Ammonoosuc River Geomorphic Assessment, Floodplain Conservation, and River Corridor Planning

Prepared for

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EXECUTIVE SUMMARY

A geomorphic assessment of the Ammonoosuc River was undertaken by the Connecticut River Joint Commissions and Field Geology Services, LLC in Summer 2009 as part of a multi-phase assessment and planning effort aimed at collecting quality-assured scientific data to help guide and inform a local river management plan. This report details the results of the assessment, mapping, and planning efforts that were completed under contract with the New Hampshire Department of Environmental Services through funding from the DES Watershed Assistance Section. The work was completed using methods described in the Vermont River Management Program's Phase 2 and Phase 3 Geomorphic Assessment Protocols and led to the development of Fluvial Erosion Hazard maps of the Ammonoosuc River, a River Corridor Planning Guide prioritizing sites for restoration in the watershed, and restoration designs of a priority site at Salmon Hole in Lisbon.

The most severe flooding and erosion problems on the Ammonoosuc River are often focused near areas where sediment transport capacity rapidly declines such as at natural valley constrictions (e.g., Salmon Hole) or expansions (e.g., Bretton Woods). The problems at these sites are exacerbated by high sediment supply related to upper watershed land clearance over 100 yrs ago and efficient sediment transport through artificially straightened channels on the valley bottom. Straightened channels tend to have degraded physical habitat due to ongoing channel adjustments that create a wide and shallow channel morphology characterized by few pools, little flow complexity, high summer water temperatures, and an armored substrate. Given the close proximity of numerous valley constrictions to wide alluvial floodplains where much of the river was straightened, the river remains dynamic and prone to rapid bank adjustments throughout much of its length.

Fluvial Erosion Hazard (FEH) maps were created for each town along the Ammonoosuc River displaying the location and severity of erosion hazards in each of the 49 Phase 2 reaches assessed. The width of the FEH zones is generally considered to be 6 to 8 times the channel width depending on the reach sensitivity. The FEH zones are often wider upstream of valley constrictions where historical or geomorphic evidence indicates the channel has migrated beyond the standard 6 to 8 times the channel width designation. This is particularly true just upstream of the Woodsville Dam where the short alluvial valley is impacted by both a valley expansion upstream and valley constriction downstream, creating large, currently abandoned, meanders with an amplitude several times the channel width.

The Phase 2 assessment data on erosion, bank composition, riparian corridor condition, physical habitat, channel dimensions, and other features were used to develop a River Corridor Planning Guide. The Planning Guide not only identifies individual restoration projects in each reach that address flooding, erosion, and habitat concerns, but describes how multiple projects can work in concert to reduce hazards and improve habitat beyond the immediate areas restored. A high priority site for restoration was

identified in the Salmon Hole area of Lisbon. A Phase 3 Assessment involving detailed topographic surveying of the site resulted in project designs incorporating log and boulder structures in the channel to improve habitat and encourage meander formation along the artificially straightened channel downstream of Salmon Hole. Conservation lands established in the riparian area adjacent to the channel will allow the meander development to occur without impacting agricultural lands or infrastructure. The growth of meanders will, in turn, reduce sediment transport and alleviate sediment build up and bank erosion downstream at the soccer field in Lisbon.

Alleviating erosion and flooding problems at the numerous valley constrictions where these problems are most pronounced will require controlling sediment supply transported through artificially straightened and derived from the upper watershed. Large accumulations of gravels at the mouths of tributaries (e.g., Zealand River) indicate sediment supply from the upper watershed remains high despite years of reforestation. While an assessment of the tributaries was not completed for this study, such an assessment is recommended in order to identify strategies for encouraging sediment storage in the tributary subwatersheds. Controlling the sediment inputs from tributaries will be essential for limiting the sediment supply to the Ammonoosuc River and for alleviating the flooding, erosion, and habitat degradation linked to excess sediment deposition.

1.0 INTRODUCTION

A geomorphic assessment of the Ammonoosuc River in New Hampshire was conducted to identify flood erosion hazards, areas of channel instability, and the underlying causes for channel adjustments threatening human infrastructure and aquatic habitat. The Ammonoosuc River has a watershed area of 395 mi^2 and flows for nearly 60 mi from the western slope of Mount Washington through the towns of Carroll, Bethlehem, Littleton, Lisbon, Landaff, Bath, and Haverhill before reaching its confluence with the Connecticut River (Figure 1). The New Hampshire Department of Environmental Services has included the river in the New Hampshire River Management and Protection Program in recognition of the river's outstanding natural and cultural resources (Web citation 1). The major outcomes of the geomorphic assessment include completion of: 1) a Phase 2 geomorphic assessment and GIS database following Vermont's geomorphic assessment protocols (Web citation 2); 2) fluvial erosion hazard (FEH) maps for each town along the river; 3) a geomorphology based river corridor planning guide to help communities select appropriate and sustainable restoration strategies; and 4) plans for river and floodplain restoration at one priority site on the river. Following a brief description of the Ammonoosuc River watershed and discussion of the assessment methods, each project outcome is presented and described below. The assessment's results were also shared with residents of the watershed at a series of public venues, including meetings with officials in each town along the river. The findings of the assessment will be used by the Ammonoosuc River Local Advisory Committee to further its development of the Ammonoosuc River Management Plan that will provide recommendations for shoreland and floodplain protection.

2.0 AMMONOOSUC RIVER WATERSHED DESCRIPTION

The Ammonoosuc River in New Hampshire drains 395 mi^2 as it flows nearly 60 mi from its source at Lake of the Clouds on the western slope of Mount Washington to its confluence with the Connecticut River (Figure 1). The lower 47 miles of the Ammonoosuc River from Bretton Woods to its confluence has an average slope of 0.0047, but the surrounding terrain, especially in the upper watershed, is quite mountainous with a total watershed relief of 4,572 ft. Geologically, the upper watershed is located in the middle of a complex suite of igneous rocks, predominately granite and granodiorite, that form the White Mountains (Town of Littleton, 2004). Metamorphic rocks, predominately schists, characterize the bedrock in the lower watershed.

More recently, geologically speaking, Glacial Lake Ammonoosuc occupied the Ammonoosuc Valley as far upstream as Littleton (Town of Littleton, 2004). The lake was part of the extensive Glacial Lake Hitchcock in the Connecticut River valley that stretched for over 200 miles from Rocky Hill, Connecticut to St. Johnsbury, Vermont (Ridge and Larsen, 1990). The lake existed from approximately 15,000 to 12,000 years ago as evidenced by a sequence of varved clay deposits (Ridge and Larsen, 1990). Well stratified sandy deposits are also found in the Ammonoosuc River valley underlaying higher terraces flanking the modern floodplain. These sediments were deposited as deltas where tributaries entered Glacial Lake Ammonoosuc or by glacial meltwaters as glaciers retreated from the region. Regardless of the formation processes, the sandy deposits serve a significant groundwater-recharge role and are also locally important economic mining resources (Web citation 3). Mapping the location of clay-rich and sandy sediments along the river is important for identifying potential mass failures and impacts to adjacent areas.

The width of the river valley is highly variable with bedrock constrictions and waterfalls narrowing the valley to only 200 ft, while adjacent areas can have an active floodplain nearly a mile wide. The widest floodplains areas (e.g., near Woodsville) are possibly the result of powerful eddies scouring less resistant valley materials as high discharges exited the more resistant narrow bedrock gorges during deglaciation or catastrophic draining of Glacial Lake Ammonoosuc. Such discharges would have been orders of magnitude greater than what has occurred historically.

Data on past historic discharges in the watershed are available from two gauges in the watershed. The record peak discharge of 27,900 ft^3 was recorded in 1936 at the former USGS river gauge near Bath (Figure 2). The only long-term still active river gauge in the watershed is at Bethlehem Junction that recorded other high discharges in 1973 and 1995 after the Bath gauge was discontinued. The peak discharge of nearly 9,000 ft^3 associated with Tropical Storm Irene in August 2011 was less than the 1995 event but greater than 1973. Knowledge of past geological events and historic flood events is important for interpreting the geomorphic assessment data and understanding how the river will respond to extreme events.

While the Ammonoosuc River watershed is largely forested, many areas are currently experiencing increased commercial and residential development with population growth exceeding previous projections (Web citation 3). Historically, 14 dams have been built on the river (Town of Littleton, 2004), but only five remain intact. The others, many in Littleton, are now in ruins and are reminders of the once active mills in the 18th and 19th centuries. By the middle of the 19th century most of the land in the watershed was cleared (Figure 3), in stark contrast to the forested landscape today. Modern land use pressures are focused more on the river's floodplain. The large box stores that have been built along the river in Littleton, for example, are raising concerns that the higher discharges and sediment loads they may generate are exacerbating erosion problems downstream. The Bretton Woods area in Carroll is also experiencing considerable floodplain development and, given that the floodplains represent some of the only level ground on which to build in the watershed, increased pressure may mount to build in these areas elsewhere in the watershed. Geomorphic assessments can help to unravel the relative influence of historic and modern land uses on current channel conditions and identify the underlying causes of chronic erosion and flooding problems.

3.0 ASSESSMENT METHODS

Recognizing the value of fluvial geomorphology to reduce erosion hazards and improve aquatic habitat, the State of Vermont developed a three phase Stream Geomorphic Assessment methodology to reveal the underlying causes for erosion and other riverine hazards (Web citation 2). These Vermont protocols are gaining wider acceptance nationally as the assessment results provide a mechanism for determining fluvial erosion hazards that can be used by municipalities for planning and regulatory purposes in conjunction with flood insurance rate maps created by the Federal Emergency Management Agency. The assessment methods detailed in Vermont's Stream Geomorphic Assessment protocols were used in the Ammonoosuc River assessment.

Fluvial geomorphology based assessment approaches, such as that developed by the State of Vermont, are devoted to understanding how the natural setting and human land use in a watershed effect river channel processes and form (i.e., channel dimensions and shape). River channels are in constant adjustment to alterations in watershed conditions, but can eventually establish an equilibrium channel form if no significant perturbations occur for extended periods. River channel adjustments may continue for thousands of years when responding to climatic influences (e.g., deglaciation in New England), so river channel changes may be ongoing throughout the design life of flood control, bank protection, and river restoration projects. Channels can also respond quickly to a single large flood or to direct human activities in the stream channel such as the construction of a dam across the river. Furthermore, rivers can experience rapid bank erosion and changes in channel position even while maintaining an equilibrium condition where the channel dimensions and planform shape remain the same. Consequently, geomorphology assessments are essential before significant efforts are made to develop river management plans. Corridor protection and restoration projects are more likely to succeed with an understanding of how the channel is responding to natural conditions and human activities in the basin and how the channel may respond to the proposed management efforts. Therefore, geomorphic assessments, such as the three-phase Vermont protocol methodologies described below, must focus on both the natural and watershed conditions that engender channel adjustments and describe the current channel conditions that reflect the ongoing evolution of channel conditions.

3.1 Phase 1 assessment

Phase 1 of Vermont's Stream Geomorphic Assessment protocols utilizes topographic maps, aerial photographs, and archival records to characterize the natural conditions and human land uses in the watershed that may be controlling morphological conditions in the channel. (The Phase 1 assessment of the Ammonoosuc River was completed by the New Hampshire Geological Survey with revisions made as part of the Phase 2 assessment reported on below). Since different portions of a river can respond differently to the same natural and human factors, one of the most important tasks of the Phase 1 assessment is to subdivide the river into distinct reaches. Within a given reach, the river is assumed to respond similarly to changing watershed conditions while adjacent reaches may respond differently. Reaches that share similar traits are referred to as “like-reaches” and an understanding of channel response or effective management techniques gained in one reach may apply to other “like-reaches”.

The break points between different reaches are made based on the presence of natural changes in valley slope, constrictions of valley width, expansions of valley width, and the confluence of a major tributary. On the Ammonoosuc River, 49 such reaches of uneven length were identified using topographic maps with the reaches numbered consecutively from the downstream end of the river and designated M1, M2, etc. to indicate that the reaches are located on the mainstem of the river (Figure 4 and Table 1). In addition to the contributing watershed area from upstream, each reach has a subwatershed from which additional flow drains directly into that reach. Thirteen of the reach breaks occur at valley constrictions, 12 at expansions in the valley, 6 at the confluence of major tributaries, and 7 at significant natural changes in valley slope. Reaches downstream of constrictions occupy more confined valleys where the river channel has a greater likelihood of flowing against glacial sediments exposed along the high valley walls. The potential for high rates of sediment production in these locations can affect channel morphology differently than reaches occupying wide valleys where the channel is more likely to encounter only floodplain sediments. Reaches downstream of tributary confluences will generally have a morphology different than reaches immediately upstream because of the introduction of sediment from the confluence. The morphological impacts of tributary confluences, as well as valley constrictions and expansions, are generally most noticeable at or near the reach break. Consequently, the locations of the reach breaks themselves are likely points of channel instability with active bar formation, bank erosion, and channel migration possible.

3.2 Phase 2 assessment

In the absence of human settlement, a channel’s morphology (i.e., cross sectional dimensions and planform) responds to natural conditions present in the watershed. Identifying the conditions adjacent to the channel (e.g., soil type, valley confinement) and in the larger watershed (e.g., drainage area, forest cover) can help determine the channel morphology that would develop in the absence of human land use. Differences between the morphology expected under natural conditions and what morphology actually exists are generally an indication that human land use is altering channel morphology. Determining and comparing these existing and expected morphological conditions within each of the 49 Ammonoosuc River reaches are accomplished through the Phase 2 assessment by analyzing topographic maps and aerial photographs, surveying channel dimensions, and mapping channel conditions.

Morphological parameters such as sinuosity, channel slope, and meander migration rates can be ascertained from current and historic topographic maps and aerial photographs and provide clues to past channel straightening and areas of rapid channel adjustment. Large bar deposits can also be identified and may indicate areas of high sediment supply or rapid loss in sediment carrying capacity. However, most of the morphological attributes of the river are characterized through fieldwork such as the mapping of channel features and topographic surveying. Some of the bed and bank features mapped along the length of the river include bank stability (i.e., location of erosion), bank material (i.e., soil type), bank height, substrate particle size, depositional features (i.e., point bars, mid-channel bars), grade controls (i.e., waterfalls, dams), encroachments (i.e., roads, railroads, berms adjacent to the channel), and riparian buffer width. The mapping was completed with a Trimble Yuma tablet computer loaded with ArcPad 8.0 GIS software and a built-in GPS unit. ArcView shapefiles were created for all bed and bank features using the Feature Indexing Tool created by the State of Vermont such that the exact location of certain channel conditions is known for the entire river.

The channel's dimensions were measured through topographic surveying using a Sokkia Set 5 electronic total station. The morphological parameters recorded within each reach were the bankfull width, bankfull depth, and the height of the adjacent floodplain relative to the bankfull level. These parameters enable a determination of the width:depth ratio, incision ratio, and entrenchment ratio, critical dimensionless values that can be compared from reach to reach and with reference values (i.e., the expected conditions in the absence of human influence) to determine the relative impacts of human activities on flooding, erosion, and aquatic habitat degradation.

The Phase 2 assessment protocols also consist of a Rapid Geomorphic Assessment (RGA) and Rapid Habitat Assessment (RHA), standardized forms that provide information on different aspects of the habitat and geomorphic conditions, respectively, of each segment. The forms provide a means by which the level of habitat (e.g., lack of pools) and geomorphic (e.g., high width:depth ratios) degradation can be compared between reaches, thus helping to select the most appropriate watershed management efforts throughout the watershed. The RGA protocol documents the past and current channel adjustments influencing the river's processes. The RGA draws on a set of specific observations to evaluate the processes of degradation, aggradation, widening, and planform adjustment in each stream reach. Observations on bank stability, the presence of headcuts and flood chutes, and the abundance and relative height of channel bars factor into scores ranging from 0 to 20 (poor to reference). The RHA protocol contains specific parameters designed to evaluate the physical components of the river, including the channel bed, banks, and riparian zone. The RHA is designed to provide an understanding of the physical conditions present that affect aquatic habitat. The results of the RHA can be used to compare physical habitat conditions between reaches and watersheds and serve as a management tool for watershed and land use planning. Each parameter is scored on a scale of 0 to 20 (poor to reference), and the results are totaled to provide an overall score that reflects the habitat condition of the reach.

The existing stream type and stream condition combine, through a rating table provided in the protocol, to yield a stream sensitivity for the reach. Stream sensitivity summarizes the likelihood that a reach will respond to a disturbance or change in watershed conditions such as a large flood or change in land use within the river corridor. A reach's sensitivity to a change in condition is dependent upon its setting, channel form, and substrate particle size. For example, an A1 stream type (i.e., steep confined bedrock channel) is much less sensitive than an A5 channel (i.e., steep confined sand channel) to human alterations of the channel or watershed.

A bridge and culvert assessment form was completed for every bridge that crosses the Ammonoosuc River and is described below for those reaches with such crossings. The form identifies potential impacts of the bridge on channel morphology with observations made on changes in bankfull channel width resulting from the abutments and depositional and erosional features found immediately upstream or downstream of the crossing structure. While the form is intended for culverts as well, only bridges were encountered during the assessment of the Ammonoosuc River mainstem. The bridge and culvert assessment protocol provides a basic assessment methodology that can be used to highlight crossing structures that may be acting as fish passage barriers, impacting sediment transport, creating fluvial erosion or flood hazards, or at risk of failure. The bridge and culvert assessment does not score the condition of individual structures but rather incorporates field observations and measurements into a database that can be accessed by state and local agencies in order to red flag structures in need of additional inspection.

As human impacts on the channel are identified during the Phase 2 assessment, the reaches are sometimes further subdivided into segments. Through this segmentation process, a single reach that would be expected to have the same morphology throughout its length under natural conditions may be broken into two or more segments of potentially different morphology due, for example, to a road built right along the edge of the river for only a portion of the reach's full length. Most reaches on the Ammonoosuc River were not segmented, because no human influence was present along the reach or the entire reach was similarly affected by human impacts. However, 8 reaches were further segmented due to variations along their lengths (Table 1). Each segment is assigned a lowercase letter beginning with "a" at the downstream end of the segmented reach such that Segment M2a is the downstream most segment in Reach M2.

The description of the Phase 2 results in Section 4.0 below refers to many geomorphic characteristics and methods that are described fully in Vermont's Stream Geomorphic Assessment Protocols (Web citation 2). The RGA, RHA, bridge and culvert assessment, and Phase 2 field forms are also available with the protocols. The data collected in the field on the field forms were compiled in a Microsoft Access database (Appendix 1) from which much of the tabular information presented in Section 4.0 has been extracted.

3.3 Phase 3 assessment and corridor planning

By completing the corridor planning process developed by the State of Vermont (Web citation 2), river management projects can be identified that address channel instabilities and, therefore, sustainably address overbank flooding, bank erosion, and aquatic habitat degradation. River corridor planning consists of four parts: 1) identification of the human stressors at the watershed and reach scale that are potentially altering the hydrologic and sediment inputs to the river channel; 2) determination of the natural and human constraints within the river corridor that alter the river's capacity to transport sediment; 3) prioritization of restoration or conservation projects that are consistent with the development of channel equilibrium and reduced channel instability; and 4) assessment of the technical and social feasibility of project implementation. The GIS data created as part of the Phase 2 assessment are used for mapping the human stressors and constraints on sediment transport and attenuation. The resulting maps, in turn, play an integral role in locating and prioritizing management efforts. The outcome of the corridor planning process is a prioritized list of restoration projects for the watershed that will return the river to an equilibrium condition and, by so doing, will achieve the following three objectives: 1) mitigate erosion and flood hazards; 2) reduce sediment and nutrient loading; and 3) improve aquatic and riparian habitat.

The Phase 3 assessment consists of a detailed topographic survey of a high priority restoration site identified by the corridor planning process. The surveyed plan views and cross sections depict the existing conditions and provide the basis for developing restoration plans. As part of the Ammonoosuc River assessment, a Phase 3 assessment was completed in the Salmon Hole area of Lisbon.

4.0 PHASE 2 GEOMORPHIC ASSESSMENT

The Ammonoosuc River was subdivided into 49 distinct reaches for the purposes of the Phase 2 geomorphic assessment (Figure 4). The significant morphological conditions of each reach are summarized in Table 2. In many cases, two or more reaches are closely interconnected such that conditions in one reach may influence morphological conditions in another. Consequently, the discussion below of the Phase 2 assessment results is subdivided into groups of reaches within the same zone of influence.

4.1 Headwater reaches (Reaches M44-M49)

The headwater reaches of the Ammonoosuc River, upstream of the Mt. Washington Resort at Bretton Woods, flow through the White Mountain National Forest in the unorganized township of Crawfords Purchase. These headwater reaches are almost entirely forested with very little development (Tables 3 and 4). However, this does not mean that the stream is in a natural or pristine condition. A significant portion of the channel has been artificially straightened and encroachments are present in the form of the Base Road and the historic railroad grade, both running along the stream and confining it in several places.

