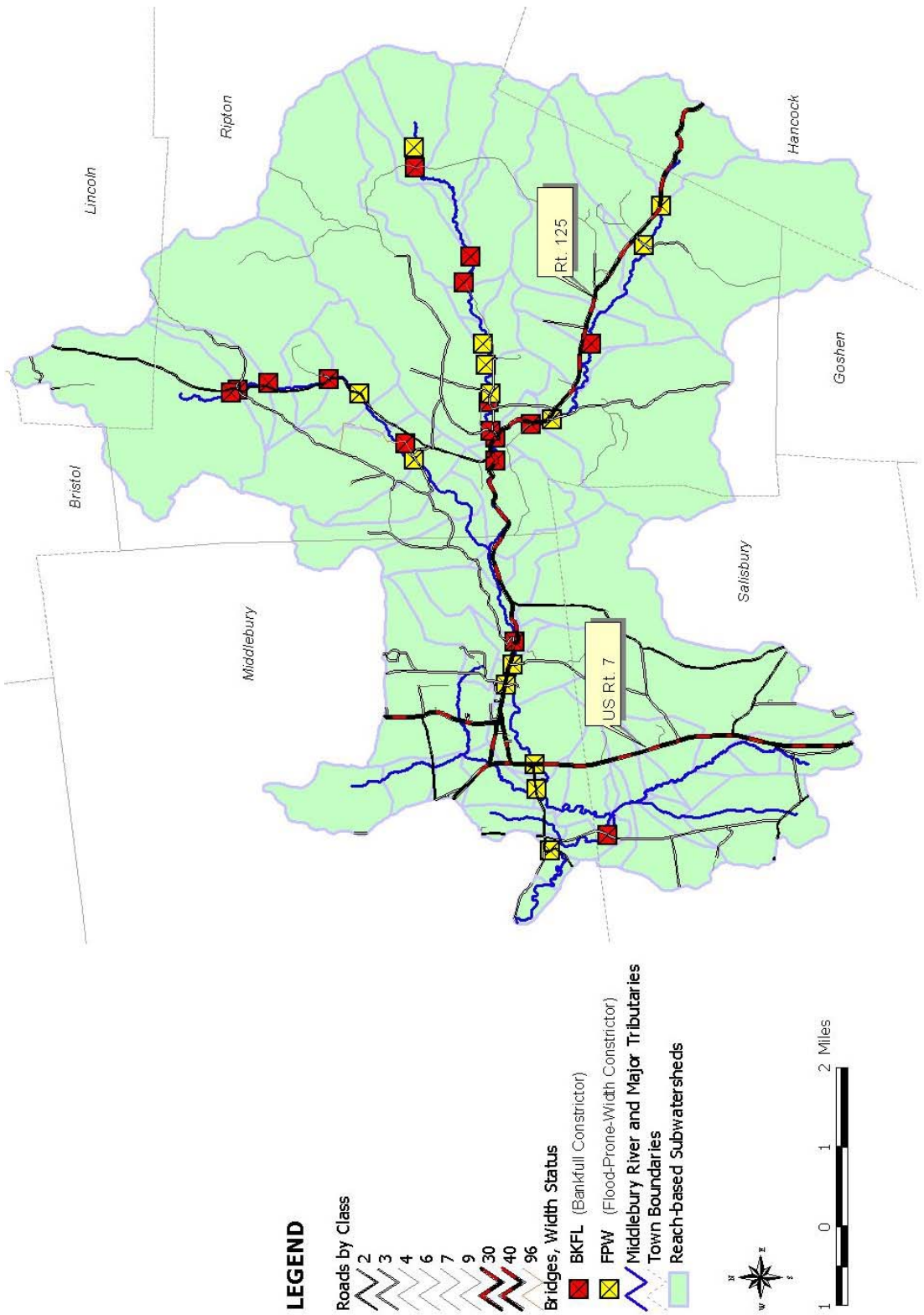


Figure 16. Bridge and in-stream culvert crossings: Middlebury River main stem and Middle, North and South Branches.

Note: Yellow symbol indicates bridge undersized with respect to the Flood Prone Width (Q10 to Q50 storm). Red indicates bridge undersized with respect to the Bankfull Width (Q1.5 storm).

