Development of River Corridor Mapping Procedure with Initial Application in the North River Watershed, MA

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April 2018

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EXECUTIVE SUMMARY

Tropical Storm Irene in 2011 was the latest of numerous floods that have caused extensive damage in Massachusetts. In the wake of Tropical Storm Irene, an effort is being made to develop an approach to identify flood and erosion hazards and to take steps, where possible, to reduce those hazards prior to the next flood event. Existing methods for assessing hazards are time consuming, expensive, and require significant expertise to undertake. To provide an approach for identifying flood and erosion hazards that communities throughout Massachusetts can complete on their own with limited financial commitment and training, a protocol for delineating the river corridor, the area on the floodplain within which river erosion and channel migration are most likely to be contained during future floods. The protocol takes a conservative approach to delineating the corridor by first assuming the river can potentially impact the entire valley bottom and then restricted to narrower areas where elevated river terraces constrain river migration and restricted even further if physical evidence of past channel positions indicate channel migration is restricted to only a portion of a wide floodplain. Zones of special concern where bank erosion and channel migration are more likely to occur can be highlighted along portions of the corridor 1) adjacent to artificially straightened channels prone to reforming meanders, 2) upstream of valley constrictions where impounded flood flows can cause rapid deposition and consequent channel migration; and 3) downstream of large tributary confluences where sudden influxes of sediment can result in severe bank erosion and channel migration.

The river corridor mapping protocol was tested on the North River, a tributary to the Deerfield River, that experienced severe damages during Tropical Storm Irene, has been the site of three previous geomorphic assessments, and is the focus of several ongoing restoration and bank stabilization projects. The river corridor maps produced using the protocol demonstrate that where the floodplain is narrow the corridor's boundaries are defined by the valley wall and river terraces as evidence for former channel positions extends across the entire floodplain. Compared to the other three geomorphic assessments completed in the North River Watershed since Tropical Storm Irene, the corridor mapping protocol is the most effective approach for identifying the extent of potential bank erosion and channel migration and for highlighting areas with the greatest likelihood for rapid channel adjustments. The limited effort, financial investment, and training required to complete the protocol makes the approach particularly accessible to small riverine communities throughout Massachusetts with a great need to complete hazard assessments but with limited resources to conduct extensive technical studies. While the corridor protocol merely identifies the location of potential hazards, the resulting river corridor maps provide an excellent first step towards 1) building recognition among landowners and other community members for the need to address fluvial hazards prior to the next flood, 2) securing funding from resource agencies for implementing restoration projects that will reduce the extent and severity of the identified hazards, and 3) engaging land trusts and other non-profit organizations interested in protecting hazardous lands from future development.

1.0 INTRODUCTION

This report describes the development of a river corridor mapping protocol based on the science of fluvial geomorphology that will allow riverine communities in Massachusetts to relatively easily and inexpensively delineate areas prone to flood and erosion hazards. The North River Watershed in Franklin County, MA (Figure 1) was used to test the methodology and compare the results with other geomorphic assessments recently completed in the watershed to identify the advantages and disadvantages of the various methods. The work presented here was completed with funding provided through a Land Conservation District Innovation Grant received by the Franklin Conservation District from the Massachusetts Executive Office of Energy and Environmental Affairs. The report is subdivided into the three sections presented below: 1) development of protocol for river corridor delineation; 2) North River corridor delineation; and 3) comparison of river corridor delineation protocol with other geomorphic assessment approaches.

2.0 PROTOCOL FOR RIVER CORRIDOR DELINEATION

Before detailing the protocol for river corridor delineation, a definition of “river corridor” is provided and the need, purpose, and value of river corridor delineation described.

2.1 Defining the river corridor

The definition and delineation of the river corridor can vary to some degree depending on whether the application is based on ecological or geomorphic principles. For this study, with a hazard assessment focus, the river corridor is defined as the area of the valley bottom and floodplain across which the river migrates over time in order to develop and sustain an equilibrium condition where changes in the channel’s dimensions, planform, and gradient are minimized. The river channel occupies only a small portion of the river corridor at any one time but through time the channel may migrate across the entire corridor. Channel migration results when sediment is deposited on the inside of a river bend, forcing flow to the outer bank where erosion occurs. In an equilibrium condition, the amount of deposition on the inside of the bend is balanced by an equal amount of erosion on the opposite bank such that the channel dimensions remain constant even as the channel migrates. The river corridor encompasses the area within which this migration is expected to occur over time with the edge of the corridor thus demarcating the outer limits of where bank erosion, channel migration, and other fluvial hazards are likely to occur (Figure 2). Where the river’s position is constrained by human alterations in the channel or on the floodplain (i.e., riprap, channel straightening), rapid channel changes are possible that can manifest during large floods as severe bank erosion or new meanders carved across the floodplain. Those changes will, however, largely be contained within the river corridor and the severity of those changes will tend to diminish over time as the river establishes an equilibrium condition within the river corridor.

In many instances, a river channel's position is largely fixed on one or both banks by natural features (i.e., river or glaciogenic terraces, valley wall) where the development of an equilibrium condition is greatly inhibited by the natural constraints such that rapid changes may persist for millennia in the form of large mass failures (off of the high river banks) and high sediment loading downstream. The outer edges of the river corridor in these settings is fixed at these natural constraints such that the width of the river corridor, so defined, is not much wider than the river channel itself in narrow gorges (Figure 2). As described further below in Section 2.3, an optional 50-foot buffer can be created along the edge of the river corridor defined by high banks when the river channel is located at or near the river corridor boundary in recognition that mass failures or rapid bank erosion can cause the corridor boundary to recede tens of feet in a single flood (Figure 3).