The headwater reaches flow across a steep alluvial fan formed at the confluence of many steeper tributaries that flow down the upper slopes of the surrounding mountains. Except for those portions of the river that flow through bedrock gorges, the reference condition is most likely an anastomosed, multi-threaded channel, with a high transport capacity. This is a dynamic system with relatively frequent channel avulsions driven by deposition and log jams (Figure 5). Bedrock controls in the form of gorges, constrictions, or waterfalls are present in all reaches (Figure 6). The substrate is coarse with a median particle size of cobble in all but Reach M44 where gravel is predominant.

The Rapid Geomorphic Assessment indicates the Segments 47A and 45B are in reference condition as these are bedrock gorges that are not adjusting to human impacts (Table 5). All other reaches in the headwaters are in fair condition, having largely completed a period of channel incision and widening in response to historical channel straightening. The prevalence of bedrock controls helps maintain relatively good geomorphic conditions in this portion of the watershed, giving rise to good habitat complexity in the form of flow complexity and deep pools. A high incision ratio, a condition that results in a lower RGA score, is partly the result of natural conditions (i.e., incision through bedrock and glacial deposits), but also due to incision after channel straightening. The incised channels prevent flood flows from spreading out across a floodplain, so, in consequence, higher peak flows and sediment loads are transferred downstream (see Section 4.2 below). Targeted wood additions could help to store sediment in the reach and alleviate sediment-loading issues downstream. In creased wood densities in the channel would also return incised portions of the channel to its multi-threaded course with higher quality habitat conditions. Wood additions could be completed with “chop and drop” techniques whereby selected trees are felled along the edge of the banks and allowed to drop across the channel. Where infrastructure approaches near the channel, wood could be more carefully placed with an excavator and anchored in place.

All reaches and segments rate Good habitat scores using the Rapid Habitat Assessment (Table 6). Epifaunal substrate and available cover scores were rated as Reference to Good while the flow velocity and depth patterns were ranked as reference conditions in all reaches. A few bridges are located within the headwaters section of the watershed with the Base Road Bridge being the furthest upstream aside from snowmobile bridges in Reach M49. The only other bridge in the upland areas is the pedestrian bridge crossing over the bedrock gorge in Segment 45B. A summary of the bridge assessment results is included in Appendix 1.

4.2 Bretton Woods (Reaches M41-M43)

The Bretton Woods reaches (M41 – M43) occupy the lower portion of a wide alluvial fan upstream of the Lower Falls Gorge. These are the first reaches within the Town of Carroll. The Mount Washington Resort and its associated golf course and ski resort dominate the land use within the stream corridor. Consequently, the percentage of corridor development is high (Table 4).

The river flows through a very broad valley, although reaches M41 and M42 are partially confined by Route 302. Given the rapid decrease in gradient from the steeper headwater reaches upstream, the reference sediment regime, even in the absence of human impacts, is dominantly depositional. Consequently, the reference planview morphology is a multi-threaded braided channel (i.e., Rosgen D-type channel). The stream was likely artificially straightened over its entire length in this section of the watershed, resulting in an incised condition. However, the high entrenchment ratio in Reach M41 and M42 indicate that at least large floods access the floodplain in these reaches (Table 2). A recent mixed rain and snow precipitation event on March 5, 2011 also demonstrated that even Reach M43 accesses its floodplain despite a low entrenchment ratio. The flood caused an ice dam that allowed the river to jump its banks and carve a new channel across portions of the golf course before re-entering the main channel in the upper portion of Reach M42 (Mount Washington, 2011).

The Bretton Woods section is characterized by the deposition of enlarged gravel bars (Figure 7a) and, as a result, dynamic channel migration that has outflanked earlier efforts at bank stabilization (Figure 7b). Active channel migration is also evidenced by the occurrence of four avulsions and two flood chutes mapped in the three reaches (Appendix 1). The sandy to gravelly banks are very unstable (Appendix 1) with 23.6 percent eroding in Reach 41 and to protect against erosion 38.8 percent of Reach 43 has been armored. At least 32 percent of the banks were mapped as armored or eroding in all three reaches bespeaking of the frequent channel avulsions, high bank erosion rates, and channel migration makes this one of the most dynamic sections of the river system.

The dynamic nature of the river in the Bretton Woods section is partially a natural phenomenon resulting from the river's declining slope between the uplands and the valley bottom, but is still worrisome given human development of the corridor. Reaches 41-43 have higher than 64 percent corridor development and little to no riparian buffer over more than 17 percent of their length (Table 4). The poor buffer conditions (Table 5) may further contribute to the high bank instability and active growth of gravel bars (Table 6). Previous efforts at bank stabilization have not stood the test of time against the actively migrating river in this area. While more recent stabilization efforts apply some concepts of natural channel design aimed at reducing erosive forces along eroding banks (Figure 8), they do not address the larger issue of high sediment supply driving the erosion. Sediment storage opportunities are key to crafting sustainable management solutions addressing active channel migration and the resulting conflicts that arise with infrastructure in the river corridor. Creation of a meander migration zone buffering the channel, at least in places, can allow channel migration to occur unencumbered, store sediment on gravel bars, and reduce the likelihood similar dynamic processes will continue downstream where infrastructure pressures may be higher. Upstream sediment storage, enhanced through wood additions, would reduce sediment supply downstream and, thereby, reduce rates of bar growth and bank erosion.

There are several bridges within the Bretton Woods section including pedestrian, golf cart, and automobiles bridges on the Resort property, a railroad bridge and two highway bridges on Route 302. The Route 302 crossings have been recently upgraded. However, the crossing further downstream appears to be out of equilibrium with the stream channel as evidenced by the significant deposition of mid-channel gravel bars within the structure as well as directly upstream and downstream (Appendix 1).

4.3 Lower Falls (Reach M40)

Lower Falls is a bedrock gorge in the National Forest and within the Town of Carroll. The gorge is a popular recreational area with many locals and tourists who swim and wade in the waters throughout the gorge and in the plunge pool below the falls. This deep pool is also a popular fishing hole. The Lower Falls section is divided into two stream segments (M40B and M40A) with the upstream segment (M40B) comprising the cascades and gorge and the lower (M40A) consisting of a narrowly confined boulder-bed channel (Appendix 1).

Lower Falls represents a significant natural grade control and channel constriction within the watershed. Lower Falls represents a barrier for fish migration as well as a geomorphic divide between upstream and downstream reaches. The gorge acts as a fixed point of elevation in the stream's longitudinal profile, controlling the channel gradient both upstream and downstream. Backwatering upstream of the Lower Falls gorge at high flow stages contributes to the deposition of sand, gravel and cobbles in enlarged bars, as is seen in the Bretton Woods reaches.

Both segments within the Lower Falls portion of the watershed are steep, narrowly confined channels (Figure 9). The river is very stable with no bank erosion mapped and very little bank armoring, and is characterized by deep pools, high flow complexity, and stable banks, so rates as Good to Reference on the RHA. No particular restoration activities are needed within the gorge, but the reach remains important given its influence on adjacent reaches.

4.4 Twin Mountain (Reaches M34-M39)

Downstream of Lower Falls the stream flows under Route 302 and enters the Village of Twin Mountain in the Town of Carroll. Reaches M38-39 are within the National Forest boundaries. The Twin Mountain section is dominated by high sediment inputs from two tributaries, the Zealand and Little Rivers, that significantly impact the morphology of the Ammonoosuc River itself. Large unvegetated gravel bars are found at the mouths of these tributaries (Figures 10 and 11). A valley constriction downstream of the Zealand River confluence further enhances deposition at the confluence and immediately downstream. The channel regularly migrates across the bars, but the buildup of gravel is slowly shifting the channel towards Route 302 (Figure 10). The confluence of the Little River occurs at a constriction in the valley such that deposition occurs at and upstream of the tributary mouth as floodwaters are impounded behind the constriction (Figure 11). The buildup of gravel at the confluence enhances the backwatering effects of the natural valley constriction. The buildup of gravel is leading to the recreation of meanders along a portion of the artificially straightened channel (Figure 11). Significant channel straightening has occurred on all reaches in this section of the river except for Reach 37, a short confined reach with no floodplain (Table 4). Sediment is efficiently moved through the straightened channels with the most deposition in this section of river focused in those areas where sediment transport capacity is lowered by valley constrictions and excess sediment delivered from tributaries.

Fortunately, the corridor in this section of the river is largely a mix of forest and residential land (Table 3), so little conflict with human assets is present. Continued channel migration near the Zealand River confluence and upstream of the Little River confluence could over time impact Route 302, so the bank erosion and channel migration should be monitored. Continued meander growth around the gravel bars forming upstream of the Little River confluence is close to eroding into old meanders that existed prior to channel straightening. The abandoned meanders run along Route 302 and contain good wetland habitat that could be altered and impact Route 302 if the active channel, with its high sediment loads, switches back into these abandoned oxbows.

Significant bank armoring has occurred along this section of river with nearly 20 percent of the banks protected in Reach 36 that passes through the village of Twin Mountain (Table 4). Straightened reaches are inherently unstable and have a propensity for reforming meanders, a process that could create bank erosion problems in Twin Mountain if not so heavily armored. Erosive forces are likely exacerbated in unarmored area. As a result of the straightening and subsequent armoring, the reaches are only in Fair geomorphic condition with Very High stream sensitivity. Sediment accumulation and the resulting channel migration could be addressed by encouraging meander formation along the straightened channels, which would encourage bar formation and a more even distribution of sediment throughout this section of the river. Unfortunately, developments right along the river limit the space available to encourage meander formation and protection of these properties will likely require the straightened and armored channel configuration remain in place. Consequently, rapid channel migration and bank erosion is likely to occur along these highly sensitive reaches, both in the known areas of deposition near the tributary confluences but potentially in new areas where transport capacity is rapidly altered by log jams or ice dams.

Segment 38A is a stable, bouldery segment with well-developed sand benches on the channel margins. Along with Reach 37, an extremely steep, step-pool boulder channel with no visible bedrock control, Segment 38A is in a stable condition and largely unaltered by the sediment inputs from the tributaries or human impacts of armoring and other activities. As a result both areas, rate as Good to Reference for both the RGA and RHA. This section of stream is popular with fishermen, who take advantage of its deep pools and available cover.

Four stream crossings are found within the Twin Mountain section including the Route 3 Bridge in Reach 36. No particular concerns at these crossings were noted through the assessments.

4.5 Upper Bethlehem (Reaches M29-M33)

Downstream of the Haystack Brook confluence, the Ammonoosuc River flows away from Route 302 and enters a largely forested, confined, steep-walled valley. The river crosses Route 302 again in Reach 30 at Pierce Bridge before flowing along River

Road downstream to the decommissioned Bethlehem Dam, which impounds the downstream portion of Reach 29.

Reaches 32 and 33 are relatively unaltered with low corridor development, less than 5 percent bank armoring and largely intact riparian buffers (Table 4). Despite the narrow valley and limited floodplain, channel straightening occurred along portions of the river, particularly in Reaches 30 and 31 where the channel was straightened along the old railroad grade. The railroad grade represents an encroachment on the river in the Upper Bethlehem section and may limit the river's ability to spread out during floods. The Upper Bethlehem section is characterized by a coarse cobble substrate with many boulders adding stability to the pools and riffles present (Table 2). Portions of the steep reaches exhibit a step-pool morphology. Most reaches are in relatively stable condition except for active incision in Reach 29 due to the drop in base level accompanying dam decommissioning and the lowering of the impoundment elevation. The active incision was noted as a headcut migrating upstream through the fine-grained-impoundment sediments only and not through coarser earlier pre-dam sediments (Figure 12). Consequently, this is not judged to be a significant risk to adjacent infrastructure.

Nice habitat was observed in the Upper Bethlehem section, with Reaches 30, 31, and 33 rating Good and Reach 32 displaying Reference habitat conditions (Table 6). Reach 32 is pristine with intact buffers, abundant wetlands, and complex instream aquatic habitat. A potential water quality impact was noted near the downstream end of Reach 31 where landfill drainage enters the left bank of the stream. While the riparian zone is largely intact along much of this section, the presence of Japanese knotweed was noted in several locations. Japanese knotweed is an invasive plant species that spreads rapidly along stream banks where it outcompetes native species and contributes to bank erosion. Its presence in Reach 30 marks its upstream-most extent along the mainstem of the Ammonoosuc River. In some areas of the lower watershed Japanese knotweed is the dominant riparian vegetation.

Two bridges cross the stream in this section, including remnants of the no longer used Pierce Bridge. Abutments of an old railroad bridge in Reach 33 do not have significant impact on the channel's morphology. Another possible bridge or mill dam was noted in Reach 30 where portions of a granite foundation remain. Additional ruins of a crib dam just upstream of the Bethlehem Dam attest to a long history of dams at this location. The narrow valley in this section of the river makes this an attractive section of the river for dam construction compared to other areas with wide floodplains. The Bethlehem Dam, which was built in 1926, is the only intact dam still standing along the Ammonoosuc River that is not currently being managed by a hydroelectric utility (Town of Littleton, 2004). Consequently, this is the only dam that has been considered for removal. The impoundment sediments behind the dam are much finer-grained than the natural cobble substrate, leading to an RHA rating of fair whereas other reaches in this section of river rate Good to Reference (Table 6).

4.6 Bethlehem Hollow (Reaches M26-M28)

Downstream of the Bethlehem Dam the stream flows into Bethlehem Hollow, a narrow steep-walled valley confined by glacial deposits. This confined condition extends from Reaches 26-28.

Reach 28, through Bethlehem Hollow, is a steep step-pool channel with a bouldery bed and a D50 of cobble (Table 2). The confined condition, steep gradient and coarse bed reflect the river's power and high capacity to transport sediment, contributing to relatively low bank stability with 10 percent of the banks mapped as eroding and an additional 17 percent armored against erosion (Figure 13 and Table 4). Wing Road encroaches along the right bank of the channel, particularly in Reach 27, contributing to poor riparian buffer conditions with greater than 19 percent of Reaches 27 and 26 having little to no buffer. While the dominant land use in the corridor is forest, the presence of gravel pits is significant in Reach 27.

All three reaches have an RGA stream condition of Fair (Table 5). These historically incised channels are now relatively stable with little active sediment deposition (Table 4), but still have a Very High stream sensitivity given the high stream power generated during floods. Habitat condition ratings are Good for all reaches with Reach 28 scoring particularly high with deep pools, sufficient cover and un-embedded substrate (Table 6).

There are two bridges in this section of the river. The first in Bethlehem Hollow (Reach 28) and the other near the upstream end of Reach 26. Above the Bethlehem Hollow Bridge there is a large mass failure off the right bank of the river behind Stoney's Auto Body. This slope failure is contributing a significant volume of sediment to the river, but the failure itself does not appear related to river processes or the bridge.

4.7 Lower Bethlehem (Reaches M22-M25)

Route 116 and the old railroad grade follow the course of the Ammonoosuc River through much of the Lower Bethlehem section with the railroad grade crossing the stream in Reach 23. These encroachments further confine a valley already naturally confined by glacial terraces. Upstream of the Alder Brook confluence, the river is wide and shallow with abundant wetlands and exposed mill pond sediments deposited upstream of former dams in the Alder Brook area. Downstream the channel is steeper and more confined with a coarser substrate. The lower portion of the Lower Bethlehem section (Reach 22) is impounded by the Littleton Dam and was not assessed due its lack of riverine features.

Reach 25, upstream of the Alder Brook confluence, has been straightened over 94 percent of its length (Table 4). The gravel bed channel is incised (Table 2), but can still access adjacent wetlands and side channels. The river banks are relatively unstable with 13 percent eroding and 6 percent armored (Table 4). Bank instability may be related to the high degree of bar deposition in the reach, since the growing bars can divert flow into the erodible sandy to cobbly banks.

Reaches 23-25 have very little development within the stream corridor. Despite the road and rail encroachments, the dominant buffer width is predominately greater than 100 ft. Reach 24, which is steeper and coarser than the adjacent reaches, has a Good RHA rating while Reaches 23 and 25 are rated only Fair (Table 6).

Mill pond sediments are found throughout Reaches 24 and 25, with the ruins of an old channel-spanning crib dam observed just upstream of the Alder Brook confluence. Historic records exist only of mill dams on Alder Brook itself, but apparently the Ammonoosuc River was also once dammed in this location. The current channel has incised into the old mill-dam sediments, characterized by organic-rich fine sand, silt and clay.

Mill dam ruins are not the only historic structures currently effecting the river. The legacy of the railroad that once ran through the valley continues to impact the river. While the railroad bridge is still in good condition and spans the full channel width, it represents a significant constriction at high flows by cutting off access to the floodplain (Figure 14a). The resulting upstream impoundment of flood flows creates high amplitude meander bends (Figure 14b) and significant sediment deposition (Figure 14c). The channel migration associated with the deposition and meander growth could lead to an avulsion whereby the channel might switch to a new position on the floodplain.

4.8 Town of Littleton (Reaches M20-M21)

Downstream of the Littleton Dam the stream corridor becomes more developed as the river enters the Town of Littleton. This section of the stream is confined by high terraces and has no floodplain. This represents one of the most highly altered sections of the river with abundant encroachments, stream crossings and bank armoring. Land use is predominantly residential, commercial, and industrial within the river corridor; this is in contrast to many of the upstream reaches where the corridor was largely forested (Table 3). More than 70 percent of the corridor is developed in all of the reaches and segments in the Town of Littleton section (Table 4). There is also a high road density for the subwatersheds, particularly for Reach 20, which has a density of greater than 10 miles of road per square mile (Appendix 1). A high road density is a proxy for greater development and more impervious surface. The associated stormwater inputs, road ditches, and culverts all have the potential to impact the water and sediment load in the tributaries and lead to increased runoff and erosion. Symptoms of urbanization observed on smaller tributaries usually include increased flood peaks and a greater flashiness of flow during intense storm events. However, the relatively small contribution of the heavily developed subwatersheds in the Town of Littleton section to the total watershed area to the Ammonoosuc River flowing through this section means that the impact of this development on the morphology of the river itself is likely very limited.

A more significant impact on the river itself is likely the result of the significant channel straightening in Reach 20 (Table 4). The riparian buffer is also poor to nonexistent and the banks completely armored in Segment 20B (Table 4). For these reasons, the reaches all rate Fair for stream condition in the RGA (Table 5).

The stream is incised, due in part to channel straightening, except in Segment 20B where a bedrock bed is present. Unable to erode down into the channel bed, this segment is prone to eroding laterally into the banks. As a result, the entire length of the banks has been armored with riprap, stone, and concrete walls (Figure 15).

4.9 Lower Littleton (Reaches M18-M19)

Downstream of the town center, the river flows under the Industrial Park Road Bridge and splits into two channels around a large vegetated island. The left, or southern, bank channel has recently become the primary channel and flows along the base of the Littleton landfill. Flow reconverges just upstream of the twin I-93 bridges carrying the north and south bound lanes of traffic high above the river. The channel then passes to the east of the rapidly developing floodplain containing many retail box stores including Wal-Mart, Shaws, Home Depot, and Lowes, before flowing through the bedrock-controlled and wetland dominated Reach 18, the former site of the Willowdale mill dam.

The Lower Littleton section of the Ammonoosuc River is adjusting to many of the same pressures accompanying development, encroachment, and historic channel alteration of the Town of Littleton section upstream. Like upstream, the channel has been extensively straightened (Table 4), but unlike the upstream section these reaches retain a strong connection to the floodplain as reflected in the C-type channel designation, high entrenchment ratio, and relatively low incision ratio (Table 2). As can be seen on historical maps and aerial photographs, Reach 19 was historically an anastomosing river transporting sediment and water in a series of interconnected channels (Figure 16a). By 1929, the river was artificially straightened and realigned along the high bank on the east side of the valley. With development of the adjacent floodplain, historically active side channels and wetlands have been infilled, although some new wetlands have been created to compensate for this loss (Figure 17). Natural side channels and interconnected wetlands have an important influence on the river's morphology and aquatic habitat as they provide storage for sediment and water at various flow stages. The network of side channels that once existed would have provided a longer flow path (with a lower gradient), higher flow complexity (with the ability to sort and deposit sediment), and increased cover and velocity refuge for aquatic organisms. Furthermore, the undeveloped floodplain with intact side channels and wetlands would have provided greater flood storage to reduce flood peaks and increase base flow during low flow periods. By cutting off access to side channels and straightening the river, the risk of flooding and erosion has increased significantly both in this section and adjacent downstream reaches.

The amount of sediment deposition in Reaches 18 -19 is high (Table 4), promoting the formation of a wide, shallow, plane-bed channel with little habitat complexity. However the presence of bedrock controls, mostly outcropping as step-forming, low relief, channel-spanning ledges, does create some good pool habitat in

Reach 18. These bedrock controls together with the wetland complexes that remain on the floodplain elevate the RHA rating to Fair.