Phase 2 results can be evaluated based on the assigned Channel Evolution Model (CEM) Stage, after Schumm (1977, 1984). Figure 18 depicts reach-based CEM stage for the watershed. CEM Stage has implications for future management strategies of these reaches and their contributing watersheds (Simon, 1995; Simon et al, 2001; VTDEC River Management Section, 2003).

Stable reaches (Stage I and V in green) are reaches considered to be in a state of relative equilibrium. Stage I and V reaches should be considered for conservation to limit potential future stressors to these reaches (such as floodplain encroachment, increased percent imperviousness, or elimination of buffers). Many of the North Branch reaches and South Branch reaches, T4.01 and T4.05 would be considered in this category.

Adjusting reaches, in Stage II, III, or IV, are those which are actively degrading, widening, or aggrading, respectively. These channels are not effectively transporting their water and sediment loads, and may be associated with substantial streambank and streambed erosion. Particularly, reaches in Stage II or III (actively deepening and widening) should be further evaluated through detailed survey work and more in depth historic assessments prior to consideration of labor- and resource- intensive restoration options (Simon, et al, 2001). For example, a well-intentioned streambank armoring project may be washed downstream in the next Spring runoff or minor flood event, when a Stage II channel continues to drop its bed and the stabilization structures are undermined and collapse into the channel.

Middlebury River reaches which were assessed to be in a Stage II or III condition are noted in orange on Figure 17. These include the majority of reaches in the Middle and South Branches and Lower Watershed reaches, M06 and M04. Stage II and III reaches which are especially susceptible to future adjustments are those containing no grade controls, those in lower gradient settings with smaller grain sizes (sands and gravels) dominating the stream bed, and those with absent or minimal forested riparian buffers:

- Lower Watershed – M04 and M06
- South Branch – T3.03, T3.04, T4.06, and T4.07

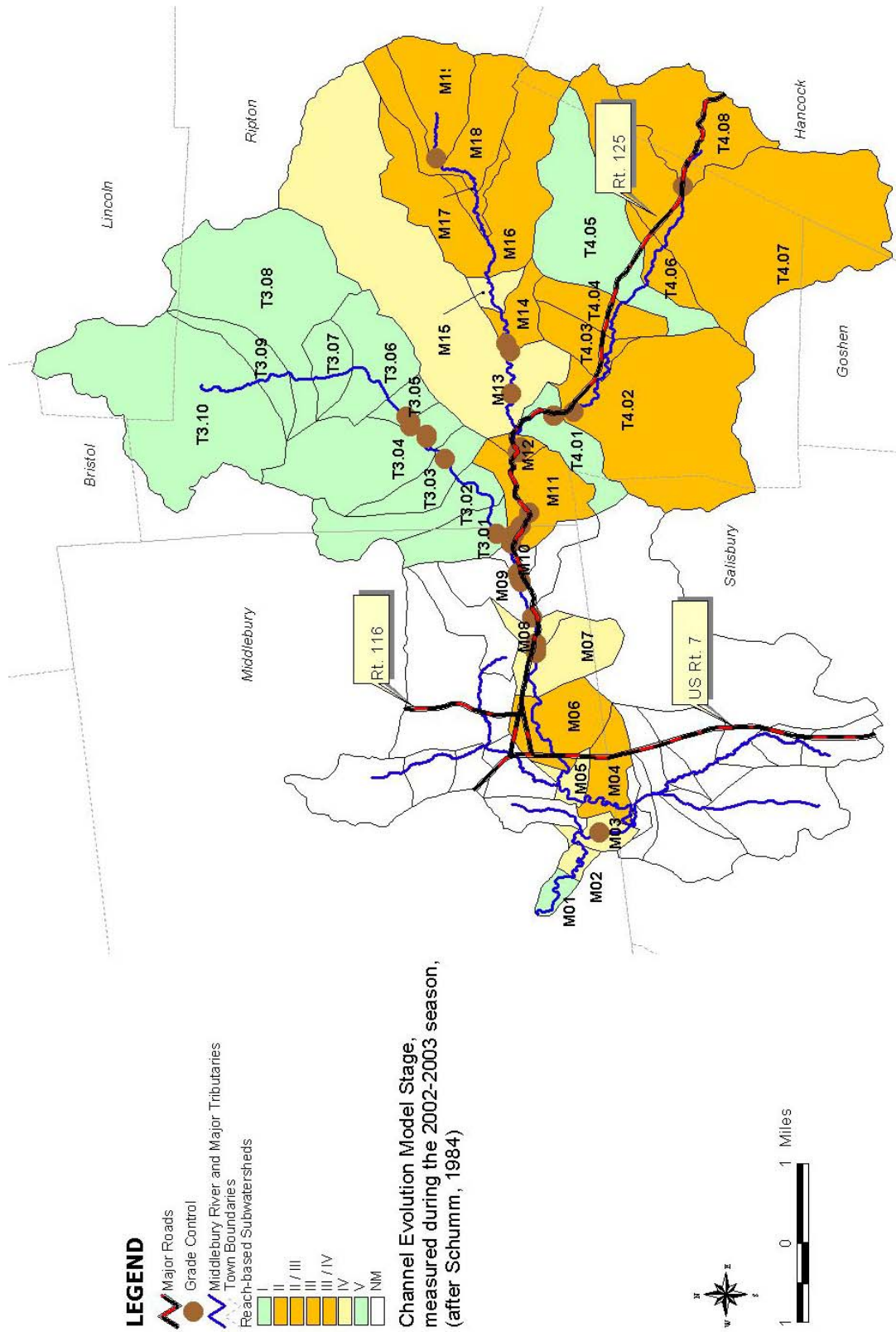


Figure 17. Reach-based Channel Evolution Model Stage Phase 2 Stream Geomorphic Assessment Results, 2002-2003, Middlebury River Watershed

Many bridges and in-stream culverts providing road crossings to the Middlebury River main stem and tributaries were determined to be undersized with respect to the bankfull flow (see Figure 16). All crossing structures were undersized when compared to flood prone widths (i.e., corresponding to the ten-year to fifty-year storm). Undersized structures can lead to channel aggradation upstream of the structure and vertical and lateral scour on the downstream side of the channel. Such conditions can, in turn, lead to destabilization of the fill and armoring material supporting the bridge and to undermining of footings or other structural components. In addition to locally constricting channels, undersized bridges and culverts can be a source for flood hazards to neighboring properties, serving as the location of debris jams or ice jams during spring runoff events or larger magnitude floods. Particularly, those bridges / culverts noted in red on Figure 16 are points to watch in future flooding conditions, as these are structures undersized with respect to the bankfull width.

Several areas of streambank erosion were inventoried during the study. In a few cases, channel adjustments had resulted in minor avulsions of the channel, where the channel had cut off a meander bend or chosen a new path (e.g., reaches T4.03, M06). Erosion of stream bed and banks, particularly in areas which have historically been farmed, can result in mobilization of phosphorous and excess sediments to the receiving waters. Streambank erosion can also be aggravated by animal crossings and by four-wheel drive and snowmobile fords, which trample stabilizing vegetation and create weak points in the streambanks and riparian buffer. Sediment mobilization degrades in-stream habitats for fish and other aquatic insects. In addition, locations of streambank erosion can be correlated to water quality issues. Elevated total phosphorus has been detected historically in the Middlebury River watershed, as well as elevated *E.coli* from possible agricultural or septic sources (Addison County River Watch Collaborative, 2001).

6.0 PHASE 3 ASSESSMENT RESULTS

Phase 3 assessments were conducted 10 July and 15 July 2003 at three locations within the Middlebury River watershed. Late-1990s bridge scour reports conducted by the United States Geological Survey (USGS) at select bridges in the watershed provided an opportunity to establish whether the channel beds had aggraded or degraded since the 1990s and to estimate an average net aggradation (or degradation) rate over the time period. Bridge-related cross sections were replicated at two locations:

- Upstream of the Lower Plains Road bridge in East Middlebury (Reach M08); and
- Upstream of the Rt. 7 bridge crossing southwest of East Middlebury (Reach M06).