2.2 Need, purpose, and value of river corridor delineation

Severe floods in Massachusetts have caused significant damage along the commonwealth's rivers for centuries. Tropical Storm Irene in 2011 was the most recent example, with damages in the Deerfield Watershed particularly severe, and has galvanized interest in identifying hazard-prone areas, so pre-disaster measures can be taken to reduce potential damages and improve emergency response preparedness in advance of the next large flood. Federal Emergency Management Agency Flood Insurance Rate maps (known as FEMA FIRM maps or simply FEMA flood maps) show areas at risk of flood inundation during a 100-yr flood (i.e., flood with a 1 percent chance of occurrence in any given year), but, as Tropical Storm Irene demonstrated, severe erosion can occur beyond the limits of the mapped FEMA flood zones (Bent et al., 2015). In contrast, river corridor maps demarcate the potential location of severe erosion, a typically far more dangerous hazard than inundation that can lead to significant property damage, bodily injury, and death. While FEMA flood maps and river corridor maps are often largely congruent, severe erosion hazards, although contained within the delineated river corridor, can sometimes fall outside of FEMA flood zones. Similarly, flood inundation as depicted on FIRMs can extend beyond the limits of the river corridor where the floodplain is very wide.

The purpose of the work reported on here is to offer an approach for delineating the river corridor – the area within which bank erosion, channel migration, and other fluvial hazards will most likely be contained in subsequent floods. The river corridor maps are not intended as, nor should they be construed to be, a replacement for FEMA flood maps. The river corridor maps instead complement FEMA flood maps by providing information on the location of certain hazards (i.e., erosion) that are not even considered by the FIRMs and, thus, can be an important complement to FEMA maps where erosion is known to be a major problem. The river corridor delineation protocol detailed in Section 2.3 will be particularly valuable to riverine communities throughout Massachusetts because physical features observable on maps or on the ground are used to establish the corridor boundaries. Consequently, limited training, materials, or financial commitment is required to complete the process. Furthermore, the community at large is more likely to accept the results when certain physical features (i.e., an abandoned channel) can be highlighted to explain why the corridor's boundary is placed at a certain location. The end product of the delineation process, the river corridor maps, show which roads, homes, land parcels, and other points of interest fall within the corridor and are, therefore, potentially at risk during a future large flood event. Potential users of such maps include, but are not limited to, landowners considering where to build new structures on their land, emergency response personnel wanting to preposition supplies in areas most likely to suffer damages, and land trusts interested in purchasing lands to limit future development in hazardous and ecologically sensitive areas.

2.3 River corridor delineation protocol

The river corridor delineation protocol is based on physical features observed on topographic maps, aerial photographs, and other remote sensing data that are subsequently ground-truthed in the field. The relatively simple two-page six-step protocol for producing river corridor maps is detailed in the *Corridor Mapping Procedures* (Appendix 1). The companion *Corridor Mapping Guidance* (Appendix 2) provides further information on completing the six steps, although the *Corridor Mapping Procedures* is considered a stand-alone document sufficient to create river corridor maps for users already familiar with the protocol or the associated background information. The protocol can be completed with limited training and knowledge in geomorphology and fluvial processes, but familiarity with using and interpreting topographic maps and aerial photographs is beneficial. The maps can be completed on paper, although will be of greater utility for users with GIS resources.

After gathering topographic maps, aerial photographs, and other resources (e.g., LiDAR, DEMs), the sharp slope break between the valley floor and valley wall in the area of interest is delineated to identify the outermost possible boundaries of the river corridor (Step 2). The river's movement would be arrested by the high side slopes of the hills or mountains bordering both sides of the valley if the channel were to migrate that far. Subsequent steps in the protocol use other physical evidence to further refine the corridor's boundaries to a narrower portion of the valley bottom. Step 3 of the protocol identifies river terraces and other high surfaces (e.g., glacial kames) whose high banks sloping down to the floodplain, known as a terrace riser (Figure 4), are delineated because these risers also represent a barrier to rapid channel migration. The remaining low valley bottom area between terrace risers (or valley side slopes where no terraces are present) on either side of the valley, in general, represents the floodplain across which the river flows. To determine if the river corridor occupies the entire floodplain or just a portion of it, evidence for former positions of the river channel, in the form of oxbows and other abandoned flow paths, are identified and the outermost limits of such evidence delineated as the corridor boundary (Step 4). Where the floodplain is narrow, the evidence for former channel positions will usually extend to the edge of terraces on the valley bottom (or to the valley wall where terraces are absent) and, therefore, no further refinement of the corridor's boundaries are needed as the edge of the terrace risers (Figure 2, Section B-B') or valley wall (Figure 2, Section C-C') are congruent with the outermost evidence of former channel positions. On wide floodplains, the evidence of former channel positions may occupy only a portion of the floodplain and the river corridor's boundaries are delineated at the outermost evidence of these former flow paths

(Figure 2, Section A-A'). In some cases, the river corridor may be defined differently on each side of the river with, for example, a terrace riser representing the corridor boundary on one side of the river while the outermost evidence of channel migration defines the corridor's boundary on the opposite side.