4.10 Upper Lisbon (Reaches M15-M17)

Downstream of the old Willowdale dam site the stream enters the town of Lisbon and flows along Route 302. This section of the stream is incised with little floodplain access, abundant bedrock controls, and considerable encroachment by the highway and railroad. The Gale River, with a watershed area of 93 mi^2, enters the Ammonoosuc River from the east in Reach 16 and increases the river's drainage area by 65 percent, so has a potentially strong influence on the channel's dimensions.

Segment 17B, at the upstream end of the Upper Lisbon section, is an incised bedrock-controlled channel. The incision ratio of 2.1 reflects the lack of floodplain access (Table 2). Bedrock within the channel controls sediment deposition in places, including a large island in the segment. Riparian buffer widths are less than 10 ft in this segment (Table 4) with the banks dominated by herbaceous vegetation (Table 3).

The remainder of the Upper Lisbon section has been significantly straightened (Table 4), and like Segment 17B, is incised below the alluvial floodplain and glacial outwash terraces (Table 2). Segment 17A is dominated by the encroachments of Route 302 along the right bank and the old railroad grade recreational path along the left bank. Further impacting the channel in Reach 17 is the presence of armoring on more than 40 percent of the banks (Table 4).

The Gale River greatly increases the flow in the Ammonoosuc River where it enters at the upstream end of Reach 16. Like the Ammonoosuc River itself, the lower Gale River was artificially straightened in the past (Figure 18a) and the resulting excess sediment delivered to the Ammonoosuc River manifests itself as a large delta bar at the confluence (Figure 18b) and a wide shallow channel in the reaches downstream. The Gale River also plays a critical factor in the development of ice jams on the Ammonoosuc River. The relative timing of ice out on the Gale River in relation to ice out on the Ammonoosuc River controls the formation and severity of ice jams on downstream reaches (Ray Lobdell, personal communication, 2011).

The high sediment delivery from the Gale River has sped up the river's adjustment to past straightening with all reaches in Stage IV of channel evolution (Table 5), having passed through an incision and widening phase and now forming large bars that may eventually develop into a new floodplain surface. The RHA rating was only fair for all reaches (Table 6) given the wide shallow nature of the channel that still persists despite the significant channel adjustments since artificial straightening.

4.11 Salmon Hole (Reaches M12-M14)

The Salmon Hole section begins upstream of the Route 302 Bridge and continues down to the dam in downtown Lisbon. Much of the Salmon Hole section has been artificially straightened (Table 4), increasing flow velocities and sediment transport capacity. In the early 1980's, a channel avulsion at Salmon Hole, precipitated by floodplain gravel mining, carved a new channel on the inside bend of a meander and mobilized a large quantity of sediment downstream (Figure 19). This sediment has been deposited on large unvegetated bars within Reach 13 (Figure 20a) and is diverting flow into the adjacent river banks where severe bank erosion is occurring (Figure 20b). Severe erosion at the practice soccer field in Lisbon occurs at the downstream end of a long artificially straightened section of the channel, so is particularly prone to sediment deposition and erosive forces (Figure 21).

Wide shallow gravel bed channels with significant instream deposition characterize Reaches M12-M14 (Table 2). While the reaches are all slightly incised, they still have access to the floodplain as evidenced by the C-type channel designation and incision ratios below 2.0 (Table 2). However, the width of floodplain available to the stream has been limited by the encroachment of Route 302 and the old railroad grade, thus limiting the entrenchment ratio to less than 4.0. The railroad grade is built up on a raised berm running parallel to the river and thus flood flows cannot spread across the entire historic floodplain. This limits the river's ability to dissipate energy and deposit sediment on the floodplain during flood flows (Figure 21).

All three reaches have a significant amount of deposition along their length (Table 4). Several prominent sediment sources are present to supply this sediment, including the Gale River, the Salmon Hole avulsion site, and the high percentage of eroding banks within Reaches M12-M14 (Table 4). The deposition is further enhanced in Reach M12 and the lower end of Reach M13 by flow impoundment behind the Lisbon Dam. The high percentage of erosion in this section of the river reflects the active widening occurring in Stage III of channel evolution along the artificially straightened channels, resulting in Fair to Poor RGA ratings (Table 5).

Bedrock outcrops in this section of the river are associated with several deep pools and provide some complexity along long stretches of shallow plane bed channel. Cover tends to be limited and the lack of a forested buffer for much of this section provides little to no channel canopy. Consequently, the RHA rating is Fair for all 3 reaches (Table 6). Improvements could be made with wood additions in the channel and growth of a wider forested riparian zone.

4.12 Lisbon Gorge (Reach M11B)

Downstream of the Lisbon Dam, the river flows through a short bedrock gorge. The segment, flowing through the center of Lisbon, is completely armored along its 473 ft length in the form of stone or concrete foundations and retaining walls (Figure 22). The School Street Bridge crosses the channel in Segment 11B.

The stream corridor is highly developed with a mix of residential, commercial and industrial land uses (Tables 3 and 4). Given the land use, the riparian buffer is, not surprisingly, in poor condition. However, the steep bedrock channel provides many deep pools and cover for fish in among the boulders and in the bubble curtain created by the turbulent flow, elevating the RGA rating to Fair despite the lack of a riparian buffer or bank vegetation (Table 6).

4.13 Lower Lisbon (Reaches M9-M11A)

Downstream of the Lisbon Gorge, the river flows in a relatively straight path confined by glacial outwash terraces. The corridor is highly developed in Segment 11A (Table 4). Reaches 9-10 are more agricultural, but several sand and gravel pits as well as the wastewater treatment plant are also near the river.

The Lower Lisbon section is naturally confined with no floodplain to dissipate flood energy. Consequently, the increased scour forces are leading to unstable banks that are, for at least 30 percent of their length in each reach, either eroding or armored (Table 4). Segment 11A is particularly unstable with 68 percent mapped as armored and 13 percent eroding. Another result of the confined condition is limited instream deposition (Table 4). Only two bars are mapped in this entire section, one being a large bedrock-controlled island that was originally deposited in the impoundment upstream of an old mill dam (Reach 10) and the other a small delta supplied with sediment from a stormwater outfall gully (Segment 11A).

Although the channel is naturally straight, the channel is still significantly altered. Significant bank armoring is present as are ruins of the mill dam with its associated upstream island composed of impoundment sediments (Figure 23). Bedrock ledge outcropping at intervals along the length of the section creates a few deep pools and some flow complexity. The riparian buffer is largely deciduous and tends to be narrow with significant stretches having little to no buffer present (Tables 3 and 4). Consequently, the RHA rating is Fair for the three reaches in the Lower Lisbon section.

4.14 Bath Meadow (Reach M8)

The herein named Bath Meadow section is an unconfined reach that begins along Gilman Hill Road in the Town of Bath and continues through a wide alluvial valley until reaching a valley constriction created by a bedrock knob (Figure 24). The impoundment of floodwaters immediately upstream of the constriction results in significant gravel deposition, bank erosion, and rapid channel migration (Figure 25). The dynamic and unstable nature of the channel in this location has caused a recent channel avulsion that has cutoff a high-amplitude meander formed as the result of recent gravel deposition (Figure 26).

The gravel deposition at the downstream end of the reach has been enhanced by significant channel straightening upstream (Table 4; Figure 24) that has increased the river's capacity to transport sediment. The stream has regained its sinuosity at the downstream end of the reach where the sediment transport capacity declines upstream of the valley constriction where the excess sediment delivered from the straightened reaches upstream is deposited upstream of the valley constriction. This process is particularly pronounced in this location due to the scale of the constriction with the valley narrowing from 2,500 ft to 250 ft, a width reduction of 90 percent (Figure 24). Upstream of the impoundment, the artificially straightened channels are wide and shallow with little flow complexity.

The corridor is almost entirely agricultural with a riparian buffer width of less than 25 ft composed largely of only herbaceous vegetation (Table 3). The landowner has planted some red pine buffers set back from the bank in an attempt to arrest or slow the rate of bank erosion. Provided that the trees mature by the time the bank recedes to that point, the roots should help hold the bank and provide increased resistance to bank erosion. The trees will also improve the currently very poor bank canopy.

4.15 Bath Upper Village (Reaches M5-M7)

Downstream of the Bath Meadow section the river passes through the narrow valley constricted by the bedrock knob. The narrow valley also acts as a grade control, because of ledge crossing the channel at the upstream end. As the channel exits the narrow valley constriction, the channel was artificially straightened. The straightening has realigned the channel such that it impinges directly on a high bank of glacial outwash sediments, creating a large mass failure due to erosion at the base of the bank (Figure 27). Downstream, the river flows under an old railroad bridge carrying the recreation trail, past Bath, and into the impoundment upstream of the Bath Dam.

Very wide shallow gravel bed reaches that have experienced extensive bank erosion resulting from gravel bar growth characterize the Bath Upper Village section (Figure 28). Reach 7 has a width:depth ratio of 75 and Reach 5 has a ratio of 79 (Table 2). Both values are significantly higher than elsewhere along the river and much higher than a value of 20 that is generally considered at the maximum end of rivers with excellent habitat conditions. A wide shallow channel leads to increased warming of water during low flow summer periods and, therefore, leads to greater thermal stress on cold water species such as trout. Sediment derived from the large mass failure in Reach 7 (Figure 27) may be a large contributor to the excess sediment load leading to the gravel bar deposition and high width:depth ratio.

More than 45 percent of the bank length was mapped as eroding in Reaches 5-6 (Table 4). Significant bank instability is typical of widening reaches with high sediment loads. Poor bank stability is also the result of a generally thin riparian buffer composed of a mix of deciduous trees and herbaceous vegetation with a significant amount of invasive Japanese Knotweed (Table 3). Herbaceous vegetation, while better than bare soil, does not have the root mass to hold the bank and resist bank scour like mature woody vegetation. This is particularly true of the rapidly spreading Japanese Knotweed that dies back in the winter and does not increase the bank's resistance to erosion.

Bedrock outcroppings are associated with deep pools, some deeper than 10 feet, throughout the Bath Upper Village section. These pools provide good fish habitat and improve the RHA to fair for all three reaches, a rating that would otherwise be poor given the high width:depth ratios elsewhere in these reaches. The Bath Dam, built in 1900 and managed for hydroelectric power generation, impounds the downstream end of Reach 5. The reach includes a large island composed of impoundment sediments and a wide agricultural floodplain. An historic covered bridge spans the channel at the downstream end of the reach.

4.16 Wild Ammonoosuc Confluence (Reaches M3-M4)

Downstream the Bath Dam, the river flows around a large forested island before reaching the confluence with the Wild Ammonoosuc River. The Wild Ammonoosuc River has a drainage area of 60 mi^2. Downstream of the confluence, the Ammonoosuc River enters a narrow steep-sided bedrock-controlled valley and passes under an old railroad bridge high above the river. Portions of this narrow valley resemble a bedrock gorge, but elsewhere glacial terraces and a narrow floodplain are present. The USGS operated a stream gage in the upper portion of this narrow gorge from 1935 to 1980 (Figure 2).

Reach 4, upstream of the narrow gorge, is a slightly incised, cobble-bed channel that still retains access to its wide floodplain during larger floods (Table 2). The incision likely reflects the channel's response to the dam upstream and artificial straightening that occurred over most of its length (Table 4). Sediment transport processes have been significantly altered within the reach, with a large dam at the upstream end reducing the sediment load and tributary inputs from the Wild Ammonoosuc River at the downstream end increasing the load. A large gravel bar has formed at the confluence (Figure 29) as the capacity to transport sediment at higher flows is reduced by the channel constriction as the river enters the bedrock gorge. Some sediment from the Wild Ammonoosuc is likely transported through the narrow gorge (i.e., Reach 3) and has formed small cobble and gravel bars within the reach. Sediment deposition may also have filled some of the pools at the downstream end of Reach 3, but the RHA rating still scores as Good, because of a relatively intact wide and forested riparian buffer (Table 3).

4.17 Woodsville (Reach M2)

Flowing along River Road in the Town of Bath downstream to the Woodsville Dam and covered bridge, the Woodsville section of the river is characterized by its very wide floodplain, abundant side channels, oxbows, and agricultural land use. The wide floodplain may be a relict feature resulting from the catastrophic draining of Glacial Lake Ammonoosuc (see Section 2.0 above). Narrow valley constrictions characterize the upstream and downstream ends of Reach 2. Backwater effects behind the constriction at the downstream end leads to the reformation of meanders along the previously straightened channel. The propensity for meanders to redevelop along the straightened channel is reflected in the bank erosion along 34 percent of the bank length (Table 4). An additional 14 percent of the bank has been armored, primarily with riprap but most recently using flow deflectors along River Road (Figure 30). The herbaceous riparian buffer with significant Japanese Knotweed does not ameliorate the unstable condition of the river banks (Table 3).

Flow expansion below the valley constriction at the upstream end of the reach promotes the development of side channels during flood flows. Many of these side channels are connected to the mainstem during high flow events, but Route 302 and berms along a portion of the highway separate at least one historically active side channel from the river. Those side channels that do retain access to the river provide valuable velocity refuge for fish and other aquatic organisms. These wetlands also likely provide important rearing habitat for juvenile fish throughout most of the year. The RHA rating is Fair with deep pools associated with bedrock outcrops and the side channel habitat offsetting the poor conditions resulting from bank erosion and channel straightening.

4.18 Woodsville Gorge (Reach M1)

Downstream of the Woodsville Dam (Figure 31), the stream flows through a short steep bedrock gorge and into a long pool that is graded to the Connecticut River. The reach is crossed at the upstream end by an historic covered bridge currently used for pedestrians only (Figure 31). A more modern bridge for Woodsville Road parallels the historic structure. At high flow stages on the Connecticut River, the lower portion of the reach backwaters and deposits sediment on a large bar that partially fills the pool. Reach 1 is relatively stable (Table 4), although one 16-foot high mass failure was observed in the reach and more than 10 percent of the banks are armored to protect infrastructure in the Village of Woodsville. Given the flow complexity associated with the bedrock, the RHA rating is Good.

5.0 FLUVIAL EROSION HAZARD MAPS

The Ammonoosuc River, like many of New Hampshire's rivers and streams, is prone to rapid and significant bank erosion as the result of the mountainous conditions and steep narrow river valleys in close association with wider floodplain areas. The climate in the region is highly seasonal with deep winter snows, spring ice jams, and intense rainfalls possible at any time of year. These natural conditions paired with the long history of human alteration of New Hampshire's watersheds make for unstable rivers capable of rapid bank erosion. Forest clearance by the end of the 19th century resulted in increased runoff and sediment delivery to the state's rivers. As towns and villages were developed, rivers were commonly moved, straightened and channelized to accommodate agriculture, log drives, and development of a road and rail infrastructure. The continuing legacy of this landscape manipulation periodically results in rapid channel adjustments during floods as channels reform meanders and redevelop more stable channel dimensions along their length.

While overbank flooding and the inundation of homes, agricultural fields, and other infrastructure causes significant damage in New Hampshire, the greatest flood damages are often caused by rapid bank erosion. The areas most sensitive to rapid adjustment and erosion tend to be where the sediment carrying capacity of the stream rapidly declines (i.e., natural valley constrictions or artificial constrictions at bridges) and the deposition of sediment in the channel diverts erosive flows into the adjacent banks. Accurately defining fluvial erosion hazards, therefore, depends on not only understanding how past and ongoing human land uses alter sediment and water discharge, but also identifying where rapid sediment deposition is possible.

Recognizing where bank erosion may occur during future floods can be used by land developers and municipalities can use information on erosion hazards to: 1) avoid at-risk areas in future development, 2) warn riverside landowners of the potential threats to infrastructure and safety, 3) identify where bank restoration is most needed to protect existing infrastructure, and 4) prevent landuse activities that might worsen the erosion hazards. Fluvial erosion hazard (FEH) zones are corridors of a defined width along the river within which the river is considered to have the potential to migrate through bank erosion during a single large flood or during a series of floods over several years or decades. Homes, roads, and other infrastructure within such a corridor are, therefore, potentially subject to damage by erosion. The meander belt width is used to define the outer limits of the corridor (Figure 32) and envelops the maximum lateral extent of the river's position or meanders on the floodplain over time, including abandoned channels and oxbows, as observed on historical aerial photographs and topographic maps.

The meander belt width varies with soil type, valley slope, and proximity to valley constrictions or expansions. In valleys confined by high glacial deposits or bedrock the fluvial erosion hazard corridor is necessarily narrow as the river is not as free to migrate laterally compared to valley reaches with a wide floodplain. In confined valleys, the FEH zone typically encompasses the entire floodplain, but hazard corridors do not extend up valley side slopes as bank retreat on higher slopes is generally considered too slow to threaten infrastructure beyond the immediate edge of the channel. However, the high sediment production from the confined valleys can significantly alter the width of erosion hazard zones downstream at areas of rapid flow expansion. Hazard zones are typically wider in areas immediately upstream of valley constrictions and downstream of valley expansions due to the associated rapid loss in sediment transport capacity that leads to bar formation, rapid channel migration, and growth of high amplitude meanders. The meander belt width will also generally be wider in lower gradient settings and in finer-textured more-competent soils (i.e., silt and clay), because flow is more easily deflected away from a straight flow path and has a greater propensity to form high amplitude meanders. Sandy bank materials are less competent and highly sensitive to channel alterations, both natural and human, and are, therefore, most susceptible to rapid bank erosion. Although sandy channels are generally straighter and have a narrower meander corridor width, the erosion hazard zones in sandier soils are assigned a higher risk rating (see below), because of the greater chance for rapid changes in a single flood event.

The process for creating fluvial erosion hazard zones is detailed by the New Hampshire Geological Survey (Web citation 5). Previous studies show that the meander belt width along many rivers is approximately 6 times the bankfull width of the active channel (Web citation 6). Therefore, the first step in creating maps of fluvial erosion hazard zones is automated by using GIS to draw corridors 6 channel widths wide that are centered on the channel's centerline (Figure 32). A wider corridor of 8 channel widths is drawn along reaches considered more sensitive to erosion including reaches with sandy soils or those that were artificially straightened in the past. In confined valleys where the floodplain is less than the designated corridor width, the erosion hazard corridor extends across the entire valley. In wider valleys, if the channel runs close to the valley sides the hazard corridor is clipped to the edge of the valley wall and the remaining width of the corridor is shifted towards the other side of the channel. The entire designated width of the hazard corridor can potentially be mapped on one side of the river if the channel runs directly against one valley wall and the floodplain is wider than the full corridor width (Figure 32).

For the purposes of designating flood erosion hazard zones, the edges of high terraces and major roadways are treated as valley walls. Significant erosion into these features is considered unlikely, because of either the large mass of material that would need to be removed where terraces are present or the significant degree of bank protection that is assumed to be present along roadways such as Route 302. Consequently, erosion hazard corridors can be narrower than the initially designated corridor width even where a wide valley is present.

Visual inspections must be made of the GIS-generated hazard zones based on multiples of the channel width. The erosion hazard corridor is intended to encompass the entire meander belt width, but the FEH zones can be redrawn manually if the inspection of aerial photographs shows that current or past channel positions extend beyond the initial FEH zones. This ensures areas all areas subject to future bank erosion are incorporated into the hazard corridor. The most common locations where manual adjustments to the flood hazard zones are needed are upstream of valley constrictions, downstream of valley expansions, or other areas where rapid changes in sediment transport capacity occur.

An FEH zone of a given width and risk rating is drawn for each reach along a river based on the channel's bankfull width, reference channel condition, soil type, and other sensitivity factors (e.g., human modifications). In addition to its width, the FEH zone for each reach is also assigned one of five risk ratings: very high, high, moderate, low, and very low. The risk rating provides an indication of how sensitive the reach is to back erosion and the likelihood for rapid or persistent erosion to occur within a given reach. The risk ratings are a relative scale enabling comparisons between reaches on the relative likelihood of hazardous erosion, but the ratings do not connote a timeframe within which (or a probability that) erosion will occur across the entire width of the FEH zone. In general, reaches with a low sensitivity to erosion (e.g., bedrock banks) will be designated with lower risk ratings while reaches with soils more susceptible to erosion (e.g., sandy banks) or unstable conditions (e.g., artificially straightened channel) will be assigned higher risk ratings.

The FEH zones are not the same as the 100-year flood zone on Federal Emergency Management Agency (FEMA) flood insurance rate maps (FIRMs), but the areas of both often overlap. The FIRMs show areas that are likely to be inundated by floodwaters that overtop the riverbanks during a severe flood with a one percent probability of occurring in any given year. However, most flood-related property damage and injuries in New Hampshire are the result of bank erosion that can undermine roads, bridges, building foundations and other infrastructure. Consequently, the fluvial erosion hazard maps are particularly useful, because they identify areas, sometimes outside the 100-year flood zone, that can be undermined as the banks collapse through erosion – a potentially much more severe hazard than flood inundation. Discrepancies between FEH maps and FIRMs are possible along incised channels where a large flood may not spread across the floodplain, but may have sufficient force to cause several feet of bank erosion through channel widening.