In addition, three monumented cross sections and a longitudinal profile were conducted along a 650-foot sub-reach of the South Branch adjacent to the Robert Frost Interpretive Trail (T4.04). Detailed survey work in this reach was conducted to support future restoration planning (US Forest Service) in this actively adjusting reach. Cross sections were monumented so that they may be re-surveyed in subsequent years to estimate rates of lateral and vertical channel adjustments.

6.1 Lower Plains Road bridge, East Middlebury (Reach M08)

The Lower Plains Road bridge in East Middlebury was constructed in 1927 following destruction of the predecessor bridge at this location in the 1927 flood (see Photo 3, Appendix C.2). A recent bridge inspection conducted by the United States Geological Survey (USGS) (Boehmler & Degnan, 1997) included cross sections of the stream channel on the approach to the bridge and downstream of the bridge. These cross sections were referenced to a brass survey plate set in the concrete bridge curbing above the left bank, upstream bridge abutment.

On 10 July and 15 July 2003, the USGS approach cross section was replicated by SMRC. The SMRC survey was referenced to the same brass survey plate and assumed the same arbitrary elevation of this plate (104.09 feet; Boehmler & Degnan, 1997). Results are presented in Appendix I (Figure I.1, Tables 1a & 1b). In general, comparison of the June 1996 and July 2003 surveys indicates that the channel in this location has aggraded by more than one foot during the last seven years (estimated net aggradation rate of 0.2 foot per year).

Survey data are not sufficient to discern whether the apparent channel aggradation is strictly a localized phenomenon related to the constriction of the channel at this location by a bridge span somewhat undersized with respect to the bankfull width. A distinct mid-channel bar was not evident upstream of the bridge. This cross section was conducted mid-riffle. Geomorphic conditions for the reach (M08) as a whole, assessed during Phase 2 work, indicated a stable channel with minimal signs of aggradation, widening or planform adjustment (see Appendix E). Several exposures of channel-spanning bedrock are located along this reach. It is located at the

transition from the steeper-gradient Gorge reaches and downstream depositional reaches (see Figure 4). During the seven years which elapsed between the USGS and SMRC cross sections, the Middlebury River watershed was subjected to two relatively high magnitude flood events in 1998 and 2000. These events mobilized substantial sediment from the Upper Watershed downstream through these transition reaches in the East Middlebury village.

Caution should be used in interpretation of these survey results. Survey comparisons were conducted to provide a generalized indication of active degradation or aggradation over the time period. Differences in survey methods and equipment (USGS versus SMRC), shifting channel dimensions, and limitations inherent in the performance of each cross section, can introduce error in this process of replicating cross sections.

6.2 Route 7 bridge, East Middlebury (Reach M06)

The Route 7 bridge crossing in East Middlebury was constructed in 1964 associated with the realignment of Route 7. A recent bridge inspection conducted by the USGS (Boehmler & Flynn, 1997) included cross sections of the stream channel on the approach to the bridge and downstream of the bridge. These cross sections were referenced to a brass survey plate set in the concrete bridge curbing above the left bank, upstream bridge abutment.

On 10 July and 15 July 2003, the USGS approach cross section was replicated by SMRC. The SMRC survey was referenced to the same brass survey plate and assumed the same arbitrary elevation of this plate (503.59 feet; Boehmler & Flynn, 1997). Results are presented in Appendix I (Figure I.2, Tables 2a & 2b). In general, comparison of the June 1996 and July 2003 surveys indicates that the channel in this location has aggraded by nearly one foot (0.9 ft) during the last seven years (estimated net aggradation rate of 0.1 foot per year).

Survey data are not sufficient to discern whether the apparent channel aggradation is strictly a localized phenomenon related to the constriction of the channel at this location by a bridge span somewhat undersized with respect to the flood prone width (i.e., estimated Q10 to Q50 storm). Geomorphic conditions for the reach (M06) as a whole assessed during Phase 2 work indicated a highly adjusting channel, with significant indicators of aggradation, widening and planform adjustment (see Appendix E). Like M08 and M07, this survey location in M06 is within a transition zone for the watershed which likely received substantial sediments as a result of the 1998 and 2000 floods. Substantial streambank erosion is also occurring within a few thousand feet upstream of the surveyed location on M06.

The same cautions discussed in Section 6.1 should be employed when considering results of this replicated cross section survey.