The river corridor is thus delimited within areas where physical evidence indicates the river has been in the past or, absent such evidence, within areas where the river's movement is unconstrained by higher terrace risers or valley side slopes. Delineating the river corridor in this manner represents a conservative approach as the corridor, at first, is assumed to extend across the entire valley and is limited to a narrower portion of the valley only if river terraces or other higher surfaces are identified on the valley bottom and still further only if the outermost evidence of former channel positions extends across just a portion of the floodplain. Only with available physical evidence is the corridor limited to an area narrower than the valley bottom. Given that terraces may not be present along the entire length of the valley and that the width of the floodplain can vary considerably, the corridor's boundary may be defined by the valley wall in some places, terrace risers in others, and the outermost evidence of former flow paths in still others (Figure 2). The final corridor boundary, therefore, may consist of an amalgamation of these three circumstances with the innermost (i.e., that closest to the river) of the three delineated features (i.e., valley wall, terrace risers, and outermost position of former flow paths) taken as the boundary of the finalized river corridor.

Not all areas within the delineated river corridor should be considered at equal risk of rapid channel migration or bank erosion. Such dramatic changes are more likely to occur in areas upstream of valley constrictions, along artificially straightened channels, or near the confluence of large tributaries where large volumes of sediment can be input during floods (see Appendix 2 for further explanation). Step 5 of the corridor delineation protocol highlights these areas within the corridor, representing zones of special concern where changes are not only more likely to occur but are likely to be more severe than other portions of the corridor. Recognizing that large mass failures can occur along high slopes where the river impinges directly against a terrace riser or valley side slope, an optional 50 ft buffer can be added where the river is currently within 50 ft of the edge of the corridor boundary and, thus, more likely in the near term to migrate against the corridor's outer edges. A distance of 50 ft is selected, because greater recession of the corridor boundary during a single mass failure is, although possible in rare situations, highly unlikely in Massachusetts. In addition, confined portions of the river where no, or limited, floodplain is present are rated as zones of moderate risk for rapid change given potential for large mass failures to alter the river's flow path by delivering large volumes of sediment in a short period of time. Such confined areas are considered less likely to be sites of rapid change than valley constrictions, straightened channels, or tributary confluences so are assigned a slightly lower risk rating (i.e., moderate vs. high risk). The final step of the corridor delineation process is to verify the accuracy of the corridor maps through field visits to various locations to confirm that interpretations from the topographic maps, aerial photographs, and other remote sensing data are accurate (Step 6).

3.0 NORTH RIVER CORRIDOR DELINEATION

The North River was selected to test the river corridor delineation protocol presented in Section 2.3 above, because the severe damages along the river during Tropical Storm Irene (Figure 5) resulted in considerable post-flood emergency work (Figure 6), subsequent river restoration (Figure 7), and at least three previous geomorphic assessments (NEE and MGS, 2013; Field, 2015; Milone and MacBroom, 2017). In addition, Trout Unlimited and the Franklin Land Trust are actively seeking restoration and conservation opportunities in the West Branch Watershed as the Connecticut River Conservancy pursues several bank stabilization projects on the mainstem and East Branch. Consequently, the river corridor maps developed for the North River (Appendix 3) may prove useful for ongoing and future work in the watershed while providing an opportunity to compare the corridor delineation protocol (Appendix 1) with the previously completed geomorphic assessments in the watershed (see Section 4.0 below).

The river corridor maps (Appendix 3) developed using the corridor mapping protocols (Appendix 1) cover the mainstem, East Branch, and most of the West Branch of the North River for a total of approximately 20 river miles. In addition to topographic maps and aerial photographs, LiDAR of the area also proved useful in identifying the location of terraces and former channel positions. Given the narrow valley, all of the corridor’s boundaries are defined by river terraces, other elevated surfaces on the valley bottom, or the valley wall as evidence of past river positions extends across the entire floodplain even at its widest portions along the mainstem. Essentially the entire corridor is designated as moderate or high risk areas given the presence of confined areas, numerous valley constrictions and tributary confluences, and artificially straightened reaches constituting over 70 percent of the length of the mainstem and East Branch (Field, 2015). Straightened channels are prone to the rapid reformation of meanders across the floodplain during floods (Field, 2007) as was the case during Tropical Storm Irene (Figure 8). At valley constrictions floodwaters are impounded during large flow events, potentially causing rapid deposition and associated channel migration. Rapid input of sediment at tributary confluences during floods can cause bank erosion and channel migration downstream as the sediment is transported downstream. Field verification confirmed the position of the river corridor boundaries by noting evidence of former channels along the edges of terrace risers and the valley wall (Figure 9).

4.0 COMPARISON OF HAZARD ASSESSMENT APPROACHES

The river corridor delineation protocol represents at least the fourth geomorphic assessment study completed on the North River since Tropical Strom Irene, providing an excellent opportunity to compare the efficacy and drawbacks of the various approaches at a time when a Fluvial Geomorphology Task Force at the University of Massachusetts is working to develop a statewide flood hazard assessment methodology. The three other assessments were completed for the University of Massachusetts (UMass) and Massachusetts Department of Transportation (Mass DOT) (Milone and MacBroom, 2017), Massachusetts Emergency Management Agency (MEMA) (NEE and MGS, 2013), and Franklin Regional Council of Governments (FRCOG) (Field, 2015), so each study had a slightly different purpose and geographic extent. Each study is briefly described below and compared with the river corridor mapping protocol presented in Section 2.3 above.