FIRMs and FEH maps should be used in concert to understand and avoid both inundation and erosion hazards, respectively. Even where the inundation and erosion hazard zones are largely overlapping, as is the case in many areas, an awareness that damage is possible from both types of hazards is important in identifying appropriate management strategies to reduce damages. In an area where both hazards exist, structural measures constructed to prevent inundation, such as a berm, could be undermined by erosion if bank protection measures were not simultaneously installed to address the erosion hazard. In general, such structural measures built directly on the river should be avoided in the future as the constraints imposed on natural processes may often exacerbate hazards in adjacent areas. However, protection of existing infrastructure within the hazard zones may sometimes require structural remedies near the river. A more thorough discussion of nonstructural measures and management strategies that do not impose constraints on natural river processes is provided in Section 6.0 below.

Once established, the FEH zones can be of use to towns wishing to prevent erosion related damages. Avoiding conflicts with the river by limiting development, bank protection measures, and flood control structures within hazard zones is the most cost-effective strategy for mitigating fluvial erosion hazards when compared to repairing, retrofitting, or replacing roadways, bridges, and other structures damaged or compromised by erosion. With this in mind, FEH zones can be an important municipal and regional planning tool for limiting encroachment along rivers. Fluvial erosion hazard maps can be used to help identify areas susceptible to erosion and support other flood mitigation opportunities including the identification of stream and floodplain restoration projects, bridge and culvert replacements, and river corridor protection opportunities.

An FEH map can be a critical tool for establishing a sustainable relationship between communities and the river corridors they depend on for economic, social and recreational benefits. Fluvial erosion hazard ordinances that restrict development in FEH zones would not effect homeowners' insurance rates, because homeowners' insurance does not cover flood erosion damages. Inclusion within an FEH zone should not change property values or property taxes either as property valuation already takes proximity to a river and susceptibility to fluvial hazards into account. A model FEH ordinance available from the State of New Hampshire (Web citation 5) has no bearing on existing structures or establishments, but does place limits on the construction of new structures within the fluvial erosion hazard zones. Permitted and conditional uses are outlined in the ordinance with the general guideline being that any improvements or adjustments should avoid encroaching upon the river. Landowners already within the FEH zones would need to check with their respective towns before pursuing new development or modifications to an existing structure. If an FEH ordinance is adopted, the town's zoning regulations would outline and explain permitted and prohibited uses. Adoption of FEH ordinances can help communities mitigate the risks associated with riverbank erosion and prevent repeated and costly damages during floods.

Six fluvial erosion hazard maps, for the 6 towns in the watershed, have been created covering the length of the Ammonoosuc River (Appendix 2). Each map is displayed with three different base formats: road network, aerial photograph, and topographic maps. The FEH zones remain the same regardless of format. A series of 13 smaller maps covering the same area and base formats is also available for easier printing on standard letter-sized paper. Important observations from the 6 larger format maps are described below to exemplify the value of the FEH maps and highlight areas of greatest concern in each town in terms of existing erosion hazards on the Ammonoosuc River.

5.1 Carroll

Located in the largely forested upper portion of the watershed, and surrounded by National Forest, the Town of Carroll includes a mix of protected and developed land with several large resort parcels. The severity of fluvial erosion hazards varies greatly within the town, with Very High hazards occurring at valley constrictions and expansions where excess sediment deposition, flow deflection, and ensuing erosion are most likely. The Bretton Woods reaches exemplify these conditions with a high sediment supply sourced from the steep valley slopes deposited on the flatter and wider valley bottom. Similarly, sediment loading from the Zealand and Little Rivers leads to heightened erosion hazards in the vicinity of these tributaries. These dynamic reaches alternate with relatively stable bedrock-controlled reaches such as the one at Lower Falls where the erosion hazards are rated Very Low. Past channel management practices such as channel straightening, in conjunction with continued development within the meander corridor, increase the risk of damaging fluvial erosion. Straightened channels, such as those near the snowmaking pond in Bretton Woods, are rated as a Very High erosion hazard, because of the potential for the very rapid reformation of meanders along this section or the shift of the river channel into the snowmaking ponds themselves.

5.2 Bethlehem

Within the town of Bethlehem, the Ammonoosuc River flows through a steep confined channel carrying a coarse bedload. The wide alluvial valleys seen in other towns within the watershed do not occur in Bethlehem where the designated fluvial erosion hazard zones tend to occupy the entire width of the narrow river valley. River reaches entering and exiting these confined valleys have a Very High erosion potential, such as upstream of Pierce Bridge or Alder Brook. Increased sediment inputs from tributary confluences also create sediment loading problems that lead to channel instability. As a result, a Very High hazard rating was assigned to the reach downstream of the Little River confluence. Despite a narrow valley, the erosion hazards are Moderate to Very High throughout the Town of Bethlehem, because high banks of glacial sediments outcropping along the length of the river provide a potentially rapidly generated source of sediment to the river.

5.3 Littleton

Located in the center of the watershed, Littleton’s town center is built around the bedrock-controlled Reach 20B with only a Moderate fluvial erosion hazard. Littleton’s many mills, dams and historic rail and road encroachments, both active and ruined, continue to influence the river today with many reaches in the town receiving Very High hazard ratings. The Littleton hydroelectric dam creates a long impoundment at the east end of town, which due to its lake-like qualities did not receive a hazard rating. Downstream of the village center the wide floodplain is the site of active development within the river corridor. This reach of the river, with a Very High hazard rating, includes many historically active channels that cut across the floodplain. The historically straightened channel, as elsewhere in New England, has a propensity to reform meanders or reactivate former channels on the floodplain, either process having the potential to impact the numerous commercial properties. Given the naturally wide floodplain, past channel management practices, and the abundance of floodplain encroachments within the meander corridor, river corridor planning could play an important role in avoiding future conflicts.

5.4 Lisbon

The severity of fluvial erosion hazards varies greatly within the Town of Lisbon. Downstream of the dam in Lisbon, the bedrock controlled river channel ranks as a Very Low hazard. In contrast, the artificially straightened reaches from the bridge at Salmon Hole downstream to the dam have Very High hazard ratings. This is an area that has seen recent channel avulsions at Salmon Hole and extensive and ongoing bank erosion along the Lisbon Village Country Club and the town soccer field. These reaches are likely to remain dynamic as the straightened channel regains sinuosity through, sometimes rapid, bank erosion.

5.5 Landaff

Landaff borders the Ammonoosuc River for only one mile and includes portions of Reaches 9 and 10 with Moderate and Very High hazard ratings, respectively. Landaff is positioned downstream of the confined and bedrock controlled reaches of Lisbon and upstream of the Very High hazard reaches of Bath. Between the Lisbon dam and the Bath dam, the presence of natural valley constrictions downstream of straightened segments with a high sediment transport capacity make for dynamic river reaches, many with Very High erosion hazard ratings.

5.6 Bath

The severity of the fluvial erosion hazards varies greatly in the lower river reaches of Bath with Very High hazards mapped upstream of the dams in the villages of Woodsville and Bath where large abandoned meanders occupy wide floodplains. Downstream of the dam in Woodsville, the bedrock controlled river channel has a Very Low hazard rating. The prevalence of bedrock along the confined stream channel downstream of the Wild Ammonoosuc confluence leads to a narrow FEH zone with a Very Low hazard rating. Within the town of Bath, the river corridor downstream of Gilman Hill Road and upstream of the Upper Village poses the highest fluvial erosion hazard. This area has experienced recent and extensive bank erosion, including a channel avulsion that cutoff a meander that had formed over several years (Figure 26). The presence of natural valley constrictions and a large sediment supply, exacerbated by past channel management practices, have created the dynamic nature of this river reach with a Very High erosion hazard rating.

5.7 Haverhill

Located at the confluence of the Ammonoosuc and Connecticut Rivers, Haverhill includes portions of Reaches 1 and 2. Reach 2 has a Very High hazard rating where large abandoned meanders occupy the wide floodplain upstream of the dam in Woodsville. Downstream of the dam, the bedrock controlled river channel ranks a Very Low hazard rating.

6.0 GEOMORPHOLOGY BASED RIVER CORRIDOR PLANNING

The results of the geomorphic assessment can be used in the river corridor planning process to identify the best management strategies for restoring channel equilibrium, reducing flood damages, and achieving sustainable habitat improvements. A stand-alone Ammonoosuc River Geomorphology Based River Corridor Planning Guide was developed from the geomorphic assessment results described in Section 4.0 above. The Planning Guide details the process of prioritizing flood management and restoration efforts in the watershed and provides a prioritized list of potential restoration projects on the Ammonoosuc River. The Planning Guide is included in this report as Appendix 3 for convenience.

7.0 PHASE 3 ASSESSMENT RESULTS AND PROJECT DEVELOPMENT

The Connecticut River Joint Commission's technical advisory group in consultation with the Ammonoosuc River Local Advisory Committees identified the Salmon Hole area as the highest priority site for restoration. Detailed topographic surveys were conducted of the area and plans developed for instream and riparian restoration. An explanation of the site, goals of the restoration, and the restoration plans were compiled in a stand-alone document entitled "Ammonoosuc River Phase 3 Assessment: Salmon Hole Stream Restoration Designs". This document is included in this report as Appendix 4 for convenience.

8.0 CONCLUSIONS

The Ammonoosuc River was subdivided into 49 geomorphic reaches of uneven length that differ significantly from adjacent reaches in terms of their valley width, valley gradient, and/or drainage area as large tributaries enter the river. The morphology of each reach was assessed to determine their dimensions and how the channel was adjusting to natural conditions (e.g., valley constrictions) and a long history of human land use (e.g., channel straightening). Identifying the reasons for and location of the most rapid channel adjustments is critical for mitigating against damaging floods, rapid bank erosion, and degraded aquatic habitat. On the Ammonoosuc River, rapid, yet natural, changes in valley width are often the sites of the most severe flooding and erosion. These conditions are made worse by artificially straightened river channels upstream that more efficiently convey floodwaters and sediment downstream. The valley constrictions, in turn, limit the likelihood that problems in one area can be transferred great distances downstream. Therefore, the recent floodplain developments in Littleton, whatever localized increases in flooding and sediment production have resulted, will unlikely have a great impact beyond the first downstream valley constriction.

Fluvial erosion hazard maps produced for each town on the Ammonoosuc River (Appendix 2) depict the corridors within which the river could migrate during a single flood or over a number of years and, thus, could be the sites of severe erosion in the near future. Reducing these threats over the long term while improving degraded aquatic habitat will require implementing recommendations made in the Corridor Planning Guide (Appendix 3). Detailed restoration plans for the Salmon Hole area in Lisbon (Appendix 4) illustrate how aquatic habitat improvements using boulder and log structures in an artificially straightened reach might simultaneously reduce flooding and erosion of downstream reaches by promoting meander formation, reducing flood flow velocities, and increasing sediment storage. Success with this project could lead to similar efforts elsewhere along the river and could eventually minimize, but not eliminate, the threat of flooding and erosion on the Ammonoosuc River while creating improved habitat for fish and other aquatic species.

9.0 REFERENCES

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Web citation 6:
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FIGURES

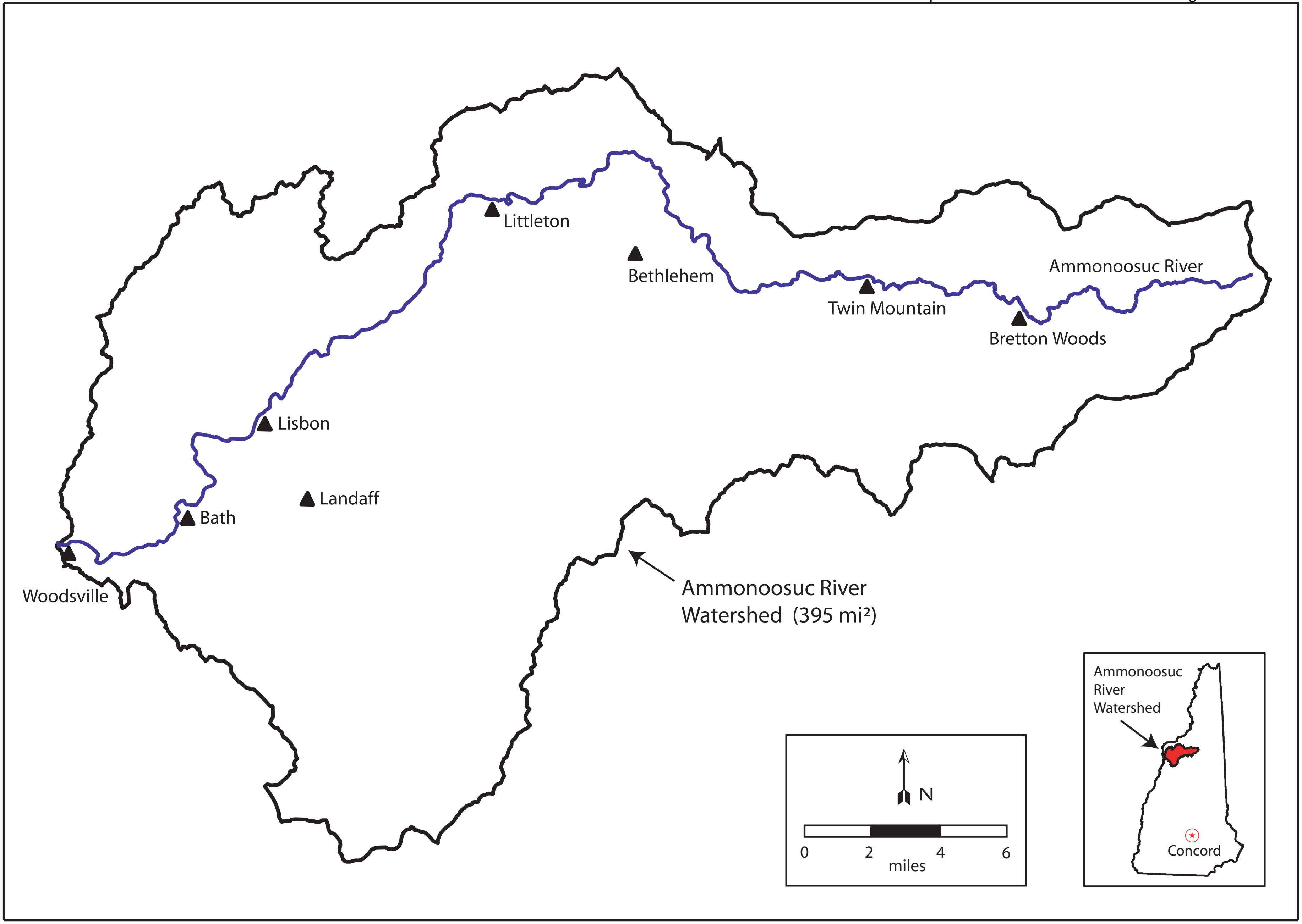


Figure 1. Ammonoosuc River watershed showing location of towns.

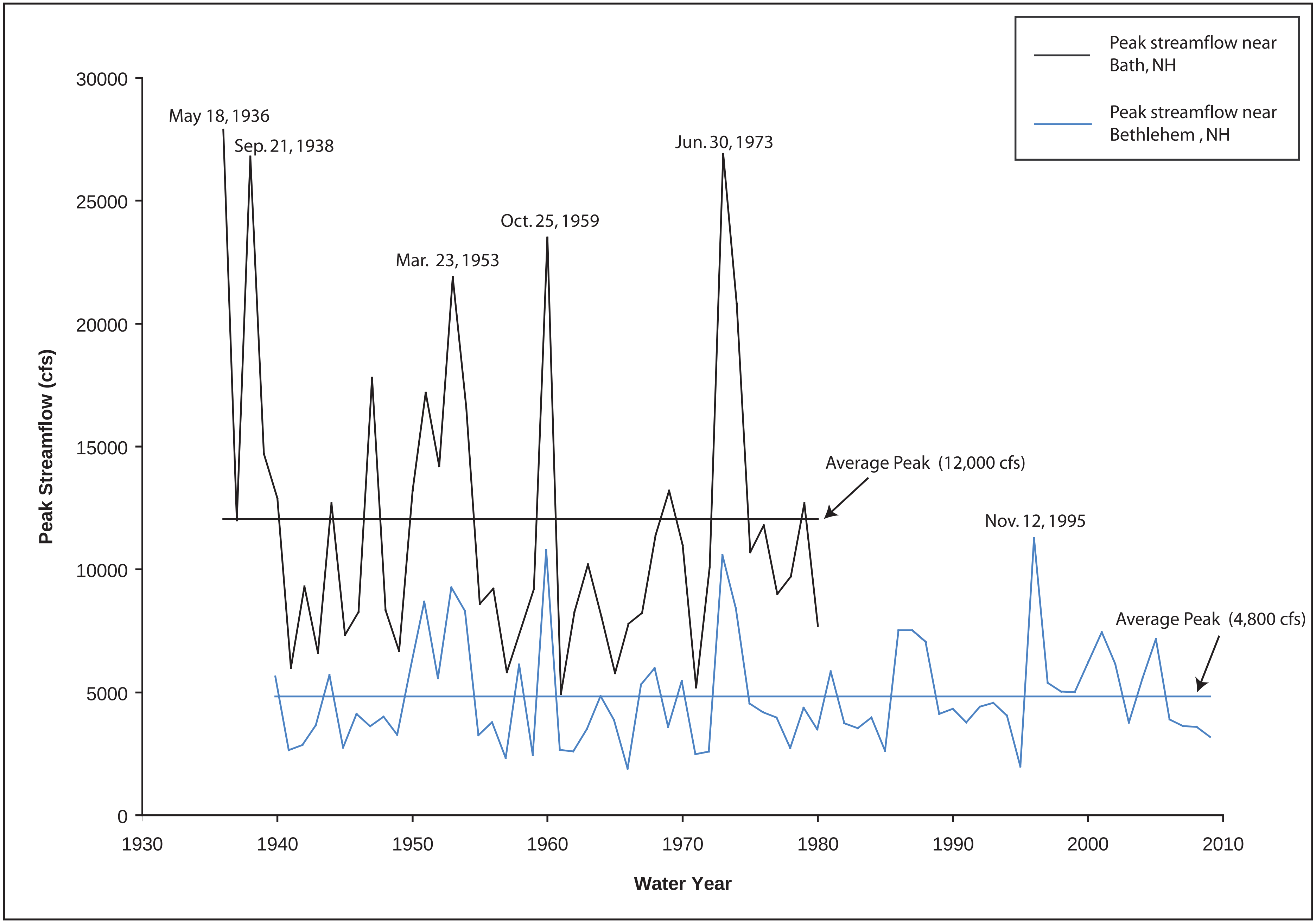


Figure 2. Annual peak discharges recorded at the Bath and Bethlehem Junction river gauges.

Figure 3. Much of the Ammonoosuc Watershed was cleared of its forests in the 19th and early 20th centuries (Photo taken in Littleton in 1908).