6.3 Robert Frost Interpretive Trail site (Reach T4.04)

A 650-foot length of channel upstream and adjacent to the Robert Frost Interpretive Trail on the South Branch in Ripton was assessed through surveyed cross sections, longitudinal profile and

pebble counts. A longitudinal profile was conducted marking the elevation of the thalweg (or deepest part of the channel) and the water surface with distance downstream. Three cross sections were conducted and monumented for future reference. Two cross sections were conducted in streambed riffles (XS-1 and XS-2). A third cross section was conducted mid-run at a natural cross-over location between two gentle meander bends (XS-3). Detailed results are provided in Appendix J.

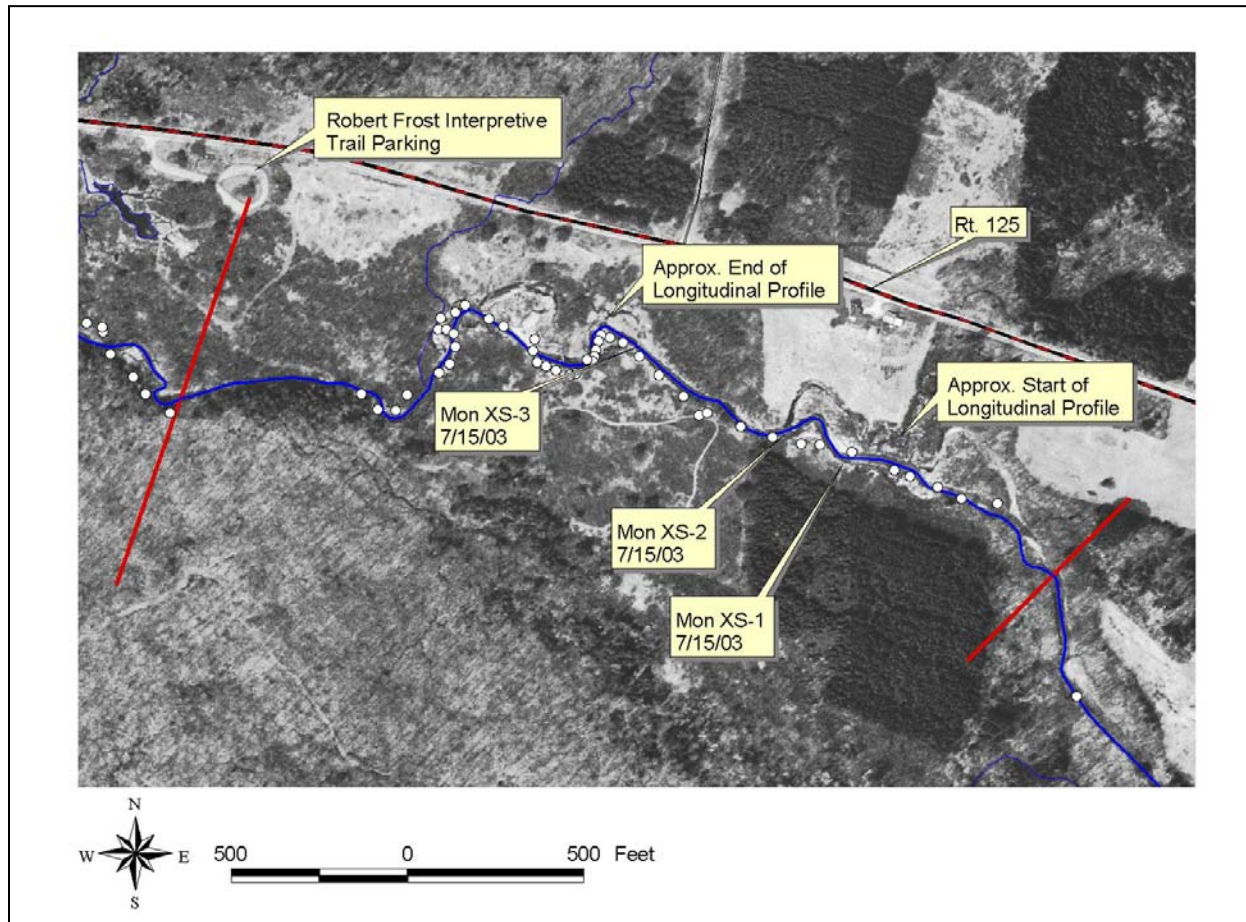


Figure 18. Location of longitudinal profile and monumented cross sections conducted 15 July 2003, South Branch Middlebury River (Reach T4.04), Ripton, Vermont. White circles indicate waypoints recorded along present (2003) channel, left bank (facing downstream). Red lines indicate downstream and upstream reach breaks of Reach T4.04. South Branch flows toward the west.