4.1 Assessment for UMass and Mass DOT

Milone and MacBroom (2017) subdivided the entire Deerfield Watershed into nearly 2,000 distinct stream and river segments covering 1st to 6th order streams with each segment generally several thousand feet long. For each reach, the potential unit stream power (i.e., the total stream power divided by the width of flow) generated by a bankfull discharge (i.e., the peak flow that typically occurs every year or two) was calculated from the segment slope (determined from LiDAR or other remotely sensed data) and drainage area (to establish the discharge and bankfull channel width from regional regression equations). Stream power is a reflection of how much “work” can be achieved by floodwaters with higher stream powers having a greater capacity to transport sediment, erode banks, and carve new channels. Although the assessment consisted of other elements, the calculated stream power was used to generate maps showing the relative magnitude of stream power for each segment rated from low to high (Figure 10). In general, stream power is highest in steep confined channels with relatively high discharges such that 1st order headwater streams that are confined and steep but have a low discharge typically have a lower stream power than 2nd or 3rd order streams that are still somewhat confined and steep but with higher discharges. Valley bottom 4th to 6th order streams have the largest discharges but typically have lower stream powers due to lower gradients and lack of confinement. The results for the North River Watershed, show stream power to be generally higher along the more confined West Branch than the East Branch and mainstem where the valley and floodplain are much wider (Milone and MacBroom, 2017, p. 42).

The Milone and MacBroom (2017) study of stream power covered the entire Deerfield Watershed and was able to assess such a large area by automating the process of determining watershed area and channel gradient with GIS. The results provide an excellent screening tool for identifying segments with the highest potential for significant bank erosion, so can be useful for organizations like Mass DOT trying to establish which stream crossings may be most vulnerable during floods and worthy of additional investigation. However, the magnitude of stream power is perhaps not as important as the rate of change in stream power along the channel. Consequently, the method does not account for significant changes that can occur in segments with low stream power but where slope, sediment load, or channel/valley dimensions change rapidly. In contrast, the river corridor mapping procedures presented in Appendix 1 categorize such areas as zones of special concern because of the potential for rapid change in channel position and dimensions. Furthermore, determining stream power for segments thousands of feet long does not provide sufficient detail as to the potential lateral extent of erosion as does the corridor mapping protocol that delineates the boundaries within which changes are most likely to occur over time, providing communities with information on what infrastructure may be at risk during a large flood. Finally, by using physical features observable on the ground, corridor mapping will be more understandable and more readily accepted by the community than would the stream power method based on abstract mathematical principles and assumptions regarding bankfull discharge based on data from watersheds that may be dissimilar from the watershed of interest.

4.2 Assessment for MEMA

NEE and MGS (2013), largely following the Vermont Geomorphic Assessment protocols (Web citation 1), completed a geomorphic assessment of a portion of the North River (and three other rivers/brooks in the Deerfield Watershed). The river is subdivided into reaches of uneven length with the breaks between reaches established where significant changes in valley width, drainage area, or gradient occur. Aerial photographs, topographic maps, GIS data, field mapping, and other data are used to characterize the current channel conditions for each reach, establish what the expected equilibrium channel dimensions would be, and identify historic human alterations and natural features reflecting the reach's sensitivity to channel adjustments. The results were used to create fluvial erosion hazard maps (or now called river corridor protection area maps) of the North River (Appendix 4). The width of the erosion hazard zone, or corridor, is generally taken as six bankfull channel widths but in reaches sensitive to change that width is increased to eight channel widths. These widths adopted in the Vermont protocols are based on the amplitude of meander zones observed on other river systems reported in the published literature and are taken to represent the full lateral extent of the river's movement over time. By establishing a uniform width, the corridors can be automatically generated in GIS once the meander centerline is hand digitized by connecting the inflection points between meander loops. Where physical evidence (e.g., oxbows) extends beyond the automatically generated corridors, adjustments can be made by hand to account for these exceptions. The erosion hazard maps also assign a sensitivity rating based on bank composition (i.e., sandy banks the most sensitive to erosion) and human alterations (i.e., straightened and bermed reaches are the most sensitive to change) to each reach providing an indication as to which reaches are more likely to experience rapid and/or frequent erosion (Appendix 4).