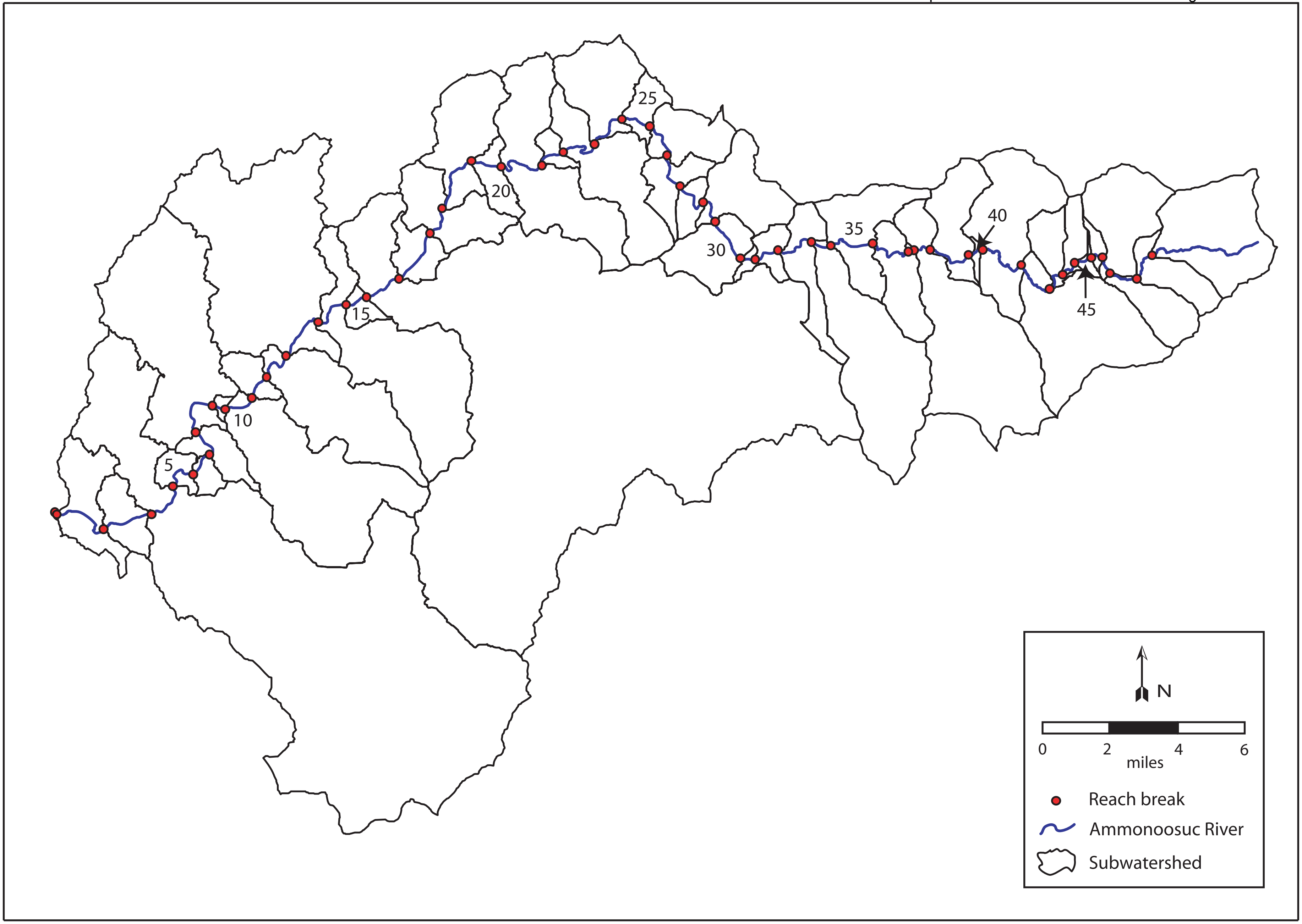


Figure 4. Ammonoosuc River watershed showing location of reach breaks and subwatersheds associated with each reach. Note every fifth reach labeled.

Figure 5. Log jams in the headwaters of the Ammonoosuc River are responsible for frequent channel avulsions between different threads of the anastomosed channels.

a)

b)

Figure 6. Bedrock in the headwater areas occurs along the channel in the form of a) gorges and b) waterfalls.

a)

b)

Figure 7. a) Large unvegetated gravel bars and b) the resulting channel migration characterize the Bretton Woods area. Channel migration in “b” is evidenced by river now flowing over previous bank stabilization efforts.

Figure 8. Recent bank stabilization project incorporating a floodplain bench in front of the eroding bank to reduce erosive forces through flow attenuation.

a)

b)

Figure 9. Lower falls showing a) bedrock constriction and grade control at the upstream end and b) a large scour pool and bedrock channel downstream of the falls.

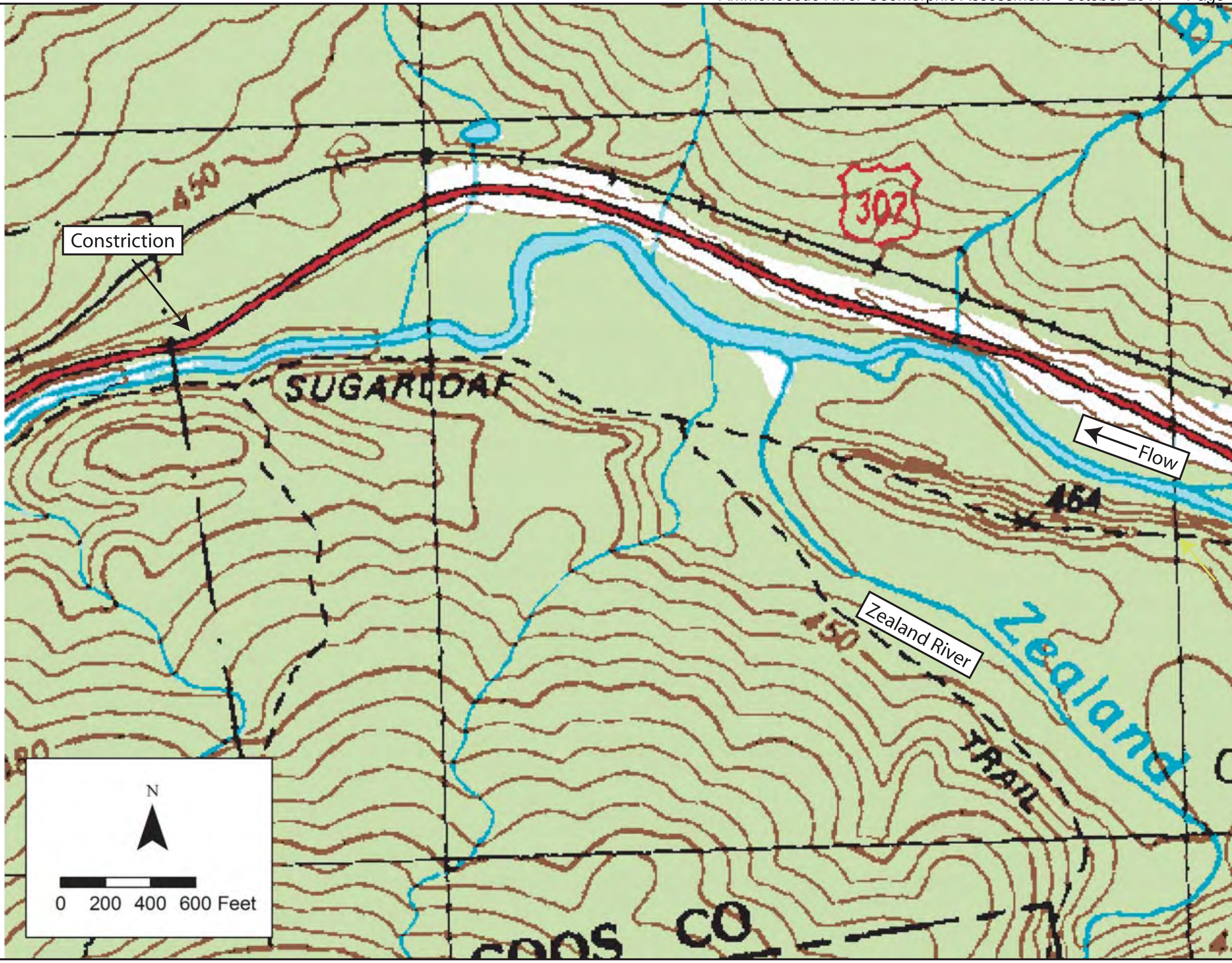


Figure 10. Sediment inputs from the Zealand River cause extensive bar formation and channel migration on the Ammonoosuc River, a situation enhanced by a downstream valley constriction

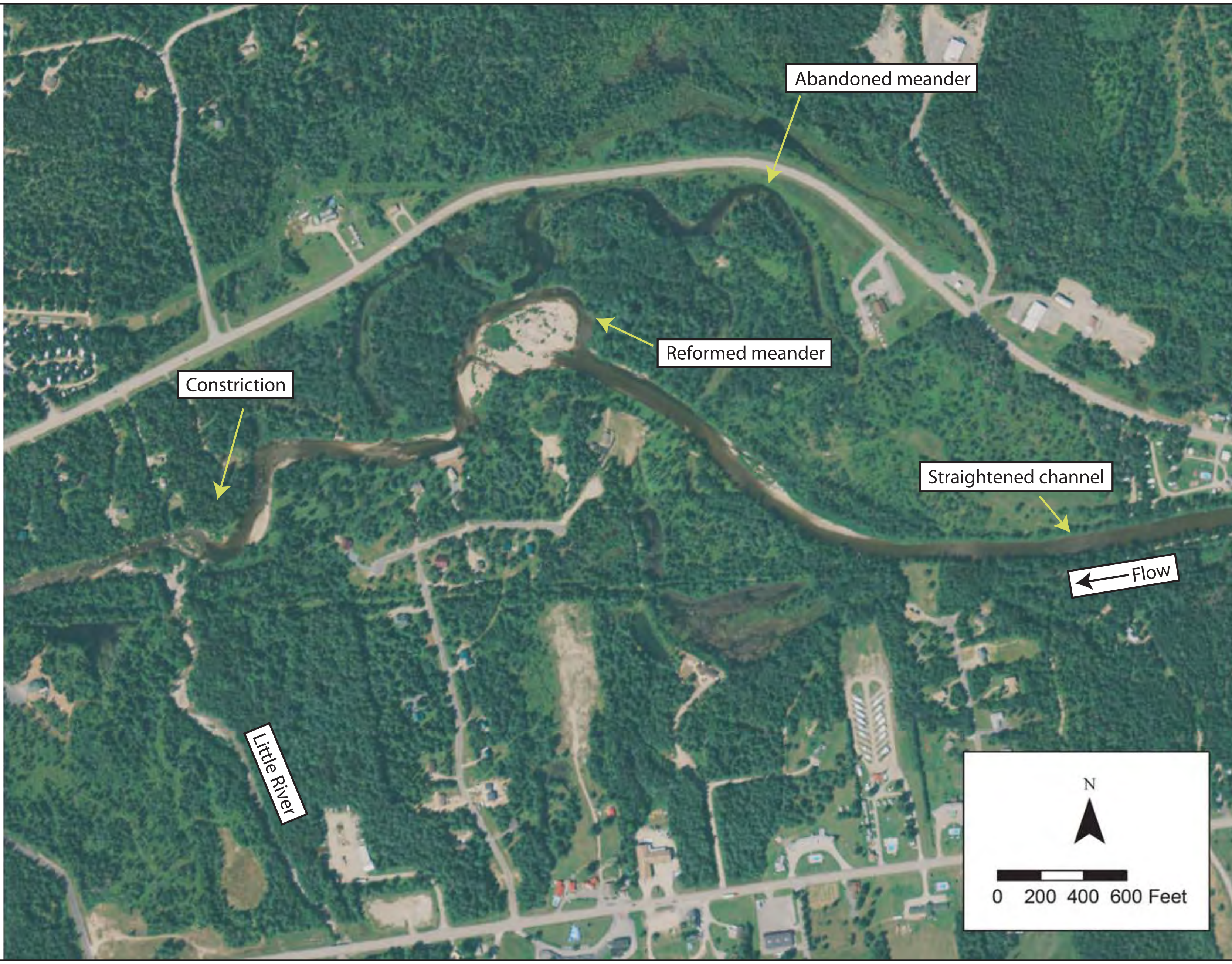


Figure 11. Sediment inputs from the Little River confluence occur at a natural valley constriction and enhance the upstream deposition responsible for channel migration and the reforming of meanders along the formerly straightened channel.

a)

b)

Figure 12. Decommisioning and lowering of the impoundment level upstream of a) the Bethlehem Dam has b) led to upstream migration of a headcut that has incised through a portion of the impoundment sediments.

Figure 13. A considerable length of the channel in Bethlehem Hollow is armored against erosion due to the steep gradient and valley confinement.

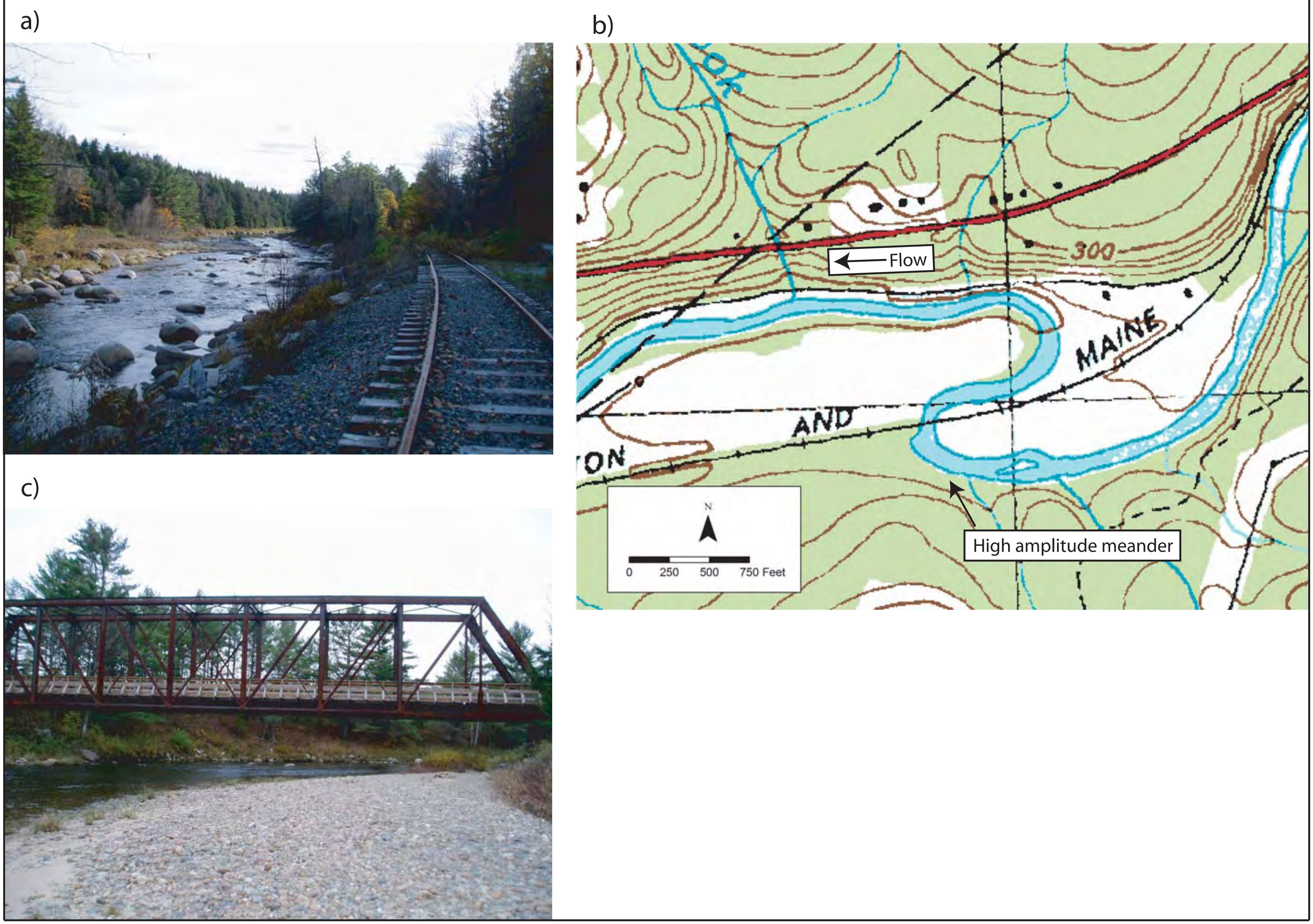
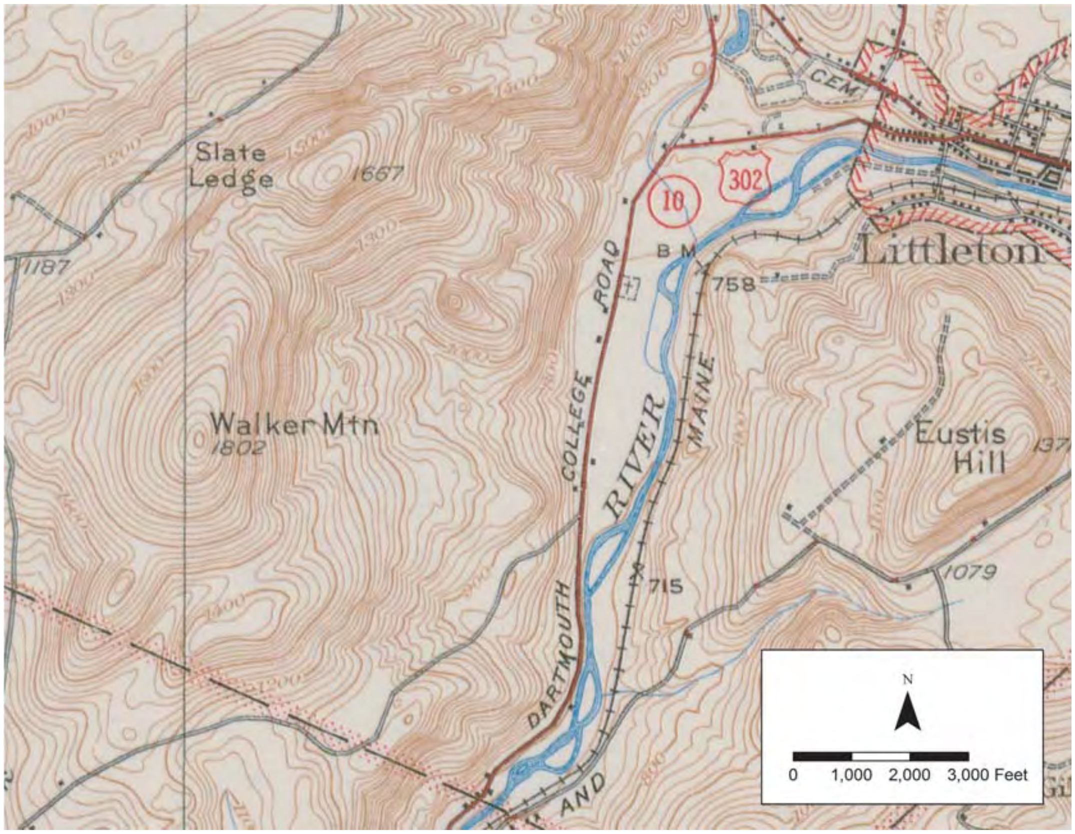


Figure 14. The railroad grade in the lower Bethlehem section a) blocks floodplain access, causing b) the growth of high amplitude meanders and c) considerable upstream sediment deposition.

Figure 15. Bank armoring is significant through the Littleton Village section.

a)

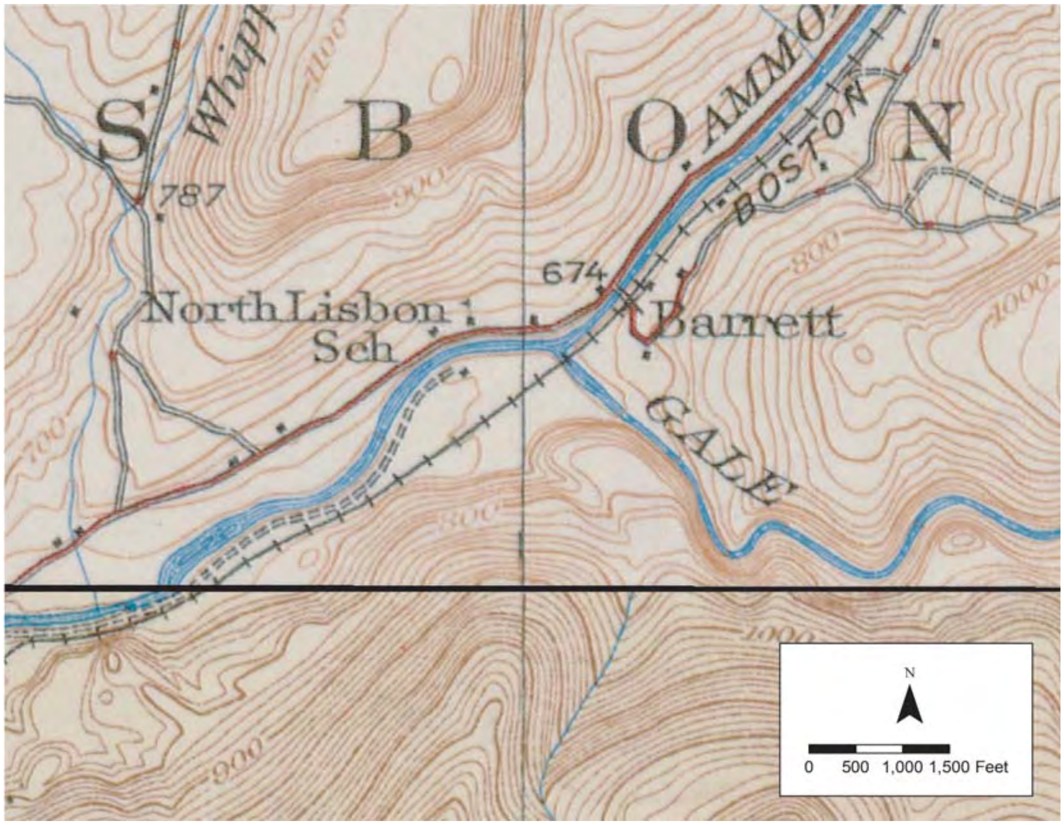


b)

Figure 16. Historical topographic maps show a) a multi-threaded anastomosing channel in the Lower Littleton section prior to b) artificial straightening of the channel as seen from the I-93 bridges.

Figure 17. Infilling of wetlands during development of the floodplain has been compensated, in part, by the creation of artificial wetlands.

