Bank Stabilization Implementation and Assessment of the Connecticut River near Colebrook and Groveton, New Hampshire

Final Report

Prepared for

Connecticut River Joint Commissions
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EXECUTIVE SUMMARY

Continuing efforts to address bank erosion problems along the Connecticut River have led to the permitting of a bioengineering project at the Colebrook Business Park, a detailed assessment of bank instability at the Northumberland Cemetery, and production of erosion hazard maps for each town along the northern Connecticut River. The permitted bioengineering project, to be constructed in Spring 2006, will utilize root wads to protect the bank while trapping additional debris to improve near bank cover habitat. To assist towns in applying this and other erosion control techniques at other sites throughout the watershed, erosion hazard maps showing the cause and location of erosion have been produced with a brochure describing the major causes for erosion and preferred methods of stabilization. The maps and brochures are to be distributed to the towns at meetings scheduled for January 12, 2006.

Bank instability at the Northumberland Cemetery is related to several factors including: 1) the breaching of the Old Wyoming Dam 3.0 miles downstream of the cemetery; 2) the breaching of Nash Stream Bog Dam in the Upper Ammonoosuc watershed; and 3) the resulting sand bar development on the Connecticut River at the confluence with the Upper Ammonoosuc River. The banks at the cemetery are naturally susceptible to erosion given the presence of seeps at the base of the bank where an impermeable silt layer underlies permeable sand. With the river still responding to the breaching of the dam downstream and still susceptible to sediment impulses from the Upper Ammonoosuc, erosive pressures at the cemetery will likely continue as elsewhere in the 3.3 mile reach between the Upper Ammonoosuc confluence and the Old Wyoming Dam. After considering a number of restoration options at the cemetery, the construction of an engineered log jam at the base of the cemetery bank was chosen as the most likely option to buttress the bank from further failure, improve physical habitat, and restore natural processes to an area impacted by human land use for over 200 years. To move project implementation forward, an engineering design for securing the logs to the bank will need to be completed.

1.0 INTRODUCTION

This report describes the results of the project entitled "Bank Stabilization Implementation and Assessment of the Connecticut River near Colebrook and Groveton, New Hampshire" completed by the Connecticut River Joint Commissions in conjunction with Field Geology Services. The study focuses on two reaches of the Connecticut River: 1) Colebrook Business Park and the adjacent confluence with the Mohawk River and 2) Northumberland Cemetery between the Upper Ammonoosuc River confluence and Old Wyoming Dam (Figure 1). The watershed area upstream of the Colebrook Business Park and the Northumberland Cemetery is 544 mi^2 and 1,182 mi^2, respectively. In addition to focusing on these two areas, the Connecticut River Joint Commissions has produced erosion hazard maps and an accompanying brochure for each town along the northern Connecticut River. The purpose of the maps and brochures is to identify the causes for bank instability within each town and describe options for managing the erosion in a sustainable habitat enhancing manner.

The 2004 *Fluvial Geomorphology Assessment of the Northern Connecticut River* identified sediment inputs from the Mohawk River as a cause for bank erosion at the Business Park (Field, 2004). An assessment of the Mohawk River was completed by the Connecticut River Joint Commissions in 2005 to identify areas where sediment could be stored before reaching the Connecticut River mainstem (see tributary assessment report). This report focuses on near term efforts (bioengineering) to reduce bank erosion rates at the Business Park while longer term initiatives to reduce sediment inputs from the Mohawk River are further developed. At the Northumberland Cemetery, the causes for erosion were not satisfactorily identified during the 2004 assessment so further studies were conducted in 2005 and are reported on here.

The Connecticut River Joint Commissions has been working since 1989 to stem riverbank erosion on the Connecticut River. In 2004, the Connecticut River Joint Commissions decided to undertake a fluvial geomorphology assessment of the northern Connecticut River in order to identify the underlying causes for erosion and develop more sustainable solutions that simultaneously reduce erosion, improve water quality, and restore aquatic habitat. Continuing efforts at the Business Park and cemetery will illustrate this process and encourage others to implement similar projects in similar settings. The erosion hazard maps and brochure are designed to assist towns in choosing the appropriate erosion control strategy for specific localities.

2.0 EROSION HAZARD MAPS

Bank stability and composition data collected during the 2004 fluvial geomorphology assessment (Field, 2004) were used to create erosion hazard maps for the 16 towns along the northern Connecticut River (Table 1 and Appendix 1). The maps display the location of eroding banks, moderately eroding banks, stable banks, and bank armoring. The eroding banks are further subdivided by the cause of erosion, if known. In addition, the maps show where the river flows against banks composed of nonalluvial glacial outwash sediments, alluvial floodplain deposits, or bedrock. Nonalluvial sediments are typically exposed in high banks 25 to 100 feet high and stabilizing such banks where they are eroding would be much more difficult than for eroding alluvial banks. Thus, users of the maps can ascertain for a specific location whether erosion is occurring, the cause for erosion, and the potential complexity in addressing the erosion problems.

The causes for erosion are further described in an erosion control brochure designed to accompany the erosion hazard maps (Appendix 2). Three primary causes for erosion were identified during the 2004 fluvial geomorphology assessment: channel straightening; sediment inputs from tributaries; and sediment inputs from high eroding banks. For each cause, the brochure prioritizes management strategies for addressing bank instability. Management strategies that directly address the cause for erosion and are effective over the long term are of the highest priority. Given the difficulties in implementing such strategies under current land use and ownership, other management strategies such as bank armoring are also discussed but are considered a lower priority because of the potential to destabilize downstream locations and harm aquatic habitat. The maps and brochure will ensure that the results of the 2004 fluvial geomorphology assessment are utilized by towns and other organizations to select management strategies that result in sustainable improvements to bank stability without degrading aquatic habitat or destabilizing adjacent reaches. The maps and brochure will be distributed to the 16 towns during a series of explanatory meetings scheduled for January 12, 2006.

3.0 COLEBROOK BUSINESS PARK

The Colebrook Business Park was chosen at the end of the 2004 fluvial geomorphology assessment as the site for a demonstration project to illustrate management strategies for addressing bank instabilities resulting from sediment inputs from tributaries (Figure 1). A series of demonstration projects along the northern Connecticut River will illustrate some of the higher priority management strategies outlined in the erosion control brochure and assist towns in implementing similar projects elsewhere. Work at the Colebrook Business Park in 2005 consisted of two parts: design and permitting of a bioengineering project and acquisition of a conservation easement.

The severely eroding portion of the riverbank at the Colebrook Industrial Park is 730 feet long. The upstream 400 feet is a high bank (15 feet) composed of loose sands and gravels and the downstream 330 feet is a low bank (6 feet) of less erodible floodplain silt and clay (Figure 2). Design specifications were developed for a bioengineering project along the lower bank at the downstream end of the site (Appendix 3). The designs were submitted to the New Hampshire Department of Environmental Services and, as a result, a Standard Dredge and Fill Permit was secured by the Town of Colebrook in November 2005 that authorizes project construction (Appendix 4). Project construction will occur on the earliest practicable date in Spring 2006 when the fields are sufficiently dry and the river level low. The bioengineering project will stabilize the bank with the use of root wads placed along the bank. The bases of the tree trunks will be buried in trenches excavated perpendicular to the bank such that the root wads will protrude from the trench and protect the exposed soil from the river's flow (Appendix 3).

The roughness of the root wads will baffle flow and trap additional debris floating down the river, which will further protect the bank and create additional cover habitat at this popular fishing locale (Figure 2b).

Funds are currently being sought to extend the bioengineering project to the upstream end of the eroding bank at the Colebrook Business Park. Given the higher bank and greater erodibility of the bank sediments at the upstream end, an additional method for securing the root wads will need to be engineered before applying for a Standard Dredge and Fill Permit. Funds are also being sought to further analyze the feasibility of restoring flow to abandoned side channels on the lower Mohawk River. Spreading flow out into several flow paths on the lower Mohawk River will reduce sediment inputs to the Connecticut River, reduce the size of the gravel bars across from the eroding bank at the Colebrook Business Park, and slow the rate of erosion (Figure 3). The permitted bioengineering project and proposed extension to the high bank upstream are designed to provide short term protection against bank erosion as sustainable restoration efforts are assessed and implemented on the lower Mohawk River.

A conservation easement is currently being negotiated for a 100-foot wide buffer along the top of the 730-foot eroding bank at the Colebrook Business Park. The Town of Colebrook's attorney, Bernie Waugh, expects to complete development of the easement in January 2006. Riparian plantings within the buffer will improve bank stability as the planted trees mature and their roots improve soil cohesiveness and strength. Although the root wads to be installed as part of the bioengineering project will decompose over time, the maturing riparian buffer will ensure that the rate of bank erosion remains low over the long term. Initial plantings will occur when construction of the bioengineering project along the lower bank is completed in Spring 2006. Additional funds are being sought to more thoroughly plant the easement area over a three year period to account for plant mortality that typically occurs during the winter months on such projects. In addition to improvements to bank stability, the 100 foot wide buffer will also improve riparian and aquatic habitat at the site.

4.0 NORTHUMBERLAND CEMETERY

Bank erosion at the Northumberland Cemetery is of great concern to the residents of Groveton and surrounding communities because of the impending likelihood that several graves will become exposed by further bank retreat (Figures 4 and 5). A report completed by the US Army Corps of Engineers in 2002 ranked erosion at the cemetery as a top priority for stabilization among several erosion sites along the northern Connecticut River (Army Corps, 2002). Interviews with local residents involved in cemetery operations indicate that erosion of the 35-foot high bank was first noticed in the early 1970’s but accelerated in the 1980’s. Since that time as much as 40 feet of bank recession has occurred along portions of the 400 feet of bank adjacent to the cemetery with a perimeter road closest to the bank lost as a result (Figure 6). While most of the erosion occurred prior to 2000, erosion continues to this day with more than 6 feet of bank recession occurring along a 15-foot portion of the bank in Fall 2005 (Figure 5).