The erosion hazard maps resulting from assessments completed using the Vermont protocols treat the entire length of a reach equally, whereas the most significant channel adjustments during a flood often occur in the immediate vicinity of the reach breaks themselves as these are areas where sediment loads increase dramatically at tributary confluences or sediment transport capacity declines rapidly at valley or channel constrictions. Although the corridor mapping protocol (Appendix 1) does not subdivide the river into reaches, the zones of special concern highlighted in Step 5 recognize that rapid bank erosion and channel migration within the corridor are possible where these reach breaks are made in the Vermont protocols and, thus, the most likely areas of change are more precisely located using the corridor mapping procedures. Portions of the corridor adjacent to artificially straightened channels are also areas more prone to rapid changes and both the Vermont protocols and corridor mapping protocol identify these areas as more sensitive to dramatic channel adjustment. The approach for establishing the corridor's width is different between the two methods with the Vermont protocols basing the width on studies from other rivers while the corridor mapping protocol takes advantage of physical evidence observable within the watershed being mapped. Although the corridor delineation process in the Vermont protocols is automated, and therefore completed quickly, a large amount of data collection and fieldwork is required before undertaking the automated process such that the corridor mapping protocol requires less overall time and resources to create the corridor maps. Consequently, more communities will be willing and able to utilize the corridor mapping protocol compared to the Vermont protocols. Furthermore, by relying on physical evidence in the watershed as opposed to data from other river systems that may be unlike the river being mapped, the results using the corridor mapping protocol are likely to be more readily accepted by community members. This comparison of methods should not be construed as suggesting that the Vermont protocols are without merit as the extensive data set assembled is extremely useful in prioritizing areas for restoration and identifying potential solutions that might reduce the likelihood for rapid channel adjustments in the river corridor. The corridor mapping protocol only shows the zones where such changes are likely to occur but is not intended for prioritizing and developing restoration projects.

4.3 Assessment for FRCOG

Field (2015) conducted a geomorphic assessment of the East Branch and mainstem of the North River to identify the reasons for, and potential restoration measures to address, channel instability, habitat degradation, and high sediment loading. The approach used was originally developed by Field Geology Services (2009) with Trout Unlimited in northern New Hampshire where, for the North River assessment, ten attributes of a stable equilibrium channel (i.e., access to floodplain, capacity for channel adjustment, presence of pools and riffles) with excellent aquatic habitat are rated to determine the "need" for restoration along different portions of the study stream where such attributes are absent or in poor condition. Data collected from remote sensing and the field are used to establish scores for each attribute that are then totaled to develop a list of priority sites for restoration that have the highest "needs" scores. Field's (2015) assessment approach uses many of the same techniques as the Vermont protocol including the identification of stream reaches, mapping of bank erosion and composition, and measurement of channel dimensions. Field (2015) further subdivided the North River reaches into shorter segments based on the location of individual morphological features such as mid-channel bars, mass failures, or straightened sections of channel; a "needs" score is then established for each segment. The segment's "needs" – a need for floodplain access for example – are then linked to a number of potential restoration measures that are scored on their ability to address those needs such as removing berms that are blocking the floodplain (to follow on with the previous example). In this manner, the assessment method not only prioritizes the segments with the greatest need for restoration but also identifies the most effective restoration approaches for addressing those needs.

The results of the Field (2015) assessment can be used to produce maps showing the location of bank erosion, height, and composition (Figure 11), so may reflect where erosion will occur in the future but the maps do not provide information on the potential extent of that erosion as do the river corridor maps created using the corridor mapping protocol (Appendix 1). The level of effort required to complete an assessment using the approach developed by Field Geology Services (2009) is much greater than needed to complete the river corridor mapping. However, the intent of the two assessment approaches are different with considerably more characterization of channel conditions in the field required to identify restoration priorities and the best restoration techniques to use for addressing channel instability, habitat degradation, and elevated sediment loading. A community interested in identifying areas potentially prone to rapid bank erosion or channel migration can do so relatively quickly with minimal investment by completing the corridor mapping protocol. Those findings could then be used to secure funding to complete more extensive assessments using the Field Geology Services (2009) method or the Vermont protocols (Web citation 1) to identify restoration opportunities to improve channel stability and reduce sediment loading that will reduce the risk for rapid changes within the river corridor.

5.0 CONCLUSIONS

Compared to other geomorphic assessment methods that are available, the river corridor mapping protocol presented in Appendix 1 and described above is more effective at identifying the location and severity of erosion hazards and channel migration that are responsible for the most severe damages during storms like Tropical Storm Irene. The corridor mapping procedures were developed for use by conservation districts, towns, and other organizations working to better plan and prepare for future floods. Communities throughout Massachusetts should find the corridor mapping protocol accessible in two respects. First, the protocol is designed to be completed by individuals with limited training or knowledge in geomorphology using widely available remote sensing data (i.e., topographic maps and aerial photographs) and additional resources if desired (e.g. LiDAR, DEMs). Consequently, most communities should be able to produce river corridor maps with only a limited investment in staff time and finances. Second, landowners and other interested community members will more readily use the river corridor maps than the results of other assessments, since they are based on physical features they know (e.g., an oxbow), linking familiar features with the implications they carry in terms of flood and erosion hazards. While the river corridor mapping protocol does not provide information suitable for planning restoration projects that might reduce the identified hazards, the resulting maps represent an important first step for building community awareness regarding flood hazards and the need to prepare in advance for the next large flood event to befall Massachusetts.