Results of the detailed cross sections generally confirm findings of the Phase 2 assessment of this reach. Downstream monumented cross section XS-3 is similar in geometry to the Phase 2 cross section conducted further downstream in June of 2003 (see Appendix F). These cross

section sites are located in fallow riparian settings which were previously agricultural. Buffers are presently dominated by grasses and shrubs, with the occasional isolated tree. The river has access to its floodplain in these portions of the reach. Streambed sediments are dominated by sands and gravels. Nearly all streambed sediments are able to be mobilized during the bankfull discharge at this mid-run cross section. In contrast, as one progresses upstream to monumented cross section sites XS-2 and XS-1, the reach is dominated by coarser particles, not all of which appear to be mobilized during the bankfull discharge (see Appendix J). This may be an indicator of active aggradation through this upstream portion of the reach. Additional indicators of aggradation noted during the Phase 2 assessment included mid-channel bars, large, unvegetated point bars, with steep faces and a mix of sediment sizes, not well sorted. The channel appears to have reasonable floodplain access along the right bank through XS-2 and marginal floodplain access (slightly entrenched) at XS-1.

A past wave of incision may have migrated through this reach within the last 30 years, as evidenced by an abandoned former channel located approximately 400 feet upstream of XS-1 (visible on the 1972 topographic map) which is approximately 2 feet higher in elevation than the current stream bed, and as evidenced by possible tributary rejuvenation noted in upstream reach T4.04 (see Appendix F). Reported historic channelization and past beaver activity (Schley, 2003; Weber, 2003), exacerbated by lack of forested buffers, may have contributed to destabilization of the channel in this reach.

7.0 CONCLUSIONS

The following conclusions are offered from the fluvial geomorphic assessment conducted in the Middlebury River watershed from the Fall of 2002 to early Summer of 2003:

- Channel disturbances along the Middlebury River, noted through field reconnaissance and historical data gathering, include:
 - Apparent or reported channelization;
 - Channel armoring (rip-rap);
 - Berming, particularly along reaches M06 and M07 in East Middlebury village;
 - Historic floodplain encroachment by Town Roads and Rt. 125 (South Branch and Upper Main Stem through the Gorge);
 - Reported historic gravel extraction, dredging and berming in East Middlebury village, particularly in response to flood events in 1927 and 1938, with the most recent dredging and berming event being circa 1989;
 - Undersized private and public bridges and in-stream culverts, serving as flow constrictors at the bankfull and/or higher magnitude flood events;
 - Minimal or negligible riparian buffers along portions of main stem reaches, particularly those associated with current agricultural land use in the Lower Watershed;
 - Active stream crossings (fords).
- Watershed stressors noted for the Middlebury River, determined from historical data gathering, include:
 - Historic (mid-1880s) deforestation of the Upper Watershed leading to historic increased percent imperviousness and sediment mobilization;
 - Recent upland development in the Upper Watershed leading to increased percent imperviousness.
 - Recent high-magnitude flood events particularly focused on the southeastern portion of the watershed in 1998 and 2000.
- The North Branch reaches in Ripton are in Good to Reference geomorphic condition, due in large part to long-time persistence of forested riparian buffers and minimal floodplain encroachments. Channel-spanning bedrock has also afforded stability to this portion of the watershed. Particularly, the lower-gradient, mid-portions of this watershed would be susceptible to upland development, deforestation, or the addition of other regional or local stressors.
- The majority of South Branch and Middle Branch reaches (Ripton) are in Poor to Fair geomorphic condition, undergoing substantial lateral adjustments with indications of

vertical adjustments, as well. Channel conditions in uppermost reaches of these tributaries appear to have been exacerbated by the recent extreme flood events of 1998 and 2000. While conversion of previously cultivated parcels to fallow land (T4.03 and T4.04) and forest (M13 and M14) is supporting the recovery process in these reaches, they remain particularly susceptible to further degradation from stressors including increased upland development, floodplain encroachment, channelization, increased hydraulic loading from the ski area, removal of riparian buffers, and undersized crossing structures. Lack of grade control in T4.03 and T4.04 increases the likelihood of future adjustments in these reaches.