The cause for erosion at the cemetery was not clearly identified during the 2004 fluvial geomorphology assessment, so a more detailed Phase 3 assessment was completed in 2005 to better understand the nature, cause, and timing of erosion before considering restoration options for stabilizing the bank. A 3.3 mile reach of the Connecticut River was assessed from the Upper Ammonoosuc River confluence downstream to the Old Wyoming Dam near the bridge between Guildhall, VT and Northumberland, NH (Figure 1). The detailed assessment consisted of: 1) a study of the bank stratigraphy and mode of bank failure at the cemetery and elsewhere in the study reach; 2) topographic surveying of a longitudinal profile and several cross sections; 3) hydraulic modeling to determine changes in water level associated with breaching of the Old Wyoming Dam; 4) a review of historical topographic maps and aerial photographs to identify changes to the sand bar just upstream of the cemetery; 5) an analysis of the causes of erosion; and 6) consideration of several restoration alternatives at the cemetery. Substrate particle size data were not collected because the entire reach has a sand bottom and additional information was deemed unnecessary for this assessment.

4.1 Bank Stratigraphy and Mode of Bank Failure

Bank erosion at the cemetery occurs as discrete shallow rotational slumps (Figure 7). More recent slumps at times bisect older slumps such that over time the entire length of bank recedes. However, during a single slump failure only a portion of the bank fails (Figures 5 and 7). Over 5 feet of bank can be lost during a single slump but typically not along more than a 30 foot length of bank. The slump block itself remains intact as it moves away from and down the river bank. While vegetation generally remains standing, taller trees tend to lean in toward the bank as a result of the rotational slumping. Bare soil is often exposed along the scarp at the head of the slump failure (Figure 5).

Bank stratigraphy at the cemetery is characterized by buff-colored stratified glacial outwash sands overlying a gray thinly laminated silt and clay (Figure 8). The contact between the permeable sand above and more impermeable silt and clay below is at or near the water surface at low flow. As a result of this bank stratigraphy the banks are naturally susceptible to bank erosion with the shallow slumps consistent with the sandy nature of the soil (clay soils would lead to deeper slumps). Water percolating through the sand creates seeps at the base of the bank at the contact with the silt and clay below (Figure 8a). This lubricates the contact surface which serves as the basal plane of detachment along which the slump blocks rotate. Since the water surface is above the stratigraphic contact during peak flow when hydrostatic pressure favors the movement of groundwater into the bank (Figure 8b), the likelihood for bank failure is greater at the receding end of high flows when the groundwater flow direction is reversed. This was the case for recent bank failures (Figure 5) and is consistent with observations by local residents.

A similar stratigraphy is exposed along nonalluvial banks throughout the reach between the Upper Ammonoosuc River confluence and the Old Wyoming Dam. Even more dramatic erosion is observed elsewhere in the reach but these locales are a lower restoration priority, because of minimal threats to human structures and investments

(Figure 9). Shallower slip failures than observed at the cemetery extend continuously for over 100 feet in certain locations, but otherwise the mode of bank failure throughout the reach is similar to conditions at the cemetery.

4.2 Topographic Surveying

A longitudinal profile and 10 cross sections were surveyed between the Upper Ammonoosuc confluence and Old Wyoming Dam using a Sokkia Set 5 Electronic Total Station and Hondex Digital Depth Sounder (Appendix 5). The cross sections are located at various places along the reach but are not equally spaced (Figure 10). An eleventh cross section was surveyed at the base of the cemetery during Phase 2 of the 2004 fluvial geomorphology assessment. The longitudinal profile recorded the elevation of the water surface and thalweg (i.e., deepest part of the channel) from the upstream to downstream end of the reach.

The most striking result of the longitudinal profile survey is the extreme depth of the channel bottom (27 feet deep) at the apex of the meander bend just upstream of the bridge between Guildhall and Northumberland (Figure 11). This point is located where the floodplain becomes constricted by 80 percent (compared with immediately upstream) between glacial uplands to the west and alluvial fan deposits from Dean Brook to the east. This constriction increases flow velocities sufficiently during large floods to scour the channel bottom to the great depths observed. This location is also coincident with large scale bank failures that have washed out the eastern half of Vermont Route 102.

The channel is also deep just downstream of the confluence of the Upper Ammonoosuc River where the floodplain is also slightly constricted between glacial uplands, although not as severely as further downstream (Figure 11). The deep pool near the confluence is also coincident with the new outfall pipe for the paper mill in Groveton, which is armored with metal sheet piling. Whether the channel has become deep as a result of encountering the sheet piling is unclear.

The channel elsewhere on the longitudinal profile is generally deeper at the apices of meander bends as is expected due to higher flow velocities on the outside bends of the channel and as the channel encounters the higher banks of glacial outwash deposits along the valley margins (Figure 11). The channel is shallowest and has its most uniform depth along the straightened portion of the channel downstream of the Northumberland Cemetery; this is consistent with the findings from other straightened channel segments studied during the 2004 fluvial geomorphology assessment (Field, 2004). The depth of the channel at the cemetery, located just downstream of a mid-channel sand bar, is deeper than elsewhere along the straightened segment but not as deep as in the meander bends.

The cross sections illustrate how the channel frequently flows against high banks of glacial outwash sediments along the valley margins with one bank generally much higher than the floodplain (Figure 12). However, the bankfull elevation is generally even with the floodplain level on the opposite bank and flood flows are able to spread out across the floodplain. Channel width:depth ratios range between 6.6 and 62.0 with the two extremes immediately adjacent to each other (Cross Sections 7 and 10) where the channel is extremely deep in the meander bend upstream of the bridge (Figure 11 and Appendix 5). The low width:depth ratio occurs at the deep pool with the high width:depth ratio found immediately upstream where the channel is shallow and wide as a result of sediment being deposited in the backwater area behind the constriction. A high width:depth ratio (43.0) also occurs at Cross Section 2 where a large point bar has developed in the meander bend immediately downstream of the long straightened segment. Increased sediment transport capacity through the straightened segment results in increased deposition in the meander downstream where sediment transport capacity is reduced. Width:depth ratios for the remaining cross sections are within expected ranges, suggesting the channel is not undergoing significant adjustments at these locations.

4.3 Hydraulic Modeling

The topographic survey data were further utilized to complete HEC-RAS hydraulic modeling of the 3.3 mile reach between the Upper Ammonoosuc confluence and Old Wyoming Dam (Appendix 6). A number of dams have been located at the site of the Old Wyoming Dam since the 1700’s with the latest rebuilt in 1936 (Figure 13a). By the mid-1980’s the dam had been breached (Figure 13b) and only the abutments at the margins of the channel remain today (Figure 13c). Water levels at the dam were several feet higher than today when the dam was in place (Figure 13). The HEC-RAS modeling was completed by Woodlot Alternatives of Topsham, ME and was used to determine how water levels and water surface gradients changed upstream, including at the cemetery, when the Old Wyoming Dam was breached in the 1980’s.

The hydraulic modeling results indicate that the water surface elevation at the cemetery for the same magnitude flow is more than 3.0 feet lower today compared to when the Old Wyoming Dam was in place (Figure 14). Although barely perceptible given the flat valley, water surface gradients at the cemetery have also doubled since breaching of the dam, a finding consistent with observations by local residents that the river’s current increased when the dam was breached. Although the dam is over 3.0 miles downstream of the cemetery, the extremely low gradient of the river through this reach allowed water impounded behind the dam to back up several miles upstream. The hydraulic modeling did not extend above the backwater influence of the dam, so the total length of river impacted by the breaching of the dam is not known.

4.4 Historical Topographic Maps and Aerial Photographs

While no major changes in channel position were observed on historical topographic maps and aerial photographs, the emergence of and changes to the sand bar immediately upstream of the cemetery are evident (Figure 15). No sand bar was present immediately upstream of the cemetery in 1933 (Figure 15a). Given that sand bars are shown on the 1933 topographic maps in many other locations on the northern Connecticut River, a bar likely would have been shown if present near the cemetery. By 1955 a small sand bar is present at the site (Figure 15b), which became much larger by 1970 (Figure 15c). The river discharge at the stream gauge in Dalton, NH downstream of the site was 640 ft^3/sec on the date of the 1955 aerial photograph (July 20^{th}) and 2,640 ft^3/sec on the date of the 1970 aerial photograph (October 19^{th}). Consequently, the difference in sand bar size is not the result of variations in water surface elevation; for the same discharge as the 1955 aerial photograph, the sand bar on the 1970 aerial photograph would have appeared even larger. The upstream end of the bar in 1970 is located at and bends toward the mouth of a small side channel of the Upper Ammonoosuc River. Since 1970, the sand bar has diminished in size from the upstream end and a portion of the bar has become vegetated (Figures 15d and 16). The 2003 aerial photograph was taken in September when river discharge for the entire month was lower than on the date of the 1970 photograph such that the smaller size of the bar is not the consequence of a higher river level.

The pattern and timing of sand bar growth suggests the side channel of the Upper Ammonoosuc River is, at least in part, the source of sediment for the bar. The side channel is active only during large flow events and the first evidence of the bar in 1955 may be related to sand deposited at the mouth of the side channel during the large 1936 flood. Another large flood in 1969 related to the breaching of the Nash Stream Bog Dam in the Upper Ammonoosuc watershed likely reactivated the side channel and enlargened the bar as observed on the 1970 aerial photograph. [The impacts of the 1969 event on the Upper Ammonoosuc are discussed further in the tributaries report]. The reforestation of the side channel since 1970 (compare Figures 15c and 15d) is consistent with the absence of large floods on the Upper Ammonnosuc River. Without sediment supplied from the side channel, low to moderate flows on the Connecticut River have slowly eroded the upstream end of the bar for the past 35 years.