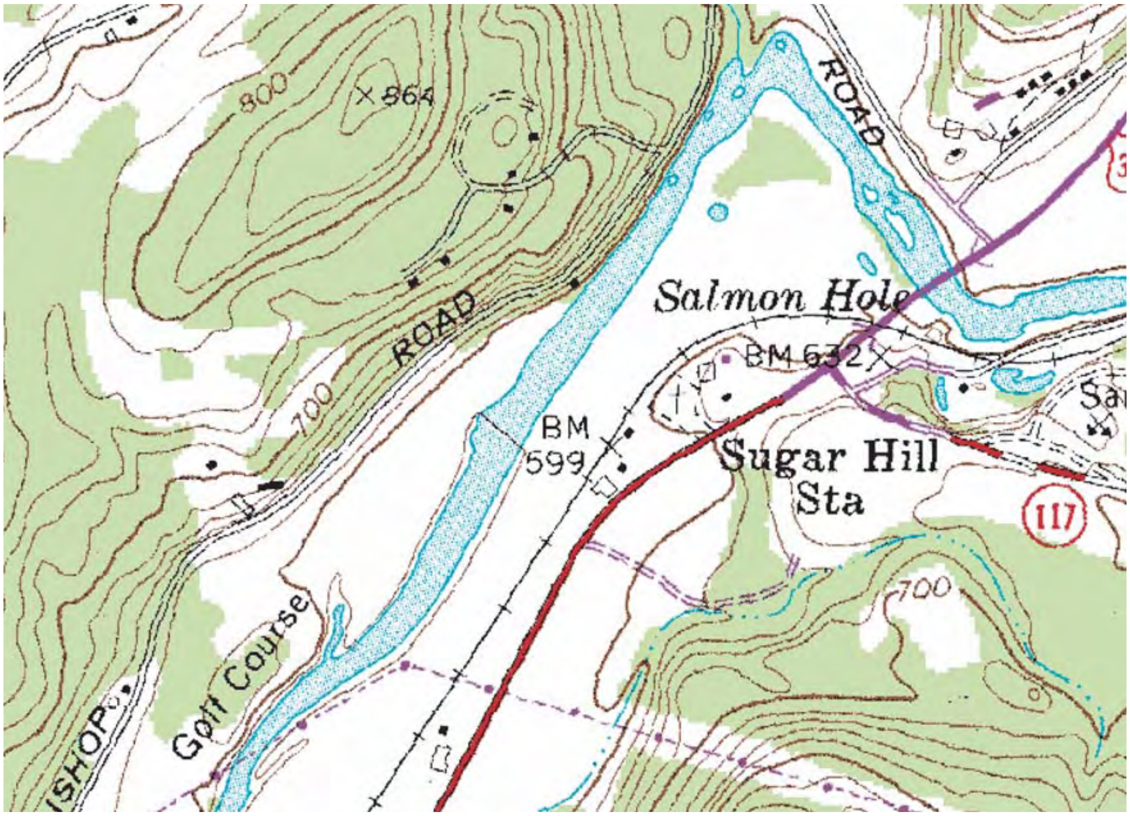
a)



b)

Figure 18. a) Past channel straightening of the lower Gale River has led to b) the formation of a large delta bar at the confluence with the Ammonoosuc River.

a)



b)

Figure 19. a) Topographic map from 1980s and b) aerial photograph from 2008 show formation of new channel on the inside bend of a meander at Salmon Hole.

a)

b)

Figure 20. High sediment supply from Salmon Hole is resulting in the formation of a) large unvegetated gravel bars that, in turn, divert flow and cause b) erosion of the adjacent banks such as at the practice soccer field in Lisbon.

Figure 21. The eroding bank at the practice soccer field in Lisbon (see Figure 20b) is at the end of a long artificially straightened section of the channel. Note railroad grade is blocking the river's access to a large portion of its natural floodplain (arrow a), reducing the space that the river currently has to spread out at high flow stages (arrow b).

Figure 22. The banks are armored through the Town of Lisbon.

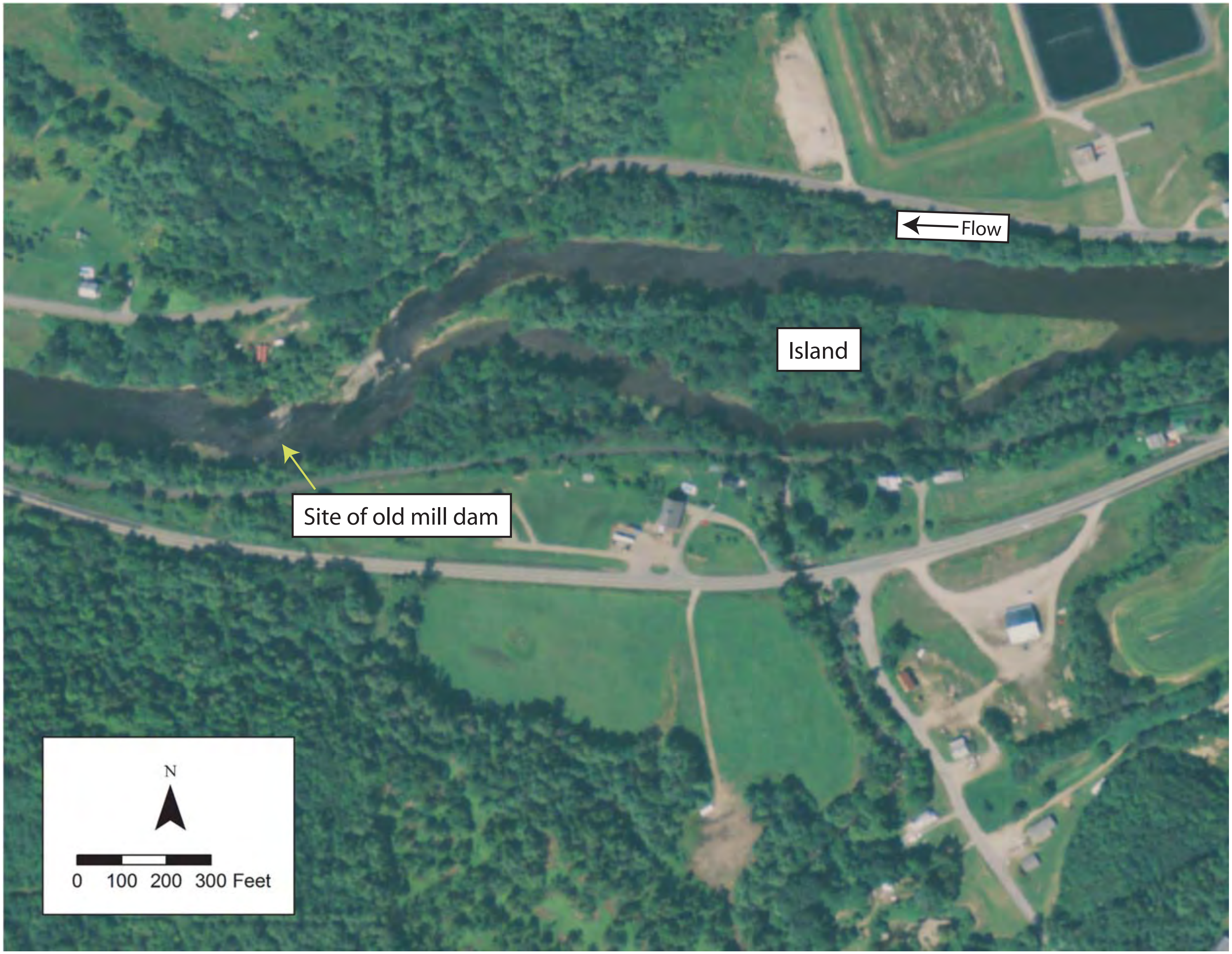


Figure 23. A large island upstream of an old mill dam in the Lower Lisbon section is comprised of fine-grained impoundment sediments.

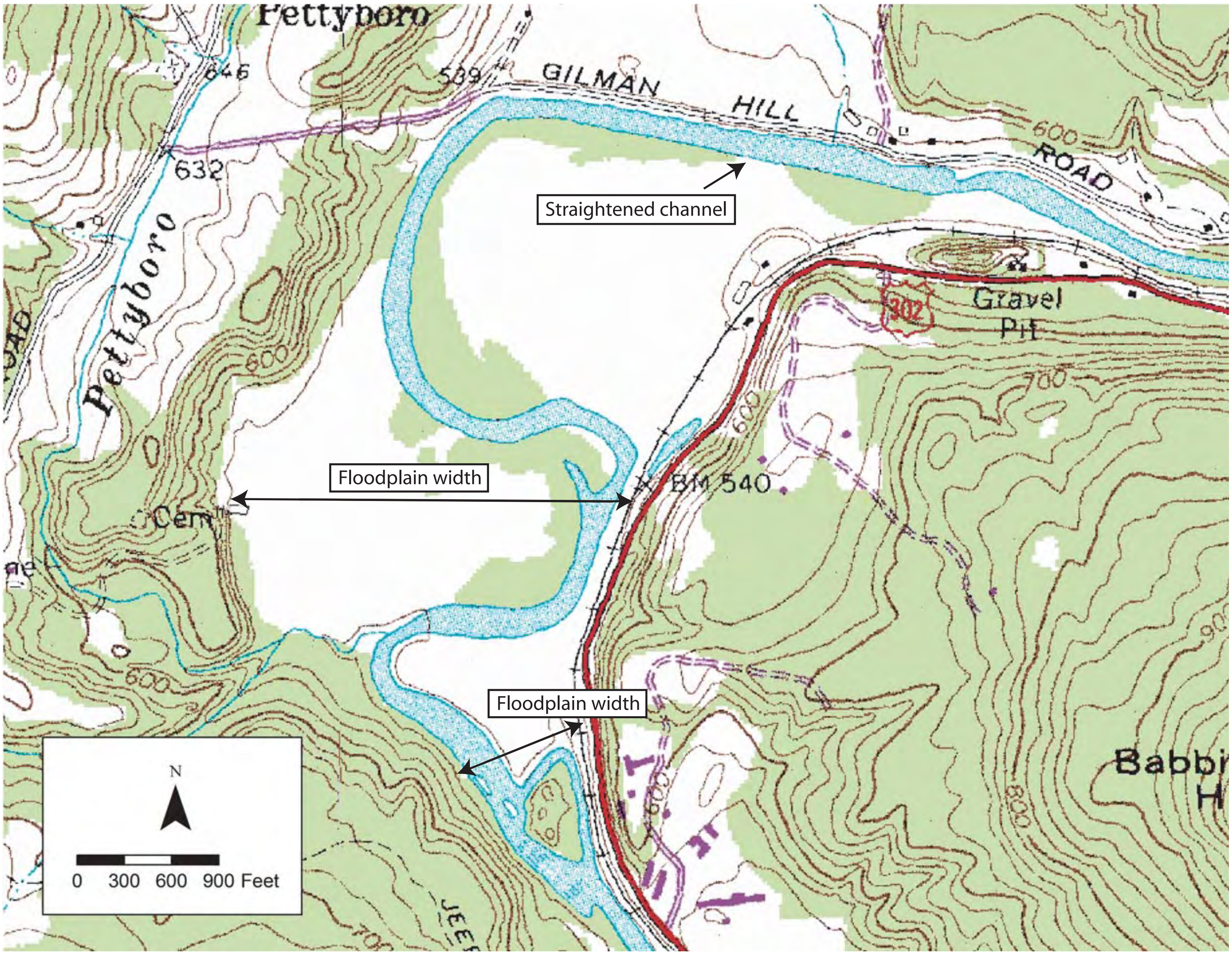


Figure 24. Topographic map showing significant floodplain narrowing at the downstream end of the Bath Meadow section. Note also artificial channel straightening further upstream.

a)

b)

Figure 25. Large unvegetated gravel bars deposited upstream of a valley constriction have led to a) bank armoring due to rapid bank erosion and b) channel migration that has allowed channel to flow over earlier bank protection efforts.

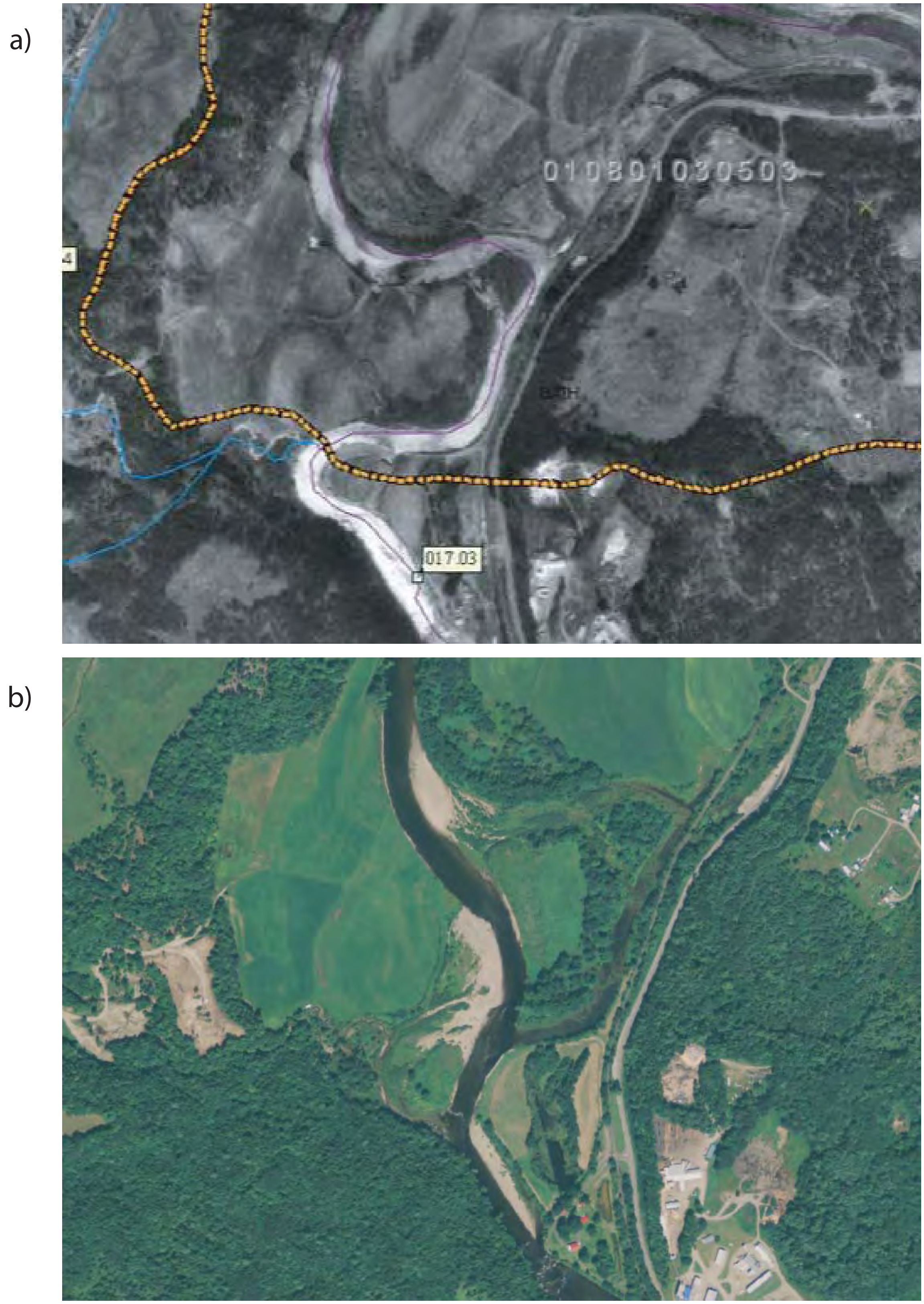


Figure 26. Historical aerial photographs from a) 1999 and b) 2008 of the area upstream of the Bath valley constriction showing channel avulsion and active channel migration.

Figure 27. Large mass failure on a high bank of glacial outwash deposits occurs at the downstream end of an artificially straightened section of the river channel.

Figure 28. Deposition of large gravel bars is leading to bank erosion and the development of a wide shallow channel throughout most of the Bath Upper Village section.

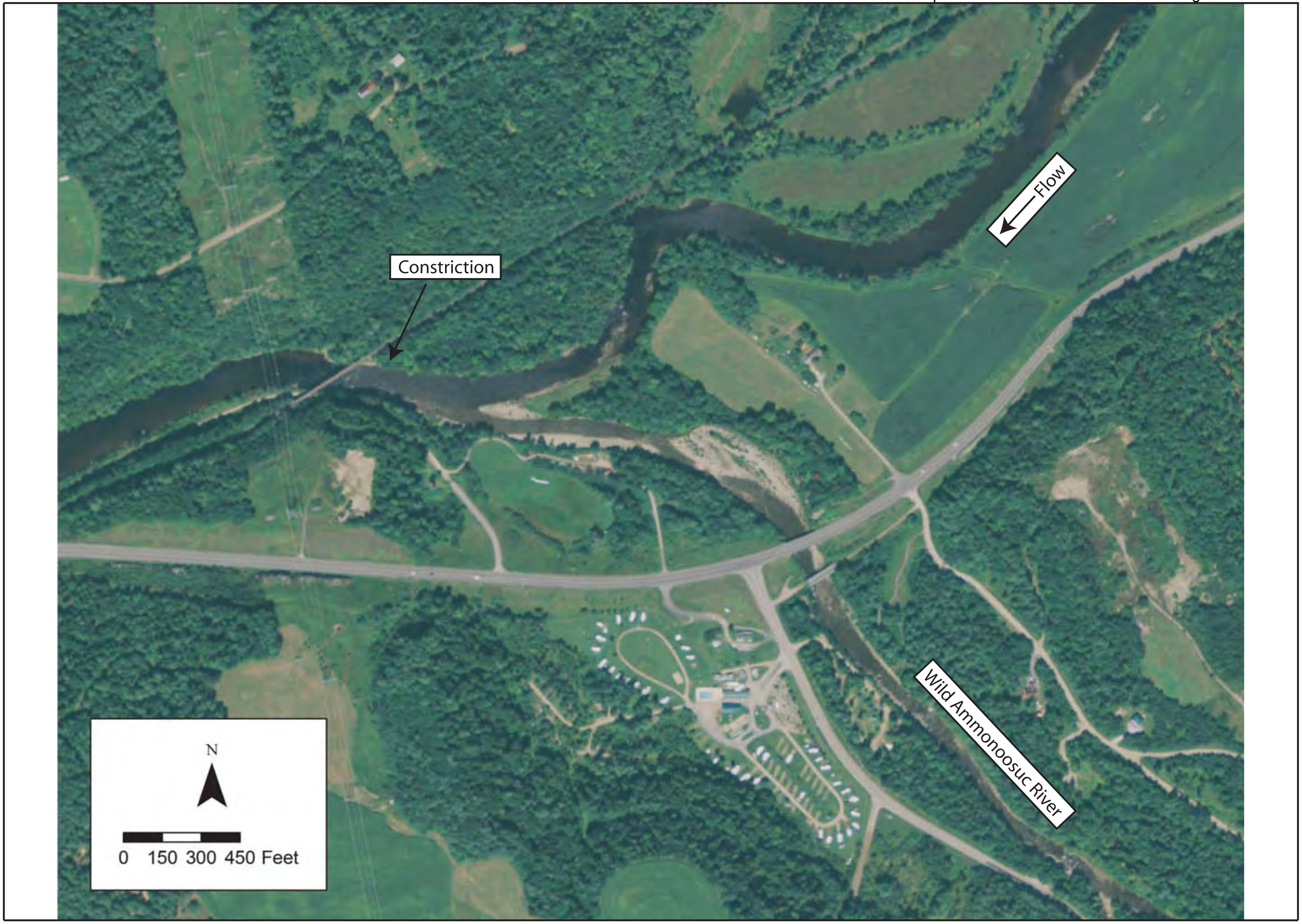


Figure 29. Gravel deposition is enhanced at the confluence of the Wild Ammonoosuc River because a valley constriction is present immediately downstream.

Figure 30. Flow deflectors are a recent approach to arresting erosion along River Road.

Figure 31. Woodsville Dam and the covered bridge are at the upstream end of Reach M1.