- Lower Watershed reaches range from Poor condition through East Middlebury to Fair to Good condition in the broader valley. A long history of channel management (channelization, gravel extraction, dredging and berming) has contributed to the degradation of East Middlebury reaches at this particularly sensitive geographic setting on alluvial fan deposits. Downstream reaches are adjusting to increased sedimentation from streambank erosion in the East Middlebury reaches, as well as to floodplain encroachments by intensive cultivation and associated loss of riparian buffers.
- Structures currently noted to be at particular risk due to undersized bridge or culvert spans, sharp approach angles of the stream channel, and/or geomorphic setting of the surrounding stream channel, are:
 - Dugway Road bridge (T3.03, North Branch, Ripton) – approach angle, undersized span
 - Private bridge (T3.04, North Branch, Ripton) – approach angle, undersized span, up to 3 ft lateral undermining of left bank footing
 - Private bridge (T3.08, North Branch, Ripton) – undersized span, up to 2 feet lateral undermining of left bank footing
 - Baker Bridge (T3.09, North Branch, Ripton) – undersized span, erosion of support fill from overland runoff due to accumulation of stormwaters at this low elevation, excessive vertical and lateral scour at in-stream culvert conveying contributing tributary.
 - Private Footbridge (T4.04, South Branch, Ripton) – undersized span, partial collapse of gabion basket footings for bridge.
 - Robert Frost Interpretive Trail (T4.04, South Branch, Ripton) – lateral channel migration undermining site marker, debris jam at same location may trigger avulsion during future flood event.
 - Peddlers Bridge Road (M13, Middle Branch, Ripton) – undersized span, approach angle, lateral scour threatens to undermine fill on right bank exit end.

- Armoring along Wagon Wheel Road 400 ft upstream of Wagon Wheel Bridge (M13, Middle Branch, Ripton) – approach angle of river is directed nearly perpendicular to upstream end of armoring at the intersection between rip-rap and native soils.
- Bridge at Wagon Wheel clearing (M16, Middle Branch, Ripton) – undersized span, approach angle, overland runoff is eroding fill at right bank upstream footing, bridge positioned at tight meander (constriction).
- Farm road (M02, Main Stem, Middlebury) – at risk from lateral channel migration
- Shard Villa Road bridge (M03, Main Stem, Middlebury) – undersized span, approach angle, bridge positioned at tight meander.
- Three Mile Bridge Road (M05, Main Stem, Middlebury) – possibly at risk from lateral channel migration, compounded by tributary confluence and stormwater runoff.
- Residential structure (M07, Main Stem, East Middlebury) - structure located within 15 feet laterally of present top of right bank, approximately 100 feet upstream of new Grist Mill Bridge; possible risk to structure in the event of higher flood stages with associated streambank erosion or collapse.
- Lower Plains Road Bridge (M08, Main Stem, East Middlebury) – undersized span, undermining of footings noted
- Box culvert on Rt.125 (M11, Main Stem, Ripton) – conveying tributary channel to main stem, vertical scour and slight undermining on exit end, accumulation of cobbles, boulders on entry end to constrict flow.
- Residential and commercial properties (M12, Main Stem, Ripton village) - possible risk if mass wasting on right bank progresses laterally toward the village

8.0 RECOMMENDATIONS

Fluvial geomorphic assessments highlight watershed management challenges to our communities to:

- recognize streams as dynamic systems conveying both water and sediment / detritus;
- understand the consequences of our land use choices on our natural systems; and
- recognize that consequences play out over sometimes substantial temporal and spatial scales.

Fortunately, planning tools and management strategies exist to minimize negative consequences of our land use choices. Following, are recommendations for the Middlebury River watershed communities, organized by topic.