4.5 Causes of Erosion

The assessment steps described above enable a critical analysis of the causes for erosion at the cemetery. Sediment inputs from tributaries were identified as a significant cause for erosion on the northern Connecticut River during the 2004 fluvial geomorphology assessment (Field, 2004). Sand and gravel bars forming at the mouths of tributaries cause the flow to be deflected into the opposite bank where erosion occurs. The sand bar just upstream of the cemetery is causing flow to be deflected into the bank on the west (Vermont) side of the river and the resulting erosion has caused a slight bend in the river (Figures 16 and 17). Flow diverted around the bar in the opposite direction runs along the base of the eastern bank and may be responsible for erosion at the cemetery. The erosion may be enhanced as flow returning to a single channel at the downstream end of the bar is aimed directly at the cemetery bank (Figure 16). Given the high bank, bank recession due to erosion on the eastern side of the river would not be as pronounced as on the western bank. The start of the erosion in the 1970’s coincides with the maximum size of the sand bar when flow deflection around the bar would have been the most severe. The acceleration of erosion in the 1980’s, however, would not be expected as the bar diminished in size, so additional causes must be responsible for the cemetery erosion.

The acceleration of erosion at the cemetery in the mid-1980's began at approximately the same time the Old Wyoming Dam was breached. Dam removal, and the accompanying increases in water surface slope and flow velocities, could have generated channel incision. Lowering of the channel bed through incision would lead to the bank slumping observed throughout the modeled reach, including the cemetery. The high steep banks that are naturally susceptible to erosion would fail and collapse when undermined. Continued active erosion throughout the project reach suggests that the channel is still responding to the dam breach over 20 years ago.

4.6 Restoration Alternatives

Both flow deflection around the sand bar and response to the breaching of the Old Wyoming Dam continue to this day. Consequently, future slumping and bank recession at the cemetery should be expected. Six management options were considered for addressing bank erosion problems at the Northumberland Cemetery: do nothing; armor the base of the bank with large rock (riprap); remove the sand bar upstream of the cemetery; realign the channel into the abandoned side channel west of the river's current position; plant trees to revegetate the eroding slope; and construct an engineered log jam at the base of the eroding bank. A conceptual plan view design and list of pros and cons were developed for each option (Appendix 7). Although realigning the channel would remove the river from the base of the bank, this option was ruled out because of the great expense, likely technical and permitting difficulties, and the strong possibility for unintended consequences during river adjustment to the new channel position. Riprap would provide temporary bank protection but the rock could potentially be undermined by continued channel incision if not adequately keyed in below the channel bottom; keying in the rock would be prohibitively expensive and technically difficult in the deep water beside the cemetery. Previous attempts to revegetate the slopes have failed. The planted trees have slid down the slope before maturing because nothing was done to stabilize the base of the slope and prevent further slumping. While removing the sand bar would reduce flow deflection into the bank, this option would not address channel incision resulting from the breaching of the Old Wyoming Dam and would provide only short term benefits since the sand bar would likely reform during subsequent large flow events.

The favored option for managing the site is to combine the planting of trees with the construction of an engineered log jam. Log jams naturally form on the Connecticut River (Figure 18) and a mass of logs at the base of the slope should buttress the bank against future slumping. Slumps that do occur will be held back behind the logs, decreasing the slope angle and reducing the likelihood of additional slumps. If channel incision continues, the logs may settle downward but should continue to provide bank support. The log jam will decompose over a period of 10 to 30 years while the planted trees have had time to mature and sustain the bank stability initiated by the bioengineered structures. In addition to providing bank stability, the engineered log jams will provide cover habitat for fish and a substrate for aquatic insect colonization. Maturing trees on the slope will also improve habitat by shading the river and providing cover as mature and dieing trees fall into the river.

The primary difficulty in constructing an engineered log jam will be anchoring the logs to the bank. Unsecured logs will have a tendency to float downstream during a high flow with the potential for damage at the Northumberland-Guildhall Bridge. Funds are being sought to complete a detailed engineering analysis that will consider multiple options for securing the logs to the bank including: cabling the logs to large rocks placed on or buried below the channel bed; attaching the logs to metal sheet piling driven into the base of the bank; cabling the logs to log pilings driven vertically into the channel bed; or tying the logs off to large trees on the slope or at the top of the bank. The cost and structural stability of each option will be compared in order to achieve project goals at minimum cost.

5.0 CONCLUSIONS

Bank stabilization and restoration efforts are moving forward at the Colebrook Business Park and Northumberland Cemetery. The Town of Colebrook has received a Standard Dredge and Fill Permit to construct a bioengineering project along the low bank at the Business Park in Spring 2006 while further engineering and hydraulic analysis is conducted on the high bank and lower Mohawk River, respectively. Bioengineering of the low bank will serve as a demonstration project to illustrate bank stabilization techniques that can be used elsewhere in the northern Connecticut River watershed. Erosion hazard maps and an accompanying explanatory brochure to be distributed to 16 towns (Table 1) on January 12, 2006 will further assist these municipalities identify the location, cause, and most appropriate remedy for erosion problems at specific points along the river.

The results of a detailed assessment of bank instability at the Northumberland Cemetery indicate that erosion likely began with flow deflection around a sand bar that grew in size after the 1969 failure of the Nash Stream Bog Dam in the Upper Ammonoosuc watershed. Despite the diminishing size of the sand bar, the erosion has accelerated and been sustained by an increase in water surface slope and flow velocity associated with the breaching of the Old Wyoming Dam downstream (Figure 13). Among multiple restoration options, the construction of an engineered log jam at the base of the bank in conjunction with tree planting on the eroding slope is considered the best approach for improving bank stability. An engineered log jam will mimic natural processes, buttress the bank against further slumping, and improve aquatic habitat. Assuming future funding is secured, bank stabilization efforts on the northern Connecticut River will continue with implementation of a bioengineering project on the low bank at the Colebrook Business Park and development of final engineering designs for the high bank at the Business Park and Northumberland Cemetery. With completion of these bank stabilization efforts, multiple demonstration projects will be available to illustrate sustainable restoration options for towns throughout the northern Connecticut River Valley.

6.0 REFERENCES

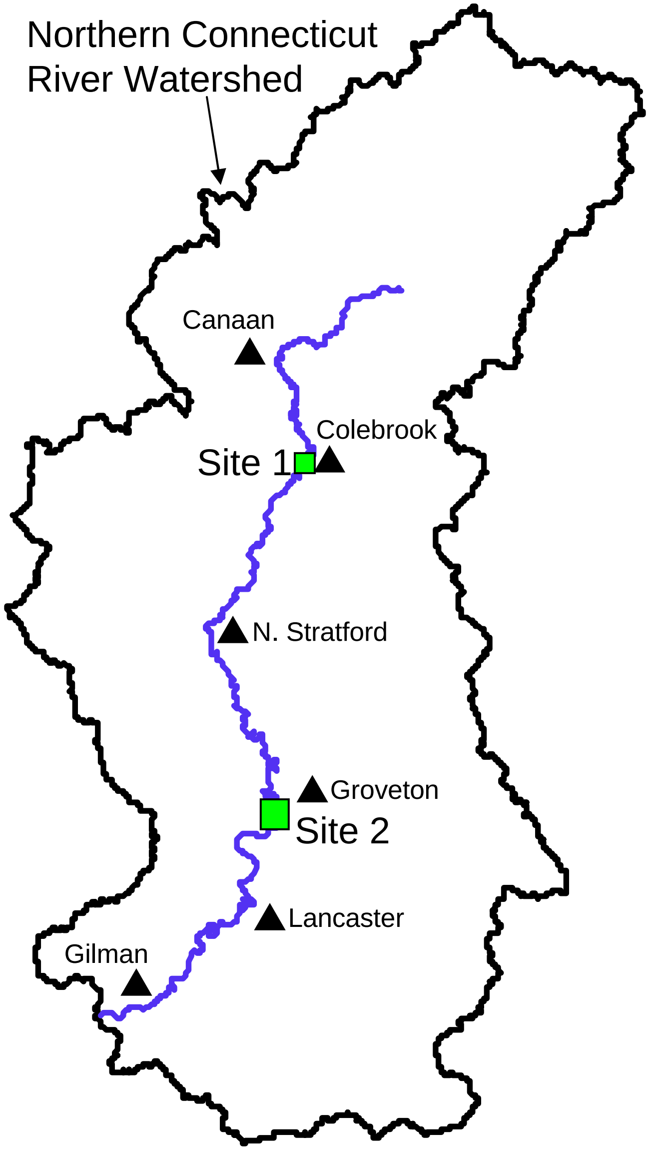
Field, J., 2004, Fluvial Geomorphology Assessment of the Northern Connecticut River: Unpublished report submitted to the Connecticut River Joint Commissions.

US Army Corps of Engineers, New England District, 2002, Connecticut River Ecosystem Restoration, New Hampshire and Vermont: Expedited Reconnaissance Report, Section 905(b) (WRDA 1986).