6.0 REFERENCES

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Web citation

Web citation 1: http://dec.vermont.gov/watershed/rivers/river-corridor-and-floodplain-protection/geomorphic-assessment (last accessed January 24, 2018)

FIGURES

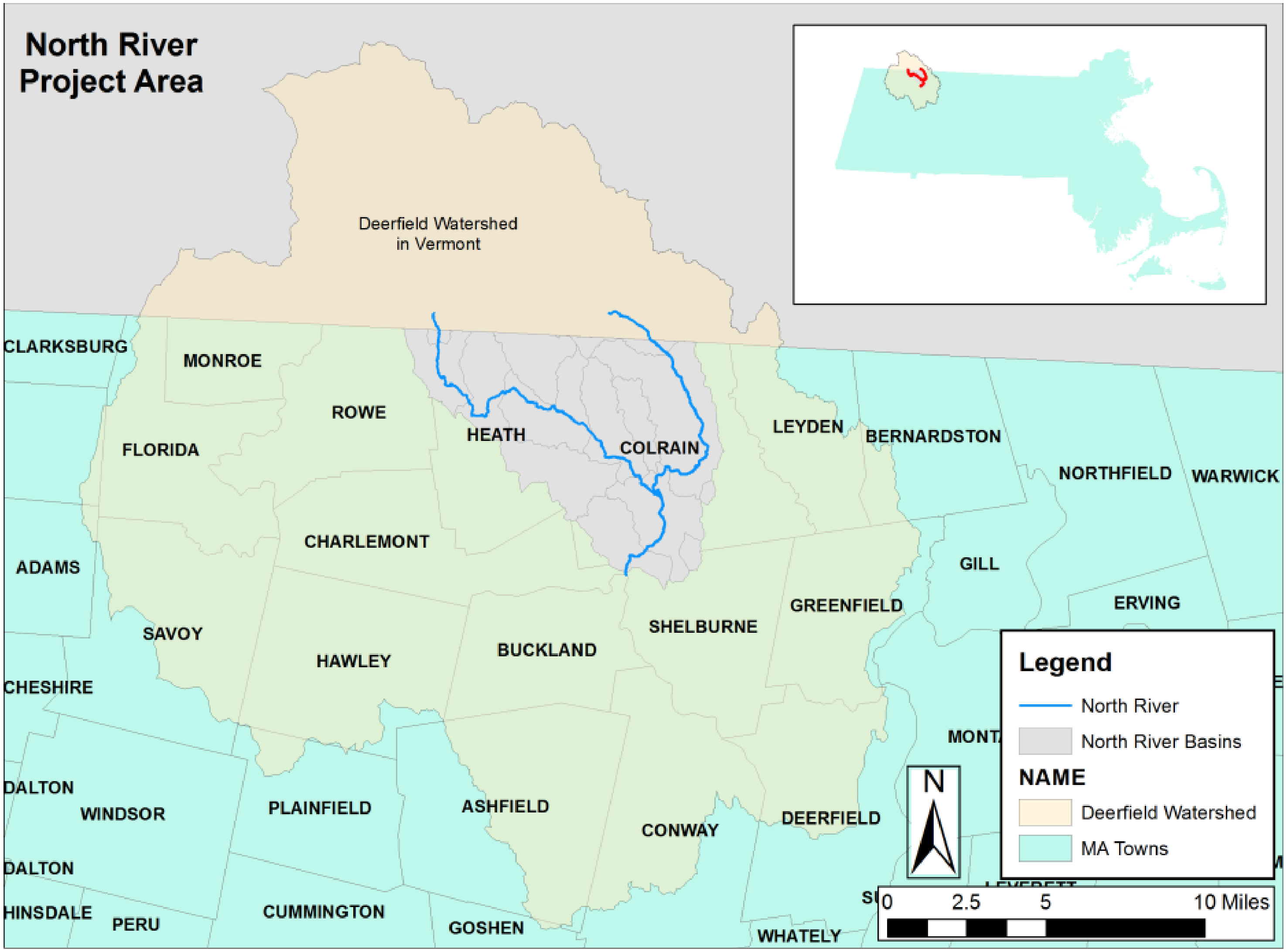


Figure 1. Map of North River project area.