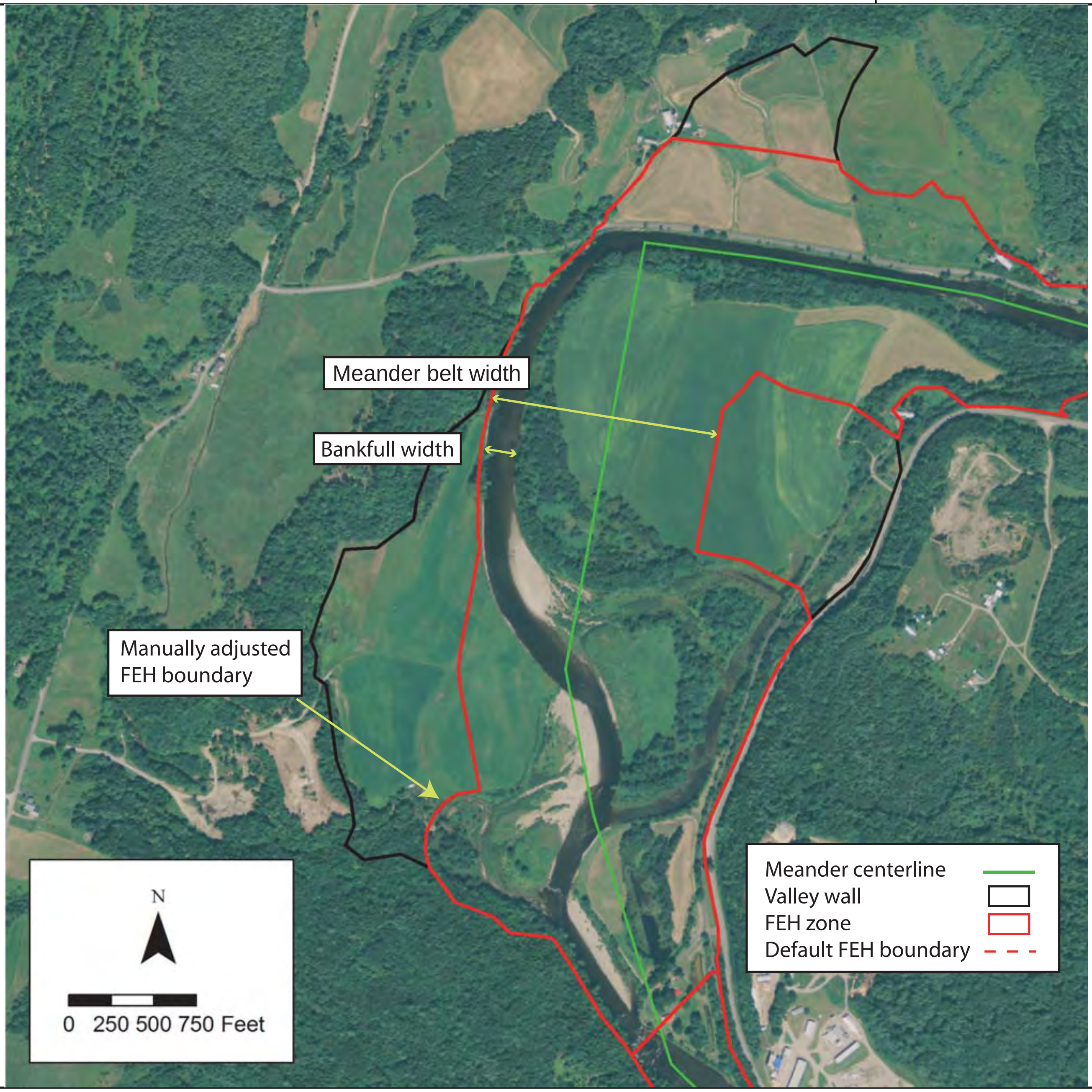


Figure 32. The meander belt width is used to define the extent of fluvial erosion hazard (FEH) zones. The meander belt width is often 6 times the bankfull width, but fluvial erosion hazard zones are created at 8 times the bankfull width in sensitive areas.

TABLES

Table 1. Reach and segment locations and reasons for reach break.

Reach / Segment	Downstream point	Reason for reach break
49	upstream of Mt Pleasant Brook	slope decrease, upstream end alluvial fan
48	Abenaki Brook	constriction
47B	along Base Rd	upstream end bedrock gorge
47A	Halfway Brook	expansion
46	Upper Falls gorge	slope increase, grade control (falls), bedrock gorge
45B	along Base Rd	downstream end bedrock gorge
45A	along Base Rd	slope decrease
44	Bretton Woods golf course	upstream end alluvial fan
43	Crawford Brook	major tributary confluence
42	Fabyan	constriction
41	Lower Falls gorge	slope increase, grade control (falls), bedrock gorge
40B	Lower Falls Rd	downstream end bedrock control
40A	Lower Falls Rd above Rt 302 bridge	expansion
39	Zealand River	major tributary confluence
38B	confined channel along Rt 302	substrate coarsens, depositional features
38A	along Rt 302	slope increase, constriction
37	along Rt 302	slope decrease, expansion
36	upstream of Old Town Rd bridge	constriction
35B	near Birch Rd	planform, depositional features
35A	Little River	major tributary confluence
34	Haystack Brook	major tributary confluence
33	Old railroad grade	constriction
32	near Bethlehem Flower Farm	constriction
31	upstream of Muchmore Rd	expansion
30	along River Rd	upstream end of impoundment
29	Bethlehem dam	dam
28	downstream of Maplewood Hill Rd bridge	expansion
27	along Wing Rd	expansion, slope decrease
26	along Rt 116	constriction
25	upstream of Alder Brook	slope increase
24	along old railroad grade	expansion
23	0.9 miles upstream of Littleton dam	upstream end of impoundment
22	Littleton hydro dam	dam
21	Rt 302 bridge in Littleton village	constriction
20B	downtown Littleton	downstream end bedrock channel
20A	Industrial Park Rd bridge	expansion, channel pattern
19	downstream of Lowes	channel pattern
18	1.7 miles upstream of Gale River	constriction
17B	1 mile upstream of Gale River	downstream end bedrock control
17A	Gale River	major tributary confluence
16	at Littleton/Lisbon KOA	constriction
15	opposite Oregon Road	expansion
14	Rt 302 bridge at Salmon Hole	expansion
13	upstream of Lisbon Water Dept land	constriction
12	Lisbon hydro dam	dam
11B	upstream of ball field	downstream end bedrock gorge
11A	0.8 miles downstream of Lisbon dam	expansion
10	downstream of Mill Brook	constriction
9	along Gilman Hill Rd	expansion
8	near H.G. Wood	constriction
7	Bath Upper Village	channel pattern
6	1 mile upstream of Bath dam	channel pattern
5	Bath hydro dam	dam
4	Wild Ammonoosuc River	major tributary confluence
3	near 90 degree bend in River Road	expansion
2	Woodsville Dam	dam
1	Connecticut River	mouth of Ammonoosuc

Table 2. Phase 2 reach and segment summary statistics for Ammonoosuc River.

Reach / Segment	Watershed Area (mi2)	Stream Length (ft)	Stream Type		Dominant Bed Substrate	Dominant Bedform	Bankfull Channel Width (ft)	Mean Channel Depth (ft)	Maximum Channel Depth (ft)	Entrench-ment Ratio	Incision Ratio	Width to Depth Ratio
49	11.3	5,104	F	3	Cobble	Riffle-pool	39	2.3	3.3	1.3	2.6	17
48	14.2	4,788	F	3	Cobble	Riffle-pool	56	2.5	3.5	1.3	1.8	22
47B	19.6	1,955	F	3	Cobble	Riffle-pool	64	2.3	3.5	1.3	1.8	28
47A	19.6	1,105	B	3	Cobble	Step-pool	57	3.2	4.5	1.5	Gorge	18
46	20.1	2,281	F	3	Cobble	Riffle-pool	83	2.8	5.4	1.2	2.4	29
45B	20.4	1,781	A	3	Cobble	Cascade	35	6.0	12.0	1.1	Gorge	6
45A	20.4	1,081	F	3	Cobble	Riffle-pool	85	2.4	4.0	1.4	2.1	36
44	21.7	3,221	B	4	Gravel	Riffle-pool	91	3.1	4.5	2.1	2.6	29
43	23.6	4,204	Bc	4	Gravel	Riffle-pool	52	1.9	2.6	1.6	2.5	27
42	34.7	7,840	C	4	Gravel	Riffle-pool	62	3.4	5.2	13.9	1.8	18
41	42.8	9,561	C	4	Gravel	Riffle-pool	69	2.9	4.0	10.9	1.5	24
40B	43.1	1,391	A	3	Cobble	Cascade	60	5.5	6.6	1.2	Gorge	11
40A	43.1	1,222	Bc	3	Cobble	Riffle-pool	107	3.0	5.1	1.6	1.0	36
39	47.0	7,521	F	3	Cobble	Riffle-pool	94	3.1	4.4	1.2	2.2	31
38B	61.9	2,437	C	4	Gravel	Riffle-pool	126	3.9	5.2	2.9	1.3	32
38A	61.9	716	F	3	Cobble	Riffle-pool	89	4.3	6.5	1.4	2.0	21
37	61.9	911	A	3	Cobble	Step-pool	87	7.5	9.5	1.3	1.0	12
36	65.5	8,256	F	4	Gravel	Riffle-pool	123	3.6	5.3	1.2	2.3	34
35B	70.6	3,455	F	4	Gravel	Plane-bed	119	3.2	4.4	1.3	2.0	37
35A	70.6	4,669	C	4	Gravel	Riffle-pool	117	4.6	5.7	9.2	1.3	25
34	83.0	3,314	F	4	Gravel	Riffle-pool	129	4.2	6.1	1.2	2.1	31
33	86.3	6,881	Bc	3	Cobble	Riffle-pool	109	4.1	6.4	1.5	1.5	27
32	87.5	4,431	F	3	Cobble	Riffle-pool	125	4.3	5.4	1.3	2.3	29
31	87.8	2,440	Bc	3	Cobble	Riffle-pool	135	5.5	6.5	1.5	1.6	25
30	91.7	7,302	Bc	3	Cobble	Riffle-pool	136	4.8	6.4	1.5	1.6	28
29	96.4	4,512	Bc	3	Cobble	Riffle-pool	152	3.0	4.5	1.5	1.9	50
28	97.6	6,455	F	3	Cobble	Step-pool	120	6.0	7.5	1.1	2.1	20
27	99.9	6,350	F	4	Gravel	Riffle-pool	121	5.1	6.4	1.3	2.0	24
26	103.3	6,475	Bc	4	Gravel	Riffle-pool	142	5.0	6.4	1.8	1.7	28
25	104.9	4,969	C	4	Gravel	Riffle-pool	174	3.5	5.8	3.6	1.4	50
24	110.2	7,111	F	3	Cobble	Riffle-pool	117	4.6	6.4	1.4	1.6	26
23	117.7	8,138	Bc	3	Cobble	Riffle-pool	114	5.2	6.4	1.4	2.0	22
22*	118.5	4,645	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	129.0	9,437	F	3	Cobble	Riffle-pool	132	4.8	6.6	1.2	1.8	28
20B	130.8	702	F	2	Boulder	Bedrock	210	4.8	7.0	1.1	1.7	44
20A	130.8	4,213	F	3	Cobble	Riffle-pool	120	4.5	6.5	1.2	2.3	27
19	136.6	10,017	C	4	Gravel	Riffle-pool	135	4.1	5.4	4.6	1.5	33
18	141.4	5,213	C	4	Gravel	Riffle-pool	144	3.0	5.1	3.7	1.5	48
17B	143.5	4,052	Bc	3	Cobble	Riffle-pool	150	7.2	8.5	1.5	2.1	21
17A	143.5	5,105	F	4	Gravel	Riffle-pool	147	5.5	7.0	1.2	2.1	27
16	241.3	6,255	B	4	Gravel	Riffle-pool	153	4.8	6.2	1.5	1.5	32
15	242.2	3,677	F	4	Gravel	Riffle-pool	180	4.2	5.5	1.2	2.4	43
14	255.7	6,548	C	4	Gravel	Riffle-pool	216	3.9	4.7	2.5	1.8	55
13	277.7	9,245	C	4	Gravel	Riffle-pool	189	4.1	6.1	2.4	1.5	46
12	287.3	6,151	C	4	Gravel	Riffle-pool	186	4.9	6.1	3.8	1.4	38
11B	288.9	473	F	1	Bedrock	Bedrock	138	8.0	11.5	1.2	Gorge	17
11A	288.9	3,792	Bc	4	Gravel	Riffle-pool	145	6.7	8.4	1.6	1.4	22
10	304.0	5,182	F	4	Gravel	Riffle-pool	228	6.2	7.7	1.3	1.6	37
9	304.3	2,128	Bc	4	Gravel	Riffle-pool	168	5.7	7.0	1.4	1.4	30
8	320.7	8,294	C	4	Gravel	Riffle-pool	228	3.6	5.8	7.3	1.7	64
7	322.8	4,997	F	4	Gravel	Riffle-pool	258	3.4	4.5	1.1	2.2	75
6	323.6	4,338	C	4	Gravel	Riffle-pool	246	4.0	5.8	2.8	1.6	62
5	324.8	5,920	C	4	Gravel	Riffle-pool	276	3.5	5.6	3.0	1.8	79
4	395.4	6,941	C	3	Cobble	Riffle-pool	177	5.2	6.8	10.2	1.6	34
3	397.9	8,394	F	3	Cobble	Riffle-pool	165	6.3	7.0	1.1	1.0	26
2	402.2	10,206	C	4	Gravel	Riffle-Pool	198	6.3	7.6	10.1	1.4	31
1	402.3	894	B	4	Gravel	Bedrock	170	13.0	19.0	1.6	Gorge	13

*Reach 22 was not assessed due to its impounded nature

Table 3. Bank and buffer conditions for Ammonoosuc River reaches and segments.

Reach / Segment	Bank	Dominant Bank Vegetation	Subdominant Bank Vegetation	Canopy Percent Catergory	Dominant Buffer Width (ft)	Subdominant Buffer Width (ft)	Dominant Buffer Vegetation	Subdominant Buffer Vegetation	Dominant Land Use	Subdominant Land Use
49	Left	Deciduous	Coniferous	76-100	>100	51-100	Coniferous	Deciduous	Forest	
	Right	Deciduous	Coniferous	76-100	>100		Coniferous	Deciduous	Forest	
48	Left	Deciduous	Coniferous	76-100	>100	51-100	Deciduous	Coniferous	Forest	
	Right	Deciduous	Coniferous	76-100	>100		Deciduous	Coniferous	Forest	
47B	Left	Deciduous	Coniferous	76-100	51-100	>100	Deciduous	Coniferous	Forest	
	Right	Deciduous	Coniferous	76-100	51-100	>100	Deciduous	Coniferous	Forest	
47A	Left	Deciduous	Coniferous	76-100			Coniferous	Deciduous	Forest	
	Right	Deciduous	Coniferous	76-100			Coniferous	Deciduous	Forest	
46	Left	Coniferous	Deciduous	76-100	>100	None	Coniferous	Deciduous	Forest	
	Right	Coniferous	Deciduous	76-100	>100	26-50	Coniferous	Deciduous	Forest	
45B	Left	Coniferous	None	76-100	>100	None	Coniferous		Forest	
	Right	Coniferous	None	76-100	>100	51-100	Coniferous		Forest	
45A	Left	Coniferous	Deciduous	76-100	26-50	51-100	Coniferous	Deciduous	Forest	None
	Right	Coniferous	Deciduous	76-100	26-50	51-100	Coniferous	Deciduous	Forest	None
44	Left	Coniferous	Deciduous	76-100	26-50	0-25	Coniferous	Deciduous	Forest	
	Right	Coniferous	Deciduous	76-100	26-50	0-25	Coniferous	Deciduous	Forest	
43	Left	Deciduous	Shrubs/Sapling	51-75	26-50	51-100	Mixed Trees	Shrubs/Sapling	Commercial	
	Right	Deciduous	Shrubs/Sapling	51-75	>100	26-50	Mixed Trees	Shrubs/Sapling	Forest	
42	Left	Shrubs/Sapling	Herbaceous	1-25	0-25	>100	Shrubs/Sapling	Deciduous	Commercial	Forest
	Right	Shrubs/Sapling	Herbaceous	1-25	0-25	>100	Shrubs/Sapling	Deciduous	Commercial	Forest
41	Left	Deciduous	Herbaceous	26-50	>100	51-100	Deciduous	None	Commercial	Forest
	Right	Deciduous	Herbaceous	26-50	>100	51-100	Deciduous	None	Commercial	Forest
40B	Left	Coniferous	Deciduous	76-100	>100	None	Coniferous	Deciduous	Forest	None
	Right	Coniferous	Deciduous	76-100	51-100	26-50	Coniferous	Deciduous	Forest	None
40A	Left	Coniferous	Deciduous	76-100	>100	None	Mixed Trees	None	Forest	None
	Right	Coniferous	Deciduous	76-100	51-100	26-50	Mixed Trees	None	Forest	None
39	Left	Deciduous	Coniferous	76-100	>100	None	Deciduous	Coniferous	Forest	None
	Right	Deciduous	Coniferous	51-75	26-50	>100	Deciduous	Coniferous	Forest	None
38B	Left	Deciduous	Shrubs	51-75	>100	26-50	Deciduous	Coniferous	Forest	None
	Right	Deciduous	Shrubs	51-75	>100	51-100	Deciduous	Coniferous	Forest	None
38A	Left	Coniferous	Deciduous	76-100	>100	None	Coniferous	Deciduous	Forest	None
	Right	Coniferous	Deciduous	76-100	>100	None	Coniferous	Deciduous	Forest	None
37	Left	Deciduous	Coniferous	51-75	26-50	0-25	Deciduous	Coniferous	Forest	
	Right	Deciduous	Coniferous	51-75	26-50	0-25	Deciduous	Coniferous	Forest	
36	Left	Herbaceous	Deciduous	76-100	51-100	>100	Coniferous	Deciduous	Forest	Residential
	Right	Shrubs/Sapling	Deciduous	51-75	0-25	51-100	Coniferous	Deciduous	Residential	Forest
35B	Left	Deciduous	Herbaceous	26-50	26-50	0-25	Mixed Trees	Shrubs/Sapling	Residential	Forest
	Right	Shrubs/Sapling	Deciduous	1-25	26-50	0-25	Shrubs/Sapling	Mixed Trees	Residential	Shrubs/Sapling
35A	Left	Herbaceous	Deciduous	1-25	>100	0-25	Mixed Trees	Herbaceous	Residential	Forest
	Right	Deciduous	Coniferous	51-75	>100	0-25	Mixed Trees	Shrubs/Sapling	Forest	Residential

Table 3 (continued).