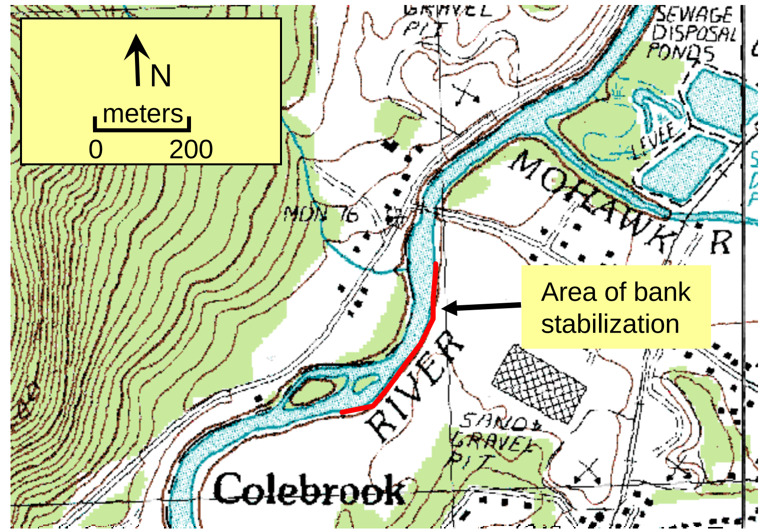
Table 1. Towns in Vermont and New Hampshire for which erosion hazard maps were made

Vermont	**New Hampshire**
Bloomfield	Clarksville
Brunswick	Colebrook
Canaan	Columbia
Guildhall	Lancaster
Lemington	Northumberland
Maidstone	Pittsburg
Lunenburg	Stewartstown
	Stratford
	Dalton

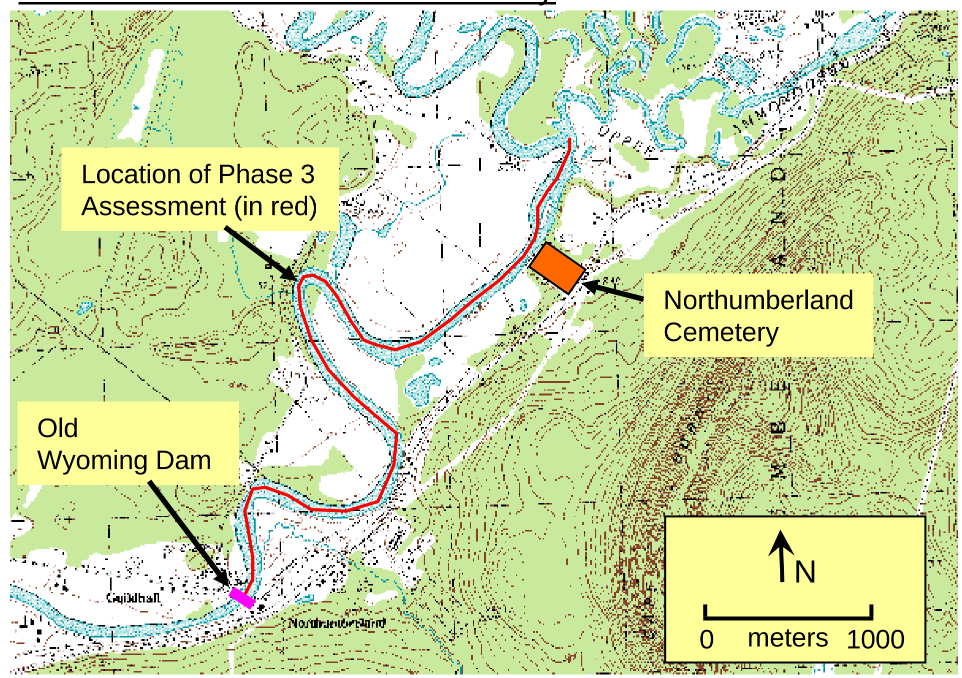
Project Location Map



Site 1 – Colebrook Business Park



Site 2 – Northumberland Cemetery



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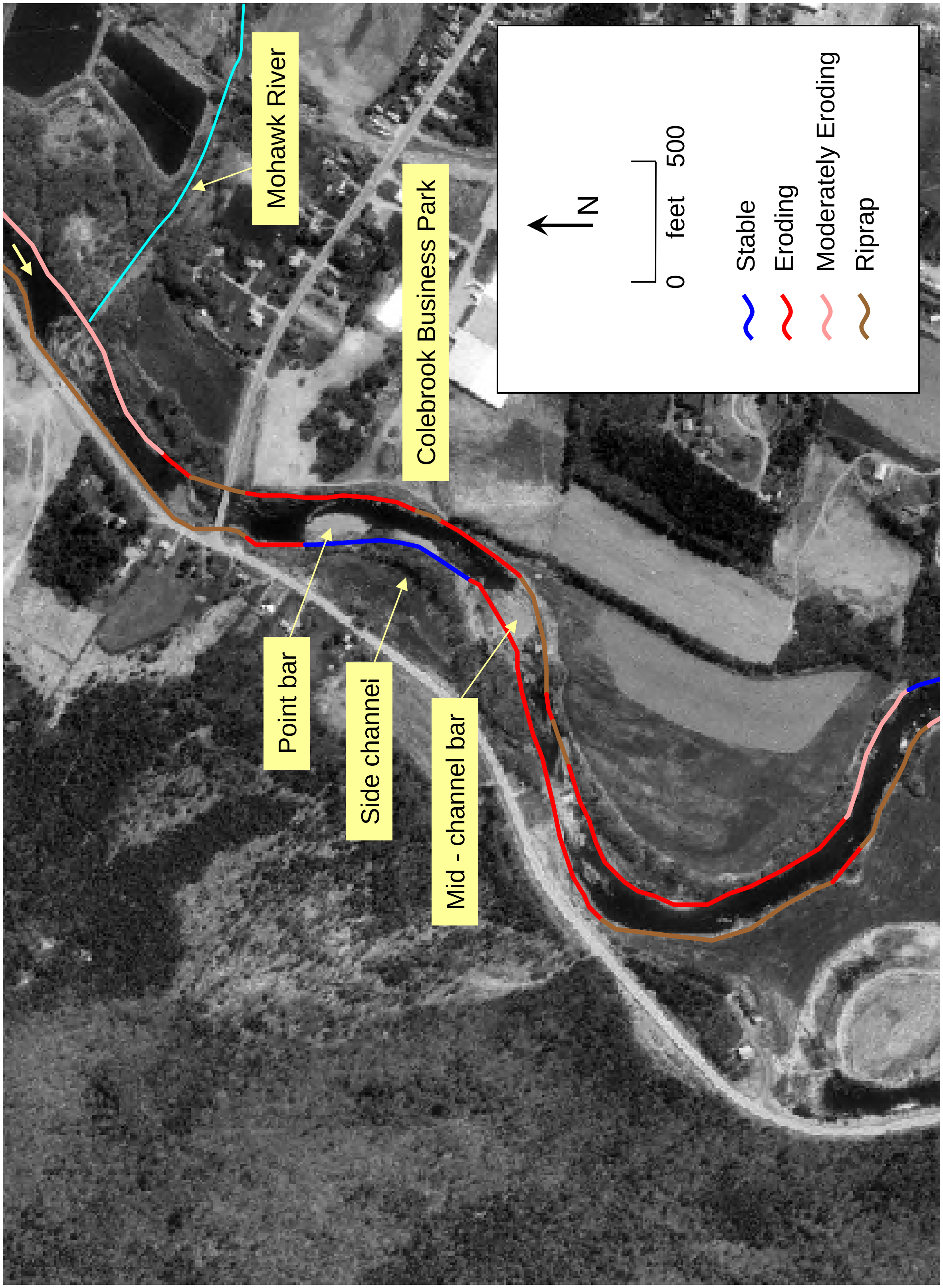
Bank Stabilization Implementation and Assessment – Figure 1

Bank Erosion at Colebrook Business Park

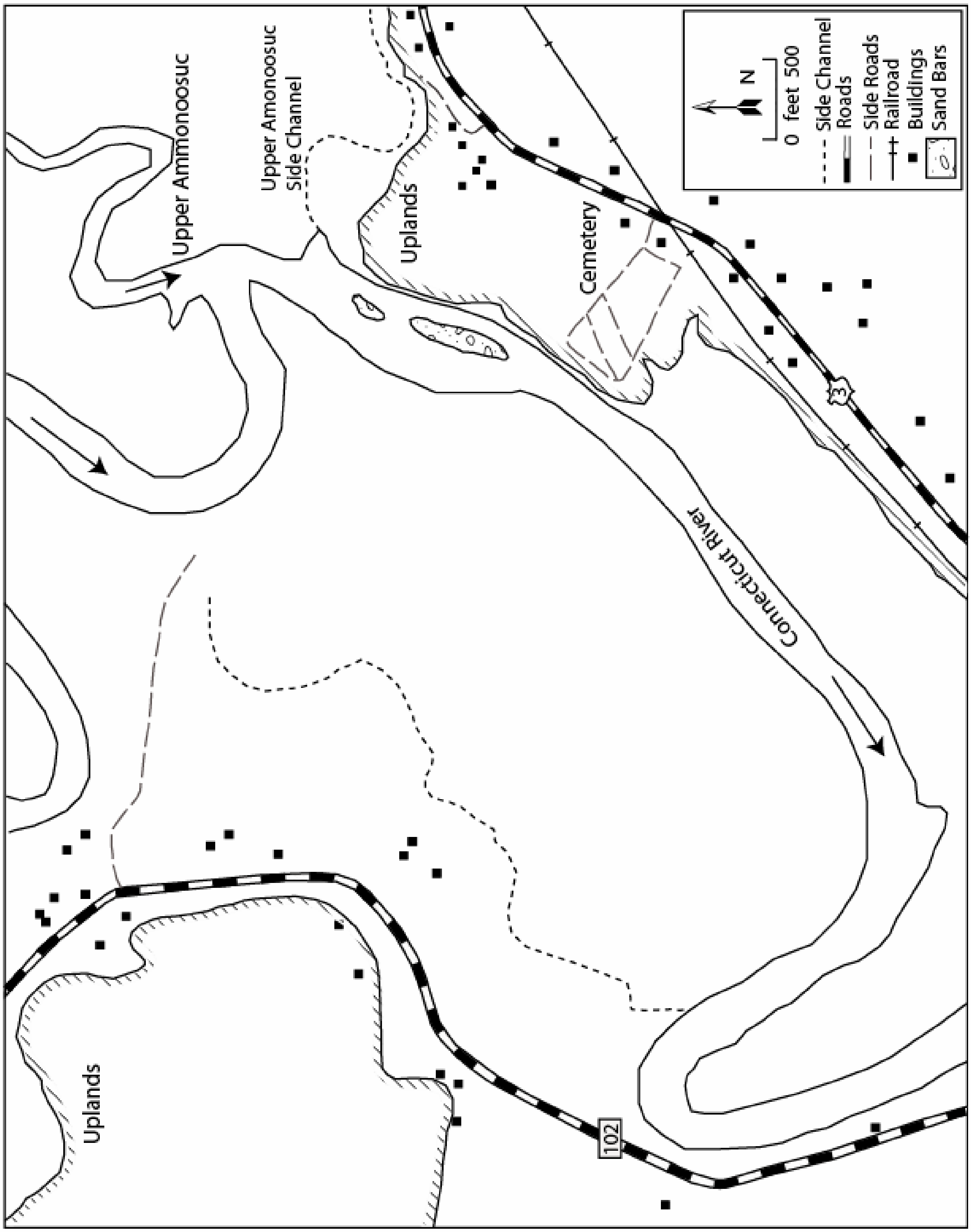
Note: High bank is just upstream of low bank