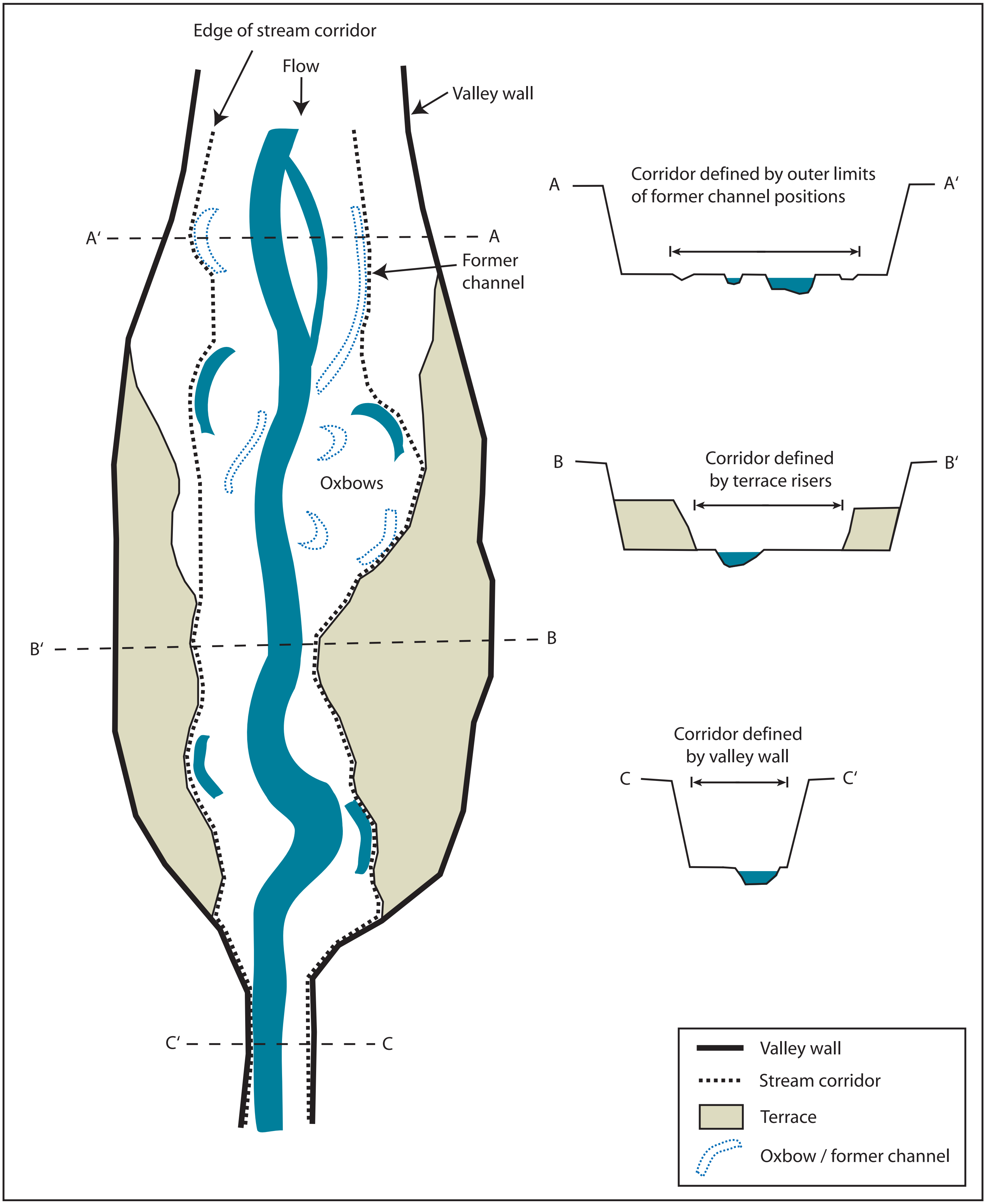


Figure 2. Limits of the stream corridor are defined by the outer limits of former channel positions (Transect A-A'), the front of terrace risers (Transect B-B'), and the base of the valley wall (Transect C-C').

Figure 3. Significant recession of an elevated river terrace occurred in Mendon, VT during Tropical Storm Irene washing out portions of Route 4.