8.1 Infrastructure

Consider the geomorphic context when designing new and rehabilitated infrastructure.

- New or replacement bridges should ideally have openings which pass the bankfull width to flood-prone-width without constriction.
- Bridges and culverts should be designed to cross the river without creating channel approaches at an angle to structures. Such sharp angles can lead to undermining of fill materials and structural components.
- The historic channel migration pattern of the river should be considered when installing new or replacement crossing structures.
- Planned build-out for watershed communities and resultant channel enlargement should be considered when designing new or replacement bridges and crossing structures.
- Divert road ditch runoff to side-slopes where energy can be dissipated, stormwaters can infiltrate, and sediment / detritus loads can be deposited on the land and not directly to streams.

8.2 Community Planning

- Adopt planning and zoning programs which minimize the creation of connected impervious surfaces (roof-tops, pavement, roads, expansive lawns). Increases of percent imperviousness in the basin leads to increased frequency and magnitude of stormwater runoff, which in turn leads to deeper and wider channels in receiving streams and increased sedimentation.

- Conduct build-out analyses for watershed townships, Middlebury and Ripton, and apply study results to published channel relaxation curves for the prediction of channel enlargement with increased percent imperviousness (e.g., after Center for Watershed Protection et al, 1999).
- Require setbacks for structures from streambanks, which recognize that specific reaches of the river may be laterally adjusting far more than others; recognize river dynamics when creating buffer guidelines and ordinances. Following completion of the surficial geologic mapping project (estimated 2004), geomorphic conditions and geologic settings along the river corridor could be interpreted by the towns of Middlebury and Ripton to develop suggested Buffer Overlay Districts for surface waters in the watershed. Buffer Overlay Districts are more comprehensive than simple setbacks from streams or default minimum buffer widths. They specify an adequate separation distance between human activities and the river, accounting for the actual width of the river at that locality, the size and nature of the watershed draining to that particular reach, the need for the river to adjust itself vertically and laterally to maintain or restore its equilibrium, knowledge of historic migration patterns of the river, and potential instability of steep slopes adjacent to the stream. Recommended buffers could be developed on a reach-specific and site-specific basis.
- Consider those reaches (and their watersheds) classified as being in Reference condition for inclusion in community conservation programs. Preservation of forested riparian buffers in these reaches will help to maintain equilibrium in the channel and limit streambank erosion and downstream sedimentation. North Branch reaches T3.01, T3.03, T3.05, T3.09, and T3.09 are presently in Reference condition, and land parcels encompassing these reaches or portions thereof are candidates for conservation.

8.3 Restoration / Water Quality

- Results of this fluvial geomorphic study should be reviewed along with the results of the streambank buffer assessment in the Lower Watershed (Federal 2002 CWA Section 604(b) study) to help understand spatial and temporal trends in historic and ongoing *E.coli* and phosphorus monitoring in the Middlebury River. Streambank erosion from adjusting channels and avulsions can mobilize significant quantities of sediment. In those areas presently or historically in agricultural use, phosphorus content of near-surface streambank sediments can be particularly elevated.
- Fluvial geomorphology results should be reviewed to help plan future channel restoration projects. Dominant adjustment processes ongoing in the river channel should be considered prior to design of restoration solutions. For example, streambank armoring and other substantial economic investments may not be prudent in a reach which is actively degrading.

8.4 Habitat / Riparian Health

- Results of this fluvial geomorphic study should be reviewed along with the results of the streambank buffer assessment in the Lower Watershed (Federal 2002 CWA Section 604(b) study) to prioritize sites for reestablishment of forested riparian buffers, particularly in the Lower Watershed and along the middle portion of the South Branch.

8.5 Technical

- Conduct detailed surficial geologic mapping to support hazard assessments and minimize future flood losses and damage to infrastructure (in progress).
- Sediment coring or cross-channel test pit excavations could be conducted to establish a more detailed time line of the geomorphic consequences of major flood events and land use changes particularly prior to recorded history (pre-1900). These data would serve to characterize the pre-settlement adjustment states of the river channel from a hydrologic, geomorphic and habitat perspective. Increased understanding of the past geologic setting will aid predictions of future watershed responses to future stressors.

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