Relationship of Colebrook Business Park to the Mohawk River



Bank Stabilization Implementation and Assessment – Figure 3

Northumberland Cemetery - Overview



Bank Stabilization Implementation and Assessment - Figure 4

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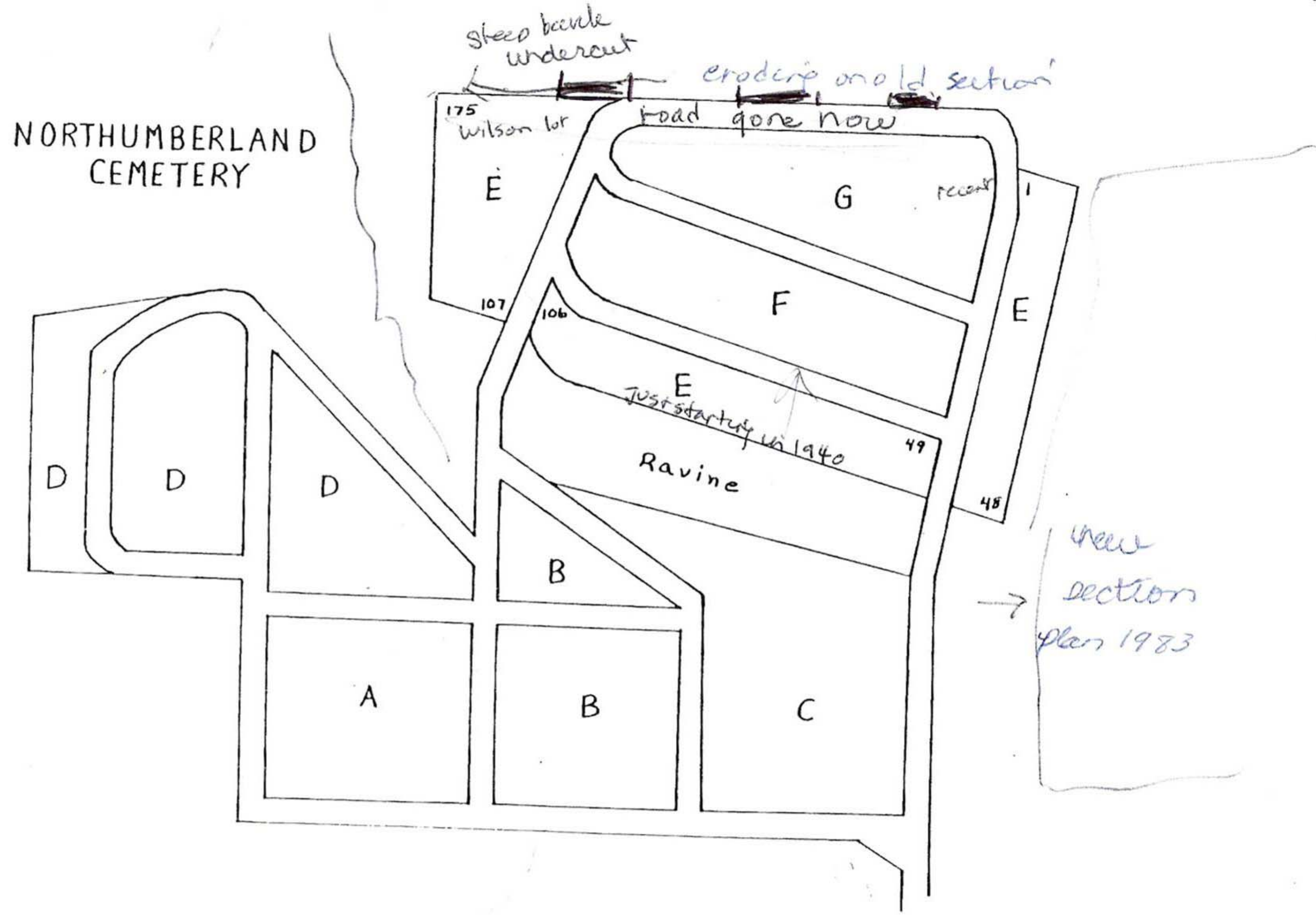
Erosion at the Northumberland Cemetery

Note: photograph from the November 11, 2005 edition of the Caledonian Record

Map of Northumberland Cemetery



Bank Stabilization Implementation and Assessment – Figure 6

Shallow Slump at the Northumberland Cemetery

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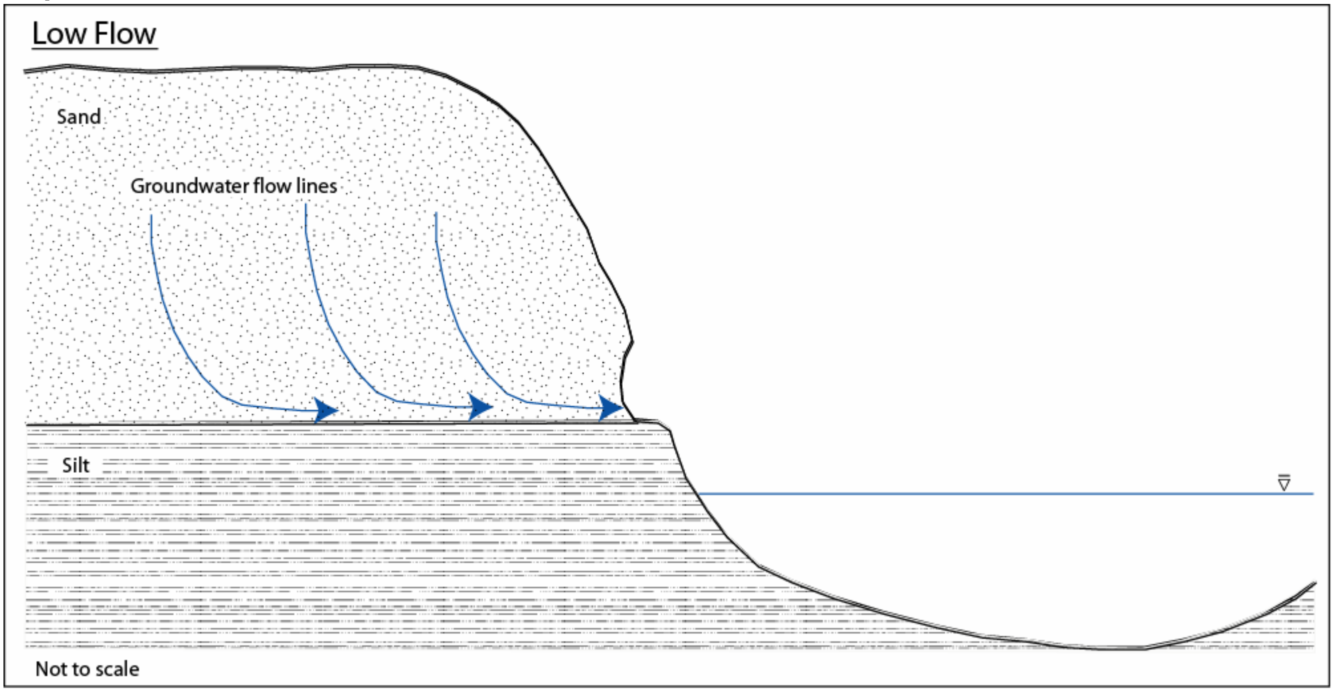
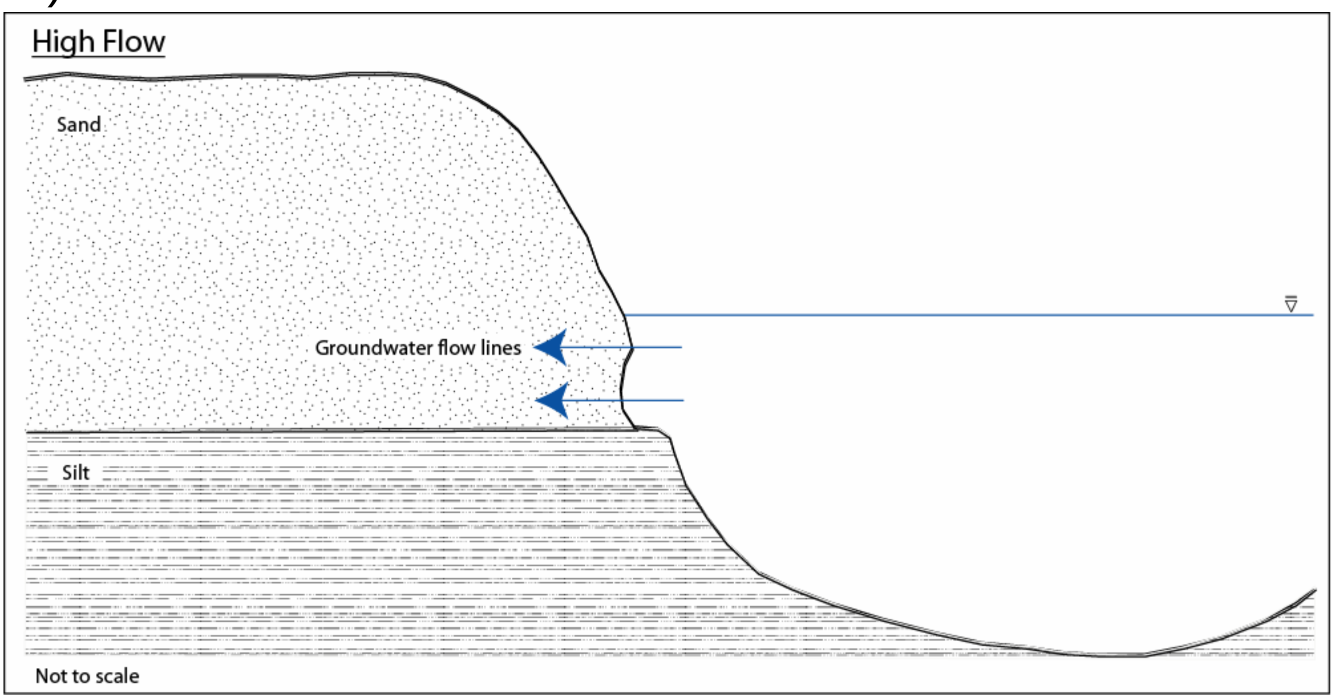
Bank Stabilization Implementation and Assessment – Figure 7