Reach / Segment	Bank	Dominant Bank Vegetation	Subdominant Bank Vegetation	Canopy Percent Catergory	Dominant Buffer Width (ft)	Subdominant Buffer Width (ft)	Dominant Buffer Vegetation	Subdominant Buffer Vegetation	Dominant Land Use	Subdominant Land Use
34	Left	Coniferous	Deciduous	76-100	>100	51-100	Coniferous	Deciduous	Forest	Residential
	Right	Coniferous	Deciduous	51-75	>100	0-25	Coniferous	Deciduous	Forest	Residential
33	Left	Coniferous	Shrubs/Sapling	76-100	>100	26-50	Coniferous	Deciduous	Forest	None
	Right	Coniferous	Shrubs/Sapling	76-100	>100	26-50	Coniferous	Deciduous	Forest	Shrub/Sapling
32	Left	Coniferous	Deciduous	76-100	>100	None	Mixed Trees	Shrubs/Sapling	Forest	None
	Right	Coniferous	Deciduous	76-100	>100	26-50	Mixed Trees	Shrubs/Sapling	Forest	None
31	Left	Deciduous	Coniferous	76-100	>100	None	Mixed Trees	None	Forest	None
	Right	Deciduous	Coniferous	76-100	26-50	51-100	Mixed Trees	None	Forest	None
30	Left	Deciduous	Coniferous	51-75	>100	51-100	Mixed Trees	None	Forest	Residential
	Right	Deciduous	Coniferous	26-50	26-50	>100	Mixed Trees	Herbaceous	Forest	Residential
29	Left	Deciduous	Shrubs/Sapling	26-50	>100	None	Deciduous	Coniferous	Forest	None
	Right	Shrubs/Sapling	Herbaceous	1-25	>100	26-50	Mixed Trees	Shrubs/Sapling	Forest	Residential
28	Left	Deciduous	Coniferous	76-100	>100	51-100	Mixed Trees	Shrubs/Sapling	Forest	Residential
	Right	Deciduous	Coniferous	51-75	>100	51-100	Mixed Trees	Shrubs/Sapling	Forest	Residential
27	Left	Deciduous	Coniferous	76-100	>100	26-50	Mixed Trees	None	Forest	Residential
	Right	Deciduous	Coniferous	51-75	26-50	0-25	Mixed Trees	None	Forest	Comm./Ind.
26	Left	Shrubs/Sapling	Herbaceous	51-75	>100	26-50	Coniferous	Deciduous	Forest	Residential
	Right	Shrubs/Sapling	Herbaceous	26-50	>100	0-25	Deciduous	Shrubs/Sapling	Forest	Residential
25	Left	Herbaceous	Shrubs/Sapling	51-75	>100	51-100	Coniferous	Deciduous	Forest	Residential
	Right	Herbaceous	Shrubs/Sapling	26-50	>100	26-50	Deciduous	Coniferous	Forest	Pasture
24	Left	Shrubs/Sapling	Herbaceous	51-75	>100	None	Coniferous	Deciduous	Forest	None
	Right	Shrubs/Sapling	Herbaceous	26-50	>100	0-25	Coniferous	Deciduous	Forest	Residential
23	Left	Herbaceous	Coniferous	26-50	>100	51-100	Coniferous	Deciduous	Forest	Comm./Ind.
	Right	Herbaceous	Shrubs/Sapling	1-25	26-50	0-25	Mixed Trees	Shrubs/Sapling	Hay	Residential
22	Left	Shrubs/Sapling	Herbaceous	1-25	51-100	26-50	Deciduous	Herbaceous	Residential	Forest
	Right	Shrubs/Sapling	Herbaceous	1-25	26-50	0-25	Deciduous	Herbaceous	Residential	Comm./Ind.
21	Left	Deciduous	Shrubs/Sapling	26-50	>100	51-100	Deciduous	Shrubs/Sapling	Forest	Industrial
	Right	Deciduous	Shrubs/Sapling	1-25	0-25	51-100	Deciduous	Shrubs/Sapling	Residential	Comm./Ind.
20B	Left	Herbaceous	Lawn	1-25	0-25	None	Deciduous	Shrubs/Sapling	Commercial/Ind.	None
	Right	Deciduous	Shrubs/Sapling	1-25	0-25	26-50	Deciduous	Shrubs/Sapling	Commercial/Ind.	None
20A	Left	Shrubs/Sapling	Deciduous	26-50	26-50	51-100	Deciduous	Shrubs/Sapling	Commercial/Ind.	Residential
	Right	Shrubs/Sapling	Deciduous	1-25	51-100	26-50	Deciduous	Shrubs/Sapling	Commercial/Ind.	Residential
19	Left	Herbaceous	Deciduous	1-25	>100	51-100	Herbaceous	Deciduous	Industrial	None
	Right	Herbaceous	Deciduous	0	>100	51-100	Herbaceous	Deciduous	Commercial	Wetland
18	Left	Herbaceous	Deciduous	1-25	>100	0-25	Deciduous	Herbaceous	Forest	Hay
	Right	Herbaceous	Shrubs/Sapling	1-25	0-25	>100	Herbaceous	Shrubs/Sapling	Residential	Commercial
17B	Left	Herbaceous	Deciduous	26-50	>100	26-50	Mixed Trees	Herbaceous	Forest	Residential
	Right	Herbaceous	Shrubs/Sapling	0	0-25	None	Herbaceous	Shrubs/Sapling	Residential	Hay
17A	Left	Herbaceous	Shrubs/Sapling	1-25	26-50	51-100	Mixed Trees	Herbaceous	Hay	Forest
	Right	Herbaceous	Shrubs/Sapling	1-25	26-50	51-100	Herbaceous	Mixed Trees	Residential	Hay
16	Left	Herbaceous	Shrubs/Sapling	26-50	26-50	0-25	Mixed Trees	Shrubs/Sapling	Forest	Hay
	Right	Herbaceous	Shrubs/Sapling	1-25	51-100	26-50	Shrubs/Sapling	Mixed Trees	Commercial/Ind.	Shrubs/Sapling

Table 3 (continued).

Reach / Segment	Bank	Dominant Bank Vegetation	Subdominant Bank Vegetation	Canopy Percent Catergory	Dominant Buffer Width (ft)	Subdominant Buffer Width (ft)	Dominant Buffer Vegetation	Subdominant Buffer Vegetation	Dominant Land Use	Subdominant Land Use
15	Left	Herbaceous	Deciduous	1-25	26-50	0-25	Deciduous	Herbaceous	Residential	Forest
	Right	Herbaceous	Deciduous	1-25	>100	26-50	Herbaceous	Deciduous	Residential	Forest
14	Left	Herbaceous	Deciduous	1-25	26-50	0-25	Herbaceous	Deciduous	Hay	Crop
	Right	Herbaceous	Deciduous	1-25	26-50	>100	Herbaceous	Deciduous	Hay	Forest
13	Left	Herbaceous	Shrubs/Sapling	0	>100	0-25	Herbaceous	Shrubs/Sapling	Hay	Crop
	Right	Herbaceous	Deciduous	0	>100	0-25	Herbaceous	Mixed Trees	Forest	Commercial
12	Left	Herbaceous	Shrubs/Sapling	0	0-25	>100	Herbaceous	Shrubs/Sapling	Commercial	Hay
	Right	Herbaceous	Shrubs/Sapling	0	>100	26-50	Herbaceous	Shrubs/Sapling	Hay	Residential
11B	Left	Shrubs/Sapling	Herbaceous	0	0-25	None	Shrubs/Sapling	Herbaceous	Commercial	Residential
	Right	Shrubs/Sapling	Herbaceous	1-25	26-50	0-25	Deciduous	Shrubs/Sapling	Residential	None
11A	Left	Deciduous	Herbaceous	26-50	26-50	0-25	Deciduous	Herbaceous	Residential	Commercial/Ind.
	Right	Deciduous	Herbaceous	26-50	0-25	26-50	Deciduous	Herbaceous	Residential	None
10	Left	Deciduous	Shrubs/Saplings	26-50	51-100	0-25	Mixed Trees	Shrubs/Saplings	Residential	Forest
	Right	Deciduous	Shrubs/Saplings	26-50	26-50	>100	Mixed Trees	Herbaceous	Residential	Forest
9	Left	Deciduous	Herbaceous	26-50	26-50	51-100	Deciduous	Herbaceous	Forest	Hay
	Right	Deciduous	Herbaceous	1-25	0-25	>100	Deciduous	Herbaceous	Residential	Hay
8	Left	Deciduous	Herbaceous	1-25	51-100	>100	Deciduous	Herbaceous	Pasture	Hay
	Right	Herbaceous	Shrubs/Saplings	0	26-50	0-25	Herbaceous	Shrubs/Sapling	Pasture	Hay
7	Left	Herbaceous	Deciduous	1-25	26-50	0-25	Herbaceous	Deciduous	Crop	Residential
	Right	Deciduous	Herbaceous	26-50	>100		Mixed Trees	Herbaceous	Forest	
6	Left	Herbaceous	Deciduous	1-25	26-50	>100	Herbaceous	Deciduous	Crop	Hay
	Right	Deciduous	Herbaceous	26-50	0-25	51-100	Deciduous	Herbaceous	Hay	Forest
5	Left	Herbaceous	Deciduous	1-25	>100	26-50	Deciduous	Invasives	Forest	Residential
	Right	Herbaceous	Invasives	1-25	0-25	26-50	Herbaceous	Deciduous	Hay	Forest
4	Left	Herbaceous	Deciduous	1-25	26-50	0-25	Deciduous	Herbaceous	Crop	Residential
	Right	Herbaceous	Deciduous	26-50	>100	26-50	Deciduous	Herbaceous	Forest	Hay
3	Left	Herbaceous	None	51-75	26-50	0-25	Mixed Trees	Coniferous	Residential	Forest
	Right	Herbaceous	Invasives	26-50	>100	51-100	Mixed Trees	Deciduous	Forest	Residential
2	Left	Herbaceous	Invasives	26-50	>100	0-25	Mixed Trees	Herbaceous	Hay	Residential
	Right	Herbaceous	Deciduous	1-25	0-25	51-100	Mixed Trees	Herbaceous	Crop	Forest
1	Left	Coniferous	Deciduous	26-50	51-100	0-25	Coniferous	Deciduous	Forest	Industrial
	Right	Deciduous	Herbaceous	1-25	26-50	51-100	Mixed Trees	Herbaceous	Forest	Residential

Table 4. Summary of Feature Indexing Tool results.

Reach / Segment	Channel Straight-ening (%)	Bank Erosion (%)	Bank Armor (%)	Deposition length (ft) per mile	Buffer Width <25 ft (%)	Corridor Develop-ment (%)
49	48.3	1.2	0.0	721	0.0	0.0
48	7.0	6.6	0.0	2663	0.0	1.0
47B	100.0	0.0	5.2	3481	0.0	1.3
47A	0.0	1.0	1.4	2076	0.0	1.3
46	0.0	3.3	2.9	1877	0.0	0.0
45B	0.0	0.0	0.0	499	0.0	0.0
45A	0.0	0.0	0.0	929	0.0	0.0
44	32.9	1.1	5.4	2549	0.0	0.6
43	100.0	7.8	38.8	2012	20.5	69.3
42	100.0	11.9	20.1	2711	17.7	64.6
41	100.0	23.6	11.6	3065	2.9	26.6
40B	0.0	0.0	19.5	406	0.0	0.6
40A	53.0	0.0	0.0	2257	0.0	0.6
39	100.0	11.6	7.8	2541	11.7	45.4
38B	100.0	47.6	7.2	4313	0.0	27.4
38A	96.3	0.0	0.0	487	0.0	27.4
37	0.0	0.0	0.0	0	0.0	94.8
36	100.0	8.1	19.4	2050	21.0	45.1
35B	100.0	7.1	13.5	479	37.1	16.9
35A	84.4	32.6	2.4	3382	9.8	16.9
34	96.3	3.1	4.0	1347	9.7	10.0
33	18.0	2.1	4.7	1775	3.2	4.9
32	0.9	2.8	3.9	2847	0.0	0.0
31	100.0	0.0	16.0	1264	0.0	0.0
30	100.0	5.5	35.4	739	6.9	17.0
29	32.0	7.8	13.2	2957	0.0	6.9
28	0.0	10.4	17.1	1007	2.7	5.3
27	37.7	4.0	22.4	494	19.4	1.9
26	39.1	2.9	17.8	1626	20.3	4.5
25	94.0	12.8	6.1	3195	4.2	1.0
24	23.1	7.3	14.7	1177	8.0	2.2
23	0.0	14.7	19.6	1069	6.1	3.2
22*	0.0	0.0	67.4	729	22.2	50.5
21	0.0	13.4	37.5	2437	34.3	78.7
20B	100.0	0.0	100.0	1061	92.4	74.6
20A	100.0	5.5	55.9	710	11.2	74.6
19	100.0	21.4	7.1	4331	0.0	42.9
18	99.0	30.2	11.2	4807	19.6	6.7
17B	0.0	5.8	43.3	2204	29.7	15.8
17A	59.1	5.3	65.9	854	7.5	15.8
16	100.0	23.1	12.3	1341	0.0	18.4
15	100.0	6.4	4.4	1255	28.6	25.6
14	100.0	17.4	22.8	2947	7.8	25.7
13	100.0	48.7	3.4	3704	10.7	12.6
12	29.3	43.7	14.0	3712	18.0	25.7
11B	0.0	0.0	100.0	1041	55.6	66.3
11A	0.0	12.9	67.5	0	45.7	66.3
10	0.0	16.2	21.6	2074	14.1	20.8
9	0.0	17.2	15.9	0	22.9	7.3
8	100.0	40.5	5.7	3083	23.2	1.5
7	100.0	25.4	5.7	1673	17.4	20.0
6	100.0	44.8	5.2	3523	30.7	1.3
5	24.4	48.1	3.3	1416	26.5	1.2
4	81.6	41.7	10.3	1316	13.0	6.7
3	0.0	14.6	19.3	2304	16.8	5.5
2	98.9	33.7	13.7	2461	27.8	15.5
1	0.0	9.3	11.0	1480	25.3	32.6

*Reach 22 was not assessed due to its impounded nature.

Table 5. Summary of Rapid Geomorphic Assessment (RGA) values for Ammonoosuc River.

Reach / Segment	Channel Degradation	Channel Aggradation	Channel Widening	Change in Planform	Total Score	Condition Rating (%)	Stream Condition	Stream Sensitivity	Channel Evolution Stage
49	5	16	13	11	45	56	Fair	Very High	IV
48	5	13	5	13	36	45	Fair	Very High	IV
47B	10	13	11	11	45	56	Fair	Very High	IV
47A	18	17	18	16	69	86	Reference	Low	I
46	5	16	14	14	49	61	Fair	Very High	IV
45B	20	16	20	18	74	93	Reference	Low	I
45A	5	13	10	15	43	54	Fair	Very High	IV
44	5	12	13	14	44	55	Fair	High	IV
43	5	13	6	9	33	41	Fair	Very High	III
42	9	5	11	3	28	35	Fair	Very High	III
41	11	5	9	3	28	35	Fair	Very High	III
40B	20	17	15	20	72	90	Reference	Low	I
40A	15	17	13	16	61	76	Good	Moderate	I
39	4	12	10	11	37	46	Fair	Very High	IV
38B	15	11	7	9	42	53	Fair	Very High	III
38A	5	15	15	18	53	66	Good	High	I
37	17	19	14	18	68	85	Reference	High	I
36	5	11	7	8	31	39	Fair	Very High	III
35B	3	5	10	12	30	38	Fair	Very High	III
35A	12	11	9	9	41	51	Fair	Very High	III
34	5	12	9	12	38	48	Fair	Very High	IV
33	5	14	10	12	41	51	Fair	High	IV
32	5	16	14	14	49	61	Fair	Very High	IV
31	13	16	14	13	56	70	Good	Moderate	IV
30	12	15	13	12	52	65	Good	Moderate	IV
29	6	7	5	5	23	29	Poor	Very High	II
28	5	16	13	12	46	58	Fair	Very High	IV
27	5	15	11	13	44	55	Fair	Very High	IV
26	5	14	14	13	46	58	Fair	Very High	IV
25	13	11	5	11	40	50	Fair	Very High	IV
24	5	16	12	13	46	58	Fair	Very High	IV
23	5	11	8	8	32	40	Fair	High	III
22*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
21	4	13	9	10	36	45	Fair	Very High	IV
20B	12	13	5	11	41	51	Fair	Moderate	III
20A	5	13	9	9	36	45	Fair	Very High	IV
19	11	10	9	5	35	44	Fair	Very High	IV
18	12	8	4	9	33	41	Fair	Very High	III
17B	3	14	11	11	39	49	Fair	High	IV
17A	3	13	9	10	35	44	Fair	Very High	IV
16	9	14	10	11	44	55	Fair	Very High	IV
15	4	11	5	14	34	43	Fair	Very High	IV
14	8	10	4	9	31	39	Fair	Very High	III
13	12	3	4	5	24	30	Poor	Very High	III
12	9	13	8	8	38	48	Fair	Very High	III
11B*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Low	I
11A	13	16	15	14	58	73	Good	High	IV
10	5	12	8	11	36	45	Fair	Very High	IV
9	13	16	13	14	56	70	Good	High	IV
8	12	11	5	3	31	39	Fair	Very High	III
7	5	10	4	11	30	38	Fair	Very High	III
6	14	9	3	12	38	48	Fair	Very High	III
5	13	12	5	11	41	51	Fair	Very High	IV
4	11	15	10	12	48	60	Fair	High	IV
3	15	15	15	18	63	79	Good	Low	I
2	15	13	10	10	48	60	Fair	Very High	IV
1	17	15	16	18	66	83	Good	Low	I

* Reach 22 was not assessed due to its impounded nature

*An RGA was not completed for Segment 11B, because it is in a bedrock gorge.

Table 6. Summary of Rapid Habitat Assessment (RHA) values for Ammonoosuc River.

Reach / Segment	Epifaunal Substrate and Available Cover	Embedd-edness	Velocity / Depth Patterns	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles / Steps	Bank Stability		Bank Vegetative Protection		Riparian Buffer Width		Total Score	Percentage	Habitat Condition
								LB	RB	LB	RB	LB	RB			
49	18	3	19	11	13	13	18	9	9	10	10	9	10	152	76	Good
48	15	15	16	15	15	17	18	8	8	10	10	9	10	166	83	Good
47B	19	17	18	8	11	9	15	10	10	10	10	7	6	150	75	Good
47A	16	15	18	14	16	18	18	9	10	10	10	10	4	168	84	Good
46	15	12	20	9	15	16	18	9	9	10	10	10	8	161	81	Good
45B	16	14	18	8	19	18	18	10	10	10	10	10	8	169	85	Good
45A	13	10	18	8	13	16	18	10	10	10	10	5	5	146	73	Good
44	17	8	18	7	13	16	18	7	10	7	10	6	6	143	72	Good
43	11	10	17	9	13	6	14	3	3	7	7	4	6	110	55	Fair
42	10	9	16	7	10	4	11	3	3	3	3	3	3	85	43	Fair
41	12	6	16	6	8	6	13	2	2	7	7	9	7	101	51	Fair
40B	13	18	18	14	19	18	18	10	9	10	9	10	6	172	86	Reference
40A	16	15	18	17	18	17	18	10	10	10	10	10	6	175	88	Reference
39	10	8	16	9	17	8	13	6	6	10	7	10	5	125	63	Fair
38B	14	13	16	6	8	13	20	3	2	10	9	9	9	132	66	Good
38A	15	13	18	16	18	18	18	9	9	10	10	10	9	173	87	Reference
37	18	18	13	20	20	20	20	8	8	8	6	3	3	165	83	Good
36	10	9	16	8	13	6	15	5	2	8	6	6	2	106	53	Fair
35B	6	7	10	8	16	1	11	5	5	6	6	3	3	87	44	Fair
35A	14	11	16	6	7	11	16	4	4	7	9	7	9	121	61	Fair
34	10	11	15	11	16	10	17	9	4	10	7	8	6	134	67	Good
33	16	13	18	11	13	12	17	9	7	10	9	9	7	151	76	Good
32	15	16	18	17	18	16	18	9	8	10	9	10	7	171	86	Reference
31	15	16	18	16	18	11	18	9	5	10	8	10	4	158	79	Good
30	12	15	18	15	18	8	15	7	3	8	5	8	5	137	69	Good
29	8	6	16	6	8	11	18	7	6	8	6	9	7	116	58	Fair
28	16	15	19	15	18	13	17	9	7	10	8	9	7	163	82	Good
27	12	10	11	15	18	9	18	10	3	9	6	8	2	131	66	Good
26	13	11	16	14	17	10	15	10	4	10	7	8	4	139	70	Good
25	9	8	11	7	12	12	14	8	4	9	8	9	7	118	59	Fair
24	10	14	18	14	14	11	18	7	5	9	7	10	6	143	72	Good
23	9	12	16	8	12	9	16	5	4	8	6	8	3	116	58	Fair
22	5	5	3	13	18	3	3	1	0	6	1	5	3	66	33	Poor

Table 6 (continued).

Reach / Segment	Epifaunal Substrate and Available Cover	Embedd-edness	Velocity / Depth Patterns	Sediment Deposition	Channel Flow Status	Channel Alteration	Frequency of Riffles / Steps	Bank Stability		Bank Vegetative Protection		Riparian Buffer Width		Total Score	Percentage	Habitat Condition
								LB	RB	LB	RB	LB	RB			
21	8	8	15	10	17	9	18	5	2	7	3	6	1	109	55	Fair
20B	7	9	16	13	10	6	20	1	1	1	3	0	1	88	44	Fair
20A	6	10	12	14	15	8	18	1	2	4	5	4	5	104	52	Fair
19	11	8	16	8	11	11	17	4	6	8	8	7	7	122	61	Fair
18	14	8	18	7	7	12	18	1	4	6	6	5	2	108	54	Fair
17B	13	11	18	14	16	5	18	5	1	7	3	7	1	119	60	Fair
17A	8	9	18	13	16	5	16	2	1	5	4	4	4	105	53	Fair
16	13	13	16	12	14	12	17	4	5	5	5	4	5	125	63	Fair
15	5	13	16	16	14	5	18	7	6	6	5	4	7	122	61	Fair
14	8	11	18	10	8	8	16	3	7	7	6	4	7	113	57	Fair
13	6	7	16	6	10	10	19	2	4	3	3	3	4	93	47	Fair
12	7	8	18	9	11	10	18	3	3	5	5	3	5	105	53	Fair
11B	15	17	18	16	13	8	18	5	7	1	4	1	3	126	63	Fair
11A	5	8	16	15	18	5	14	2	1	4	4	3	1	96	48	Fair
10	8	8	18	10	16	11	13	5	4	8	7	4	4	116	58	Fair
9	6	8	14	14	18	8	16	3	4	4	3	4	1	103	52	Fair
8	8	7	18	8	9	10	19	4	2	5	3	7	3	103	52	Fair
7	8	6	18	6	14	11	19	4	5	3	8	3	10	115	58	Fair
6	6	6	19	7	8	12	17	4	2	4	7	3	2	97	49	Fair
5	12	6	15	7	12	7	11	3	4	6	5	9	3	100	50	Fair
4	10	5	16	14	13	8	16	2	4	5	6	9	3	111	56	Fair
3	16	16	18	18	18	17	18	6	8	7	9	3	9	163	82	Good
2	10	10	18	9	15	6	16	5	5	7	5	6	3	115	58	Fair
1	11	9	16	11	19	15	18	5	7	7	7	6	5	136	68	Good

APPENDICES
(see attached DVD)