Bank Stratigraphy at the Northumberland Cemetery

a)

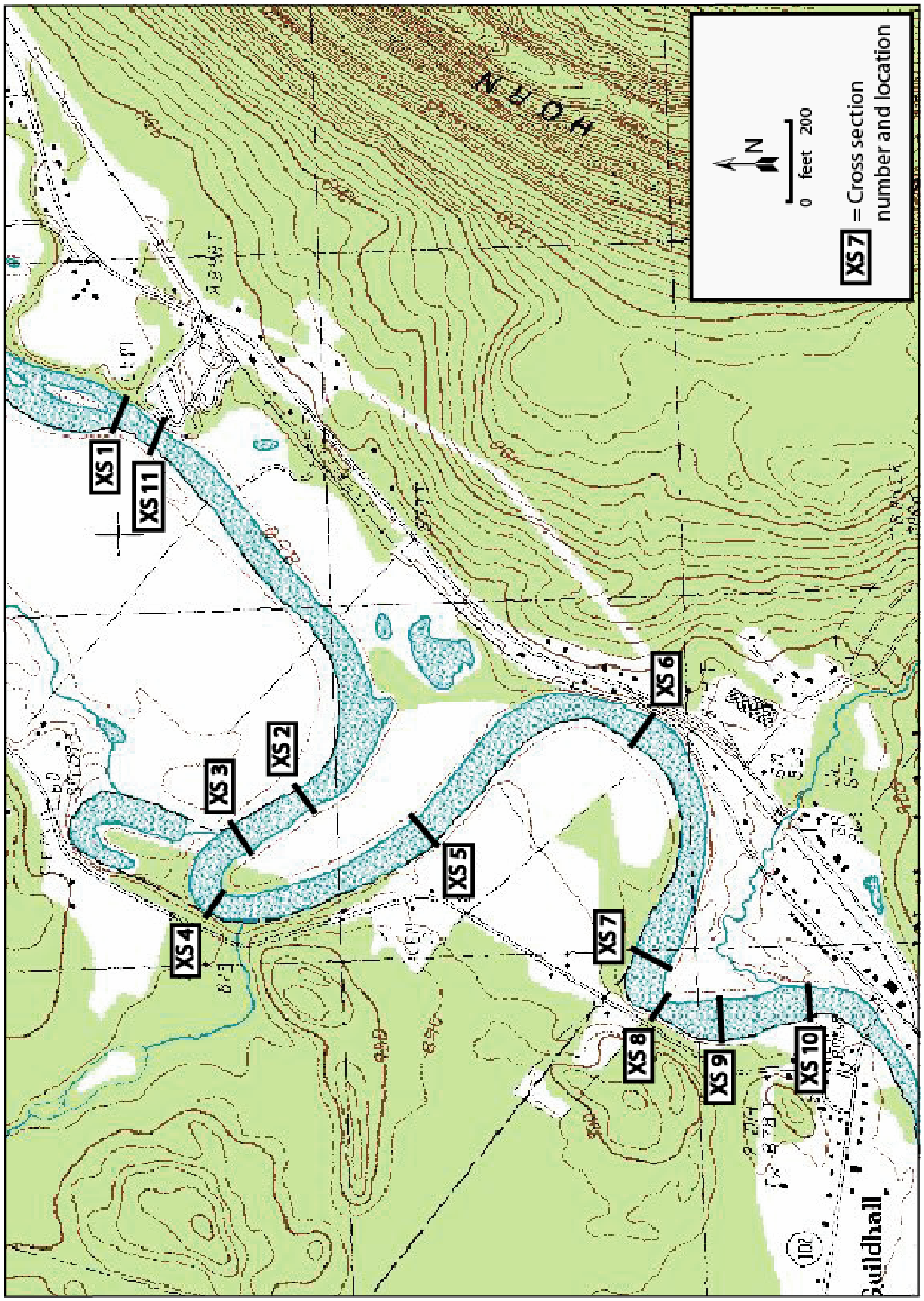


b)



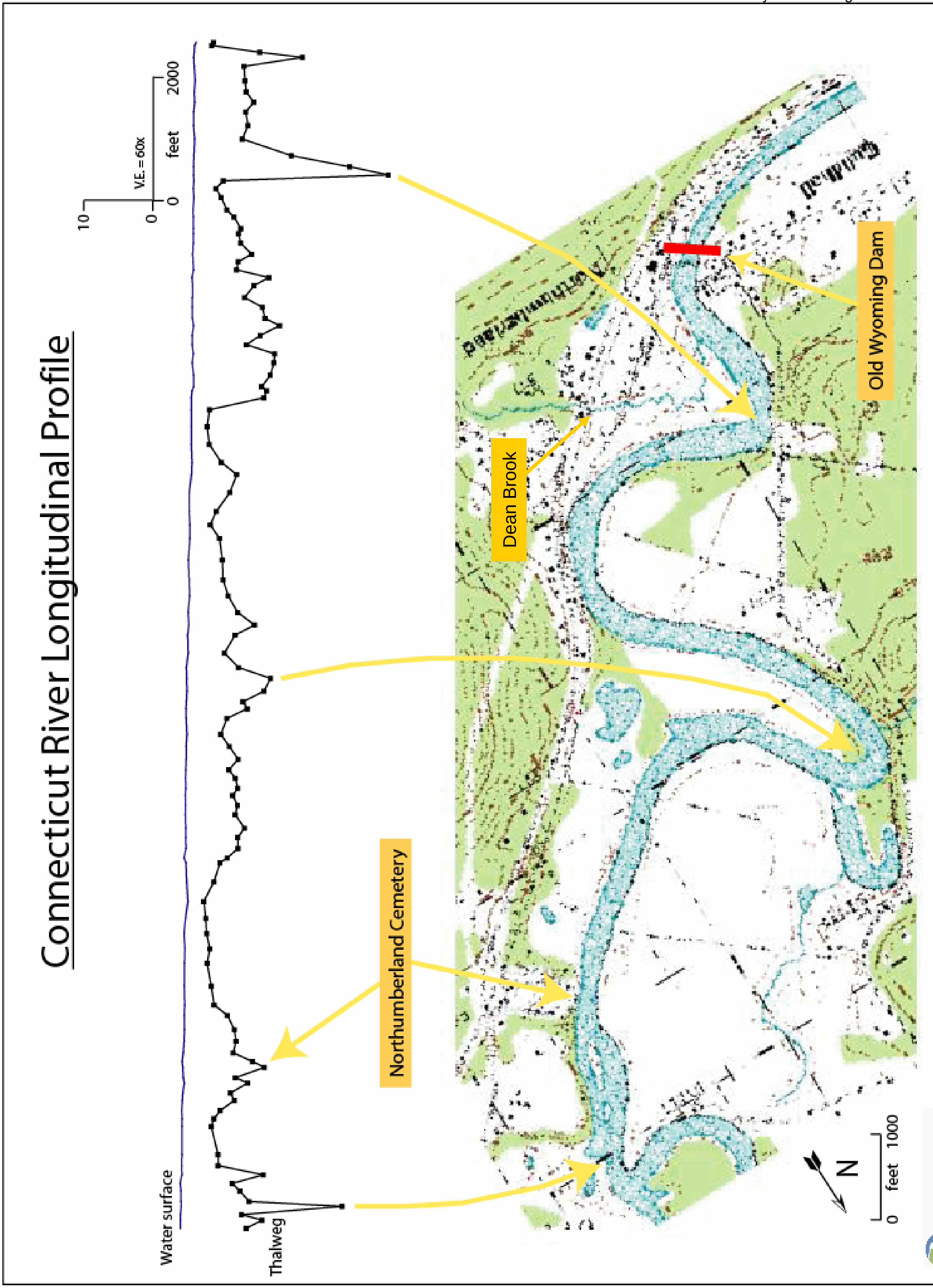
Eroding Bank Upstream of the Old Wyoming Dam

Location of Connecticut River Cross Sections



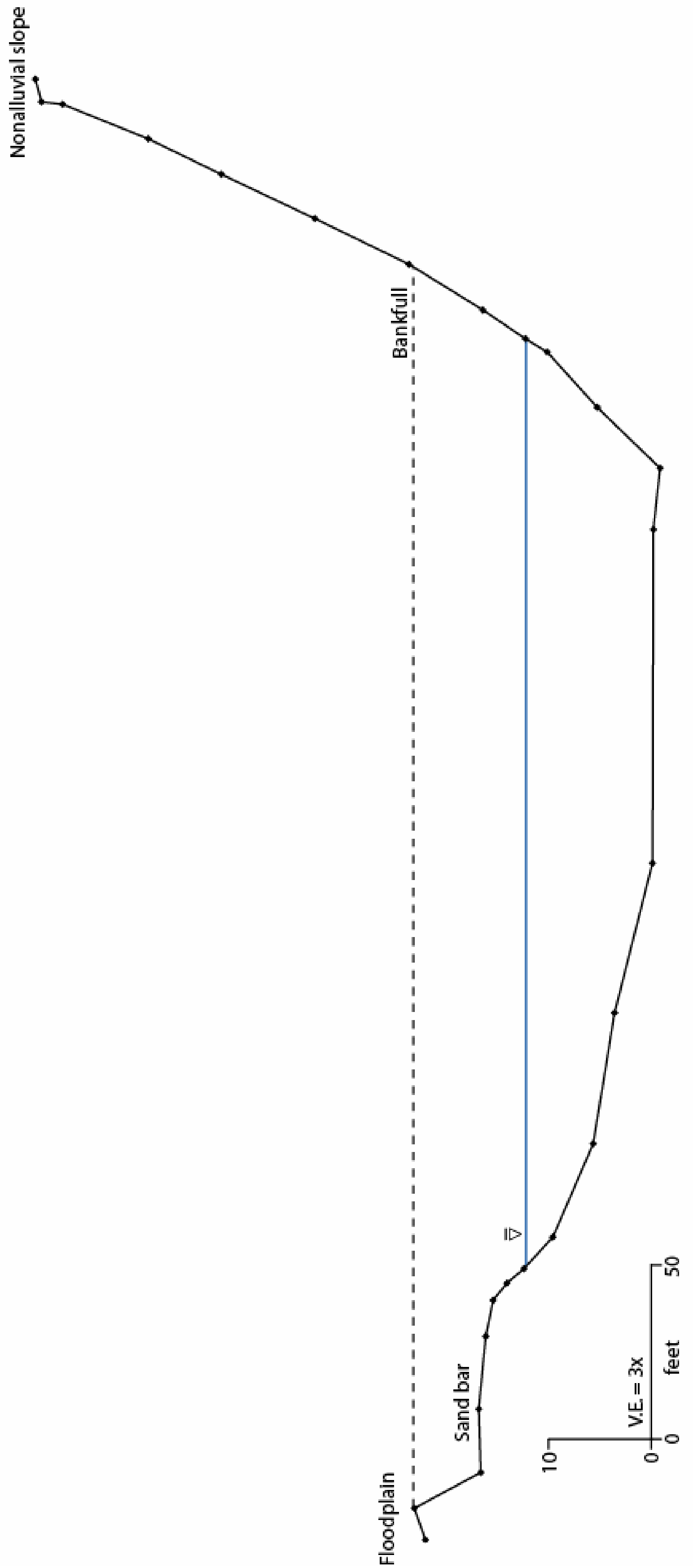
Bank Stabilization Implementation and Assessment - Figure 10

Field Geology Services



Bank Stabilization Implementation and Assessment – Figure 11

Connecticut River Cross Section



Bank Stabilization Implementation and Assessment – Figure 12

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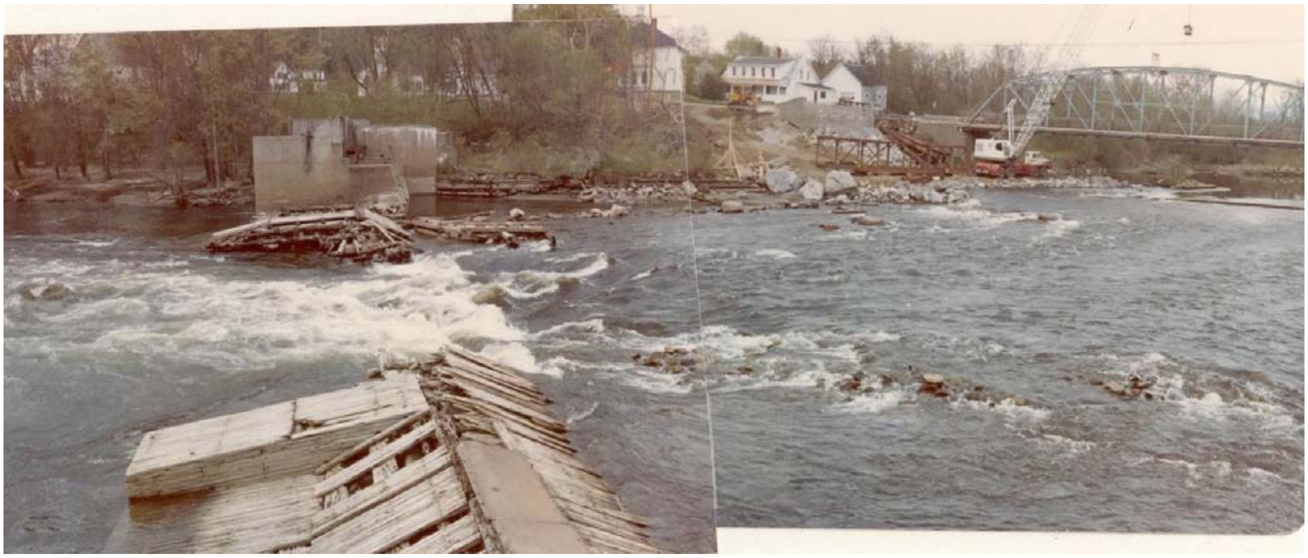
Changing Condition of the Old Wyoming Dam

a) 1936

b) 1984



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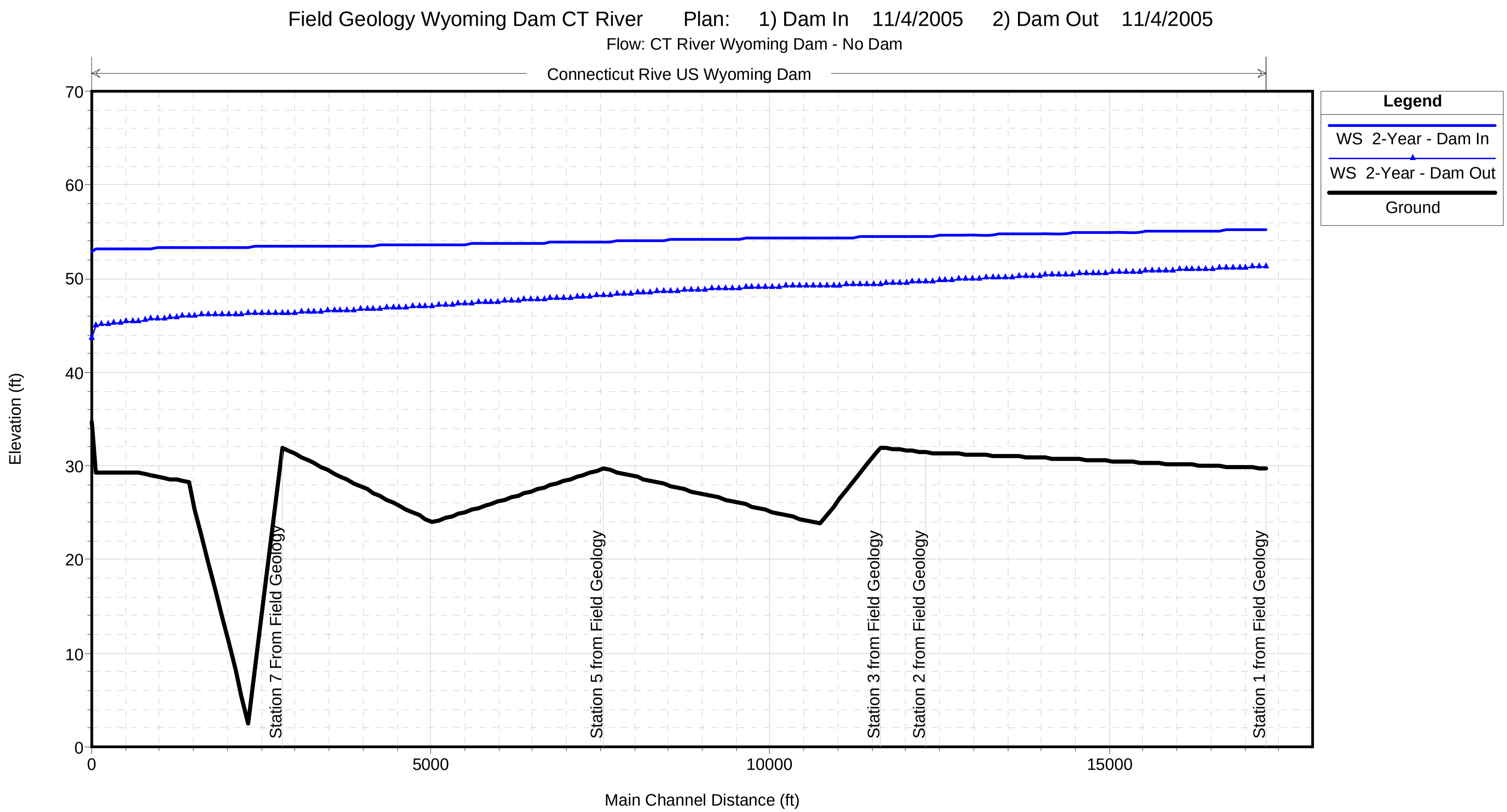
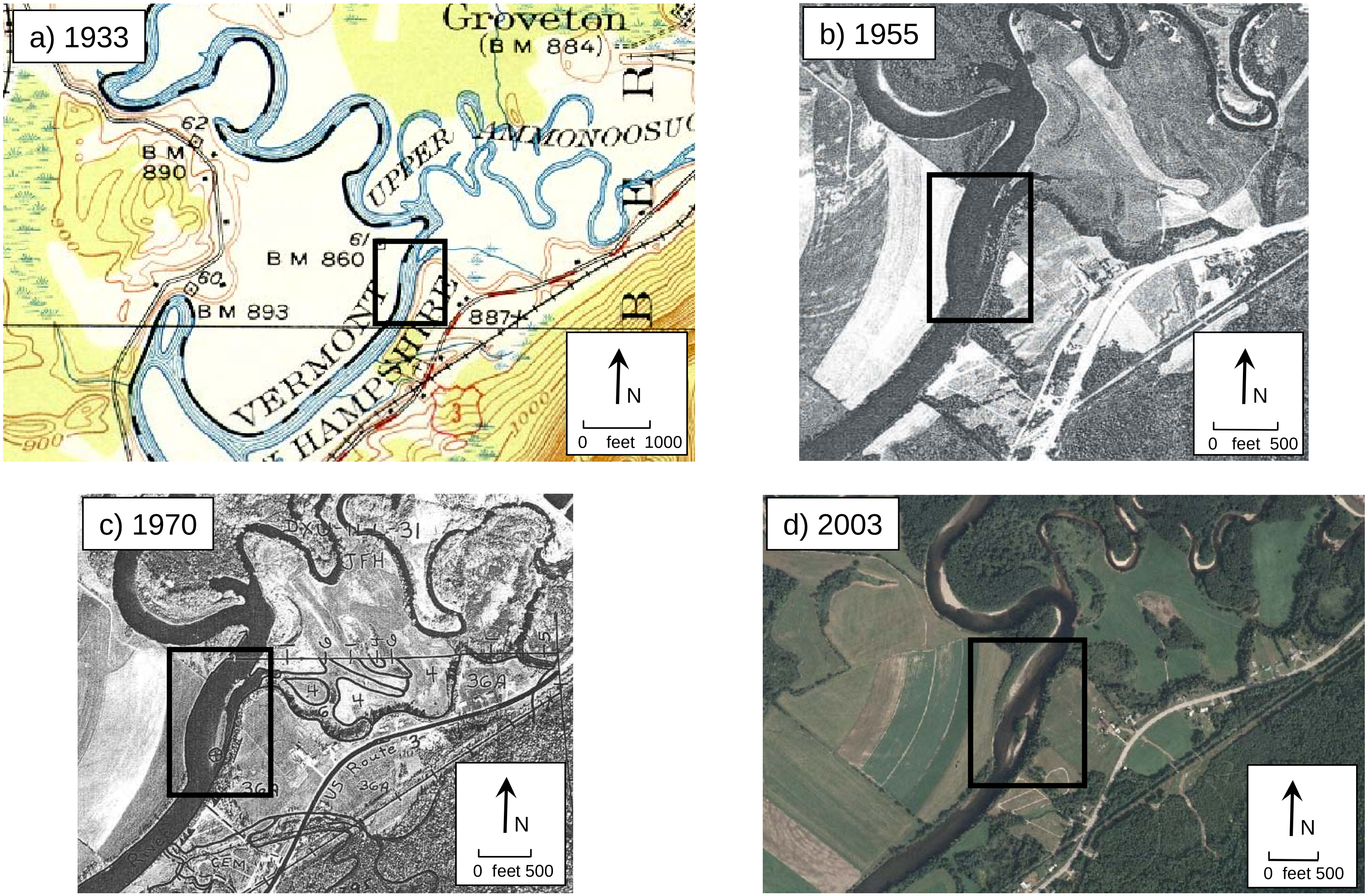
Bank Stabilization Implementation and Assessment – Figure 13

Computed Water Surface Profile for 2-Year Event



Note: Old Wyoming Dam at left margin of graph. Station numbers are same as cross sections shown in Figure 8 with Station 1 at Northumberland Cemetery.

Changes to Sandbar Upstream of the Northumberland Cemetery

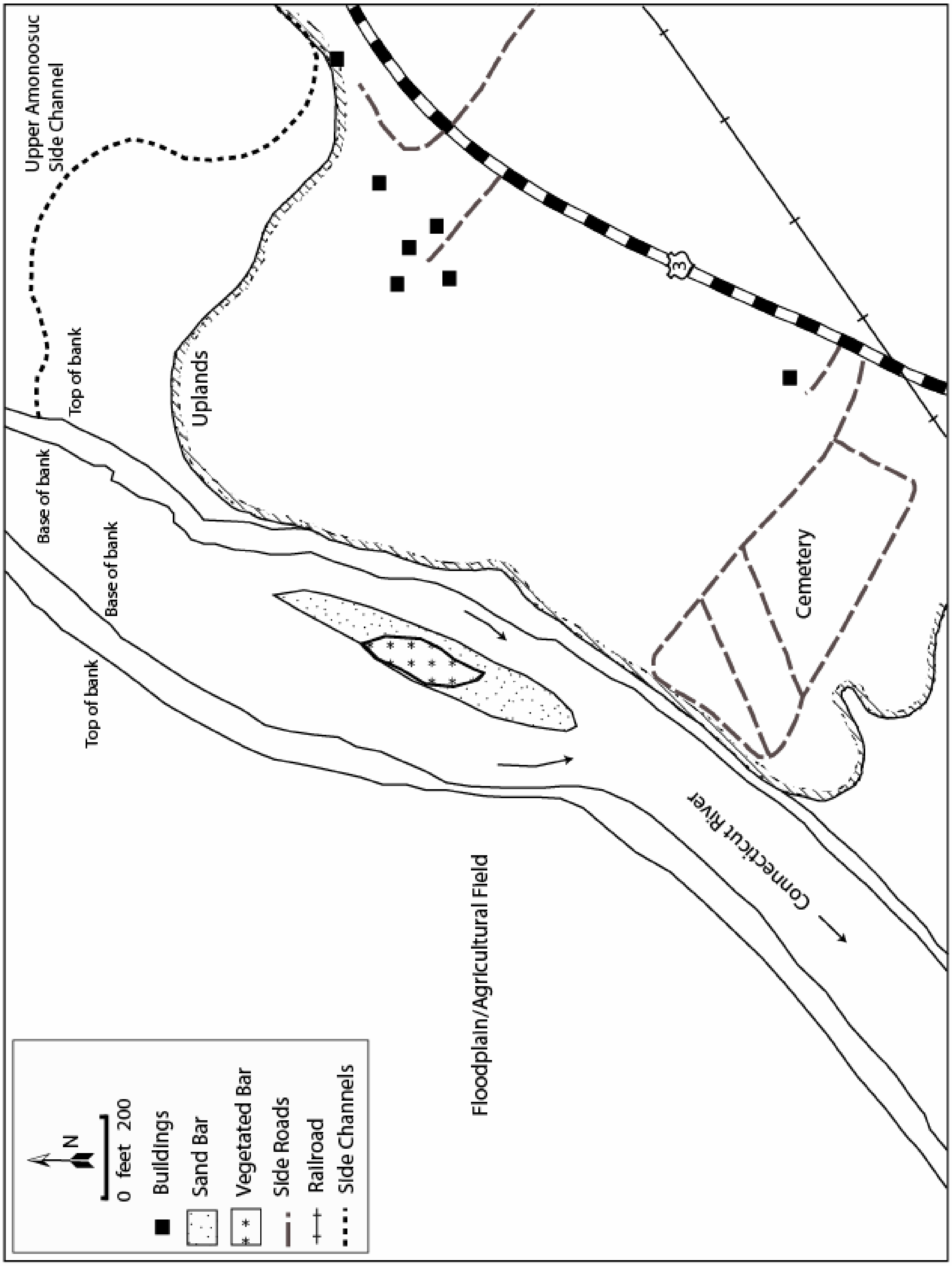


Note: Black box in each photograph surrounds location of sand bar discussed in text

Field Geology Services
Fluvial Geomorphology

Bank Stabilization Implementation and Assessment – Figure 15

Northumberland Cemetery - Close-up



Bank Stabilization Implementation and Assessment - Figure 16

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Erosion on Vermont Side of River Opposite the Cemetery

Note: Photograph taken from top of bank at cemetery with sand bar at center right of photo

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Naturally Occurring Log Jam on the Connecticut River

Note: Located just upstream of the Upper Ammonoosuc River confluence

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Bank Stabilization Implementation and Assessment – Figure 18