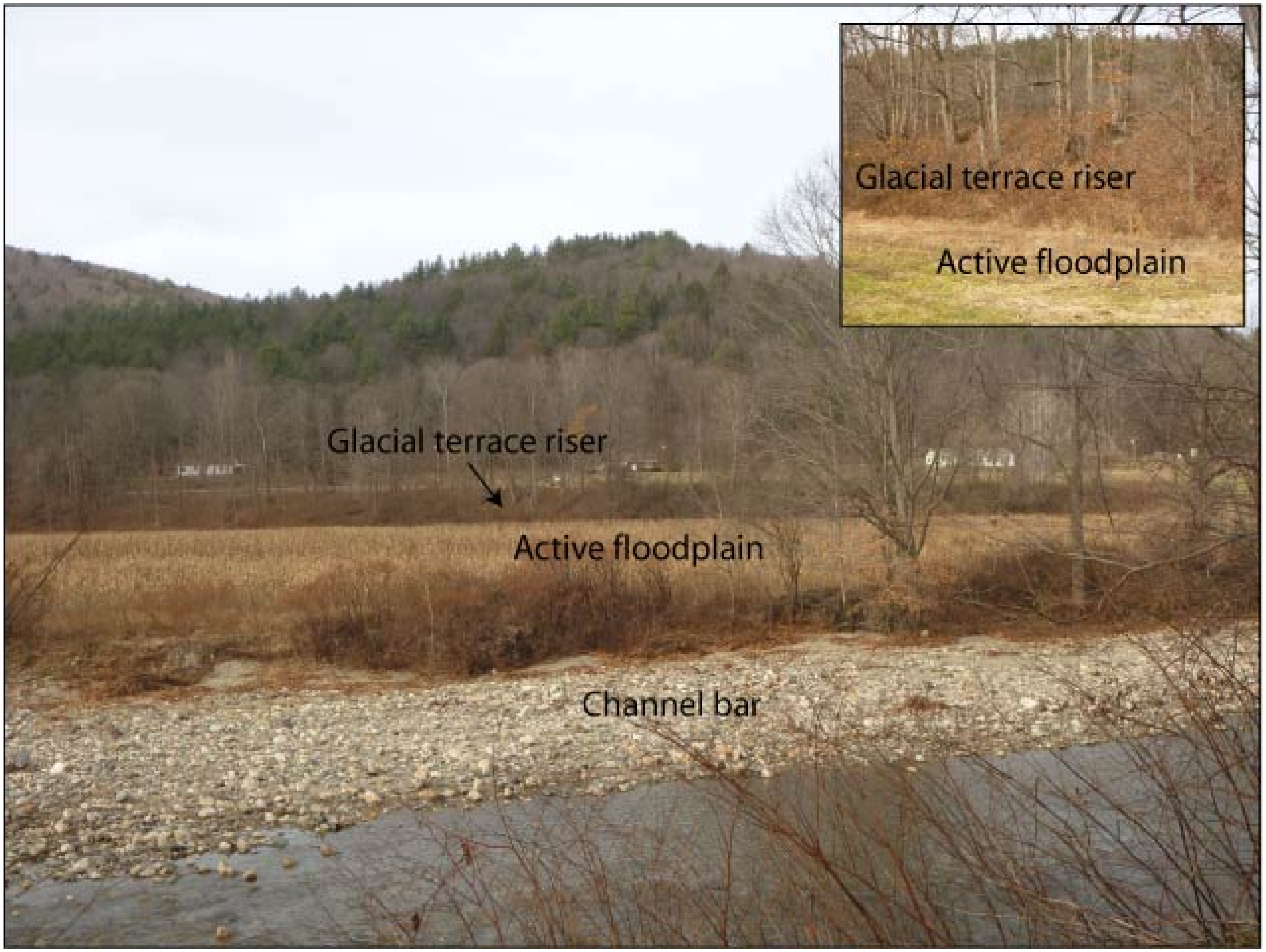


Figure 4. Glacial terrace riser on the backside of the floodplain represents the edge of the river corridor on this section of the North River mainstem.

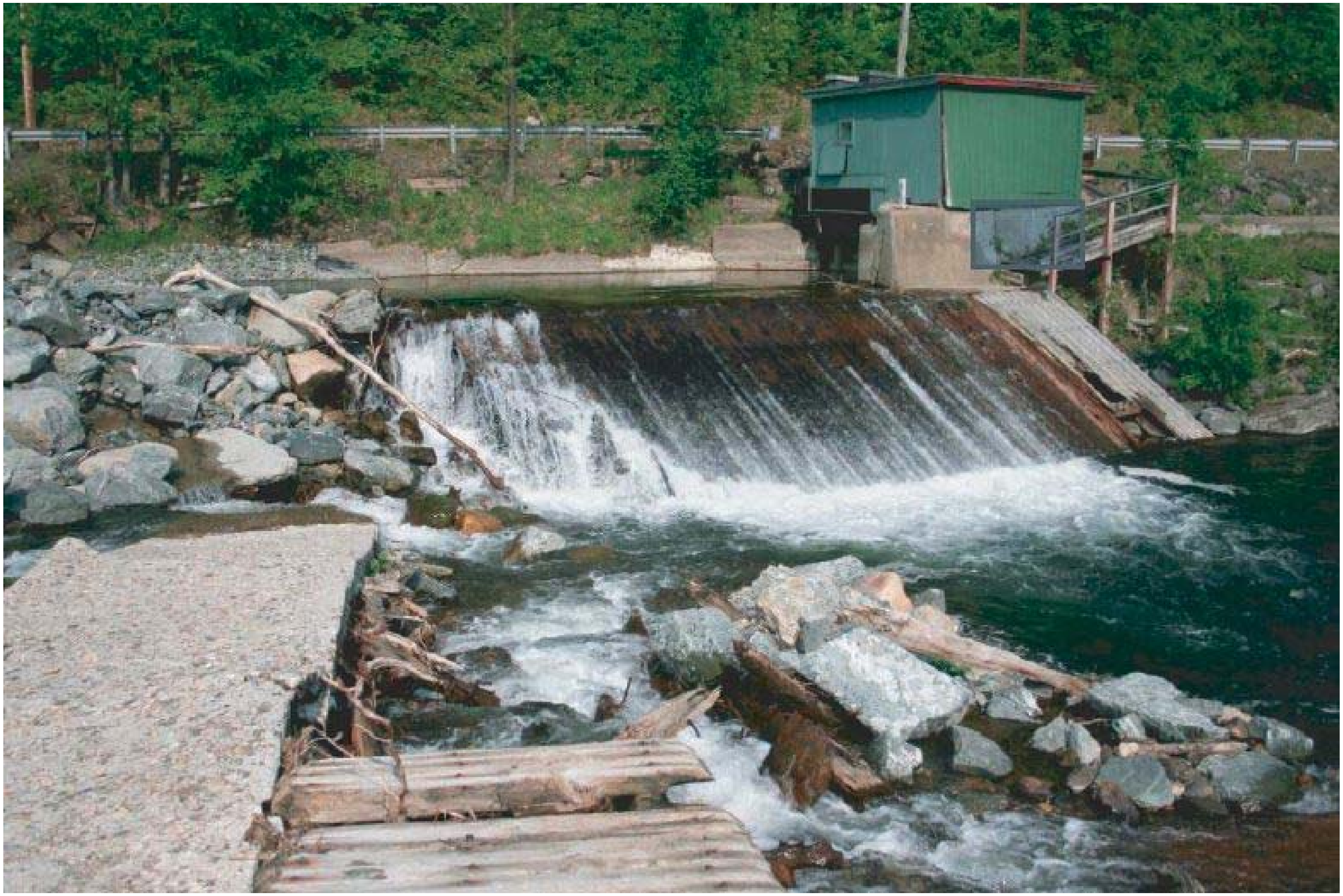


Figure 5. A portion of the Kendall Company No. 1 Dam on the North River was damaged during Tropical Storm Irene flooding.

Figure 6. A berm built on the bank of the West Branch of North River as part of the post-Irene emergency work.

Figure 7. Wood and boulders added to the West Branch channel as part of restoration efforts following Tropical Storm Irene and post-flood emergency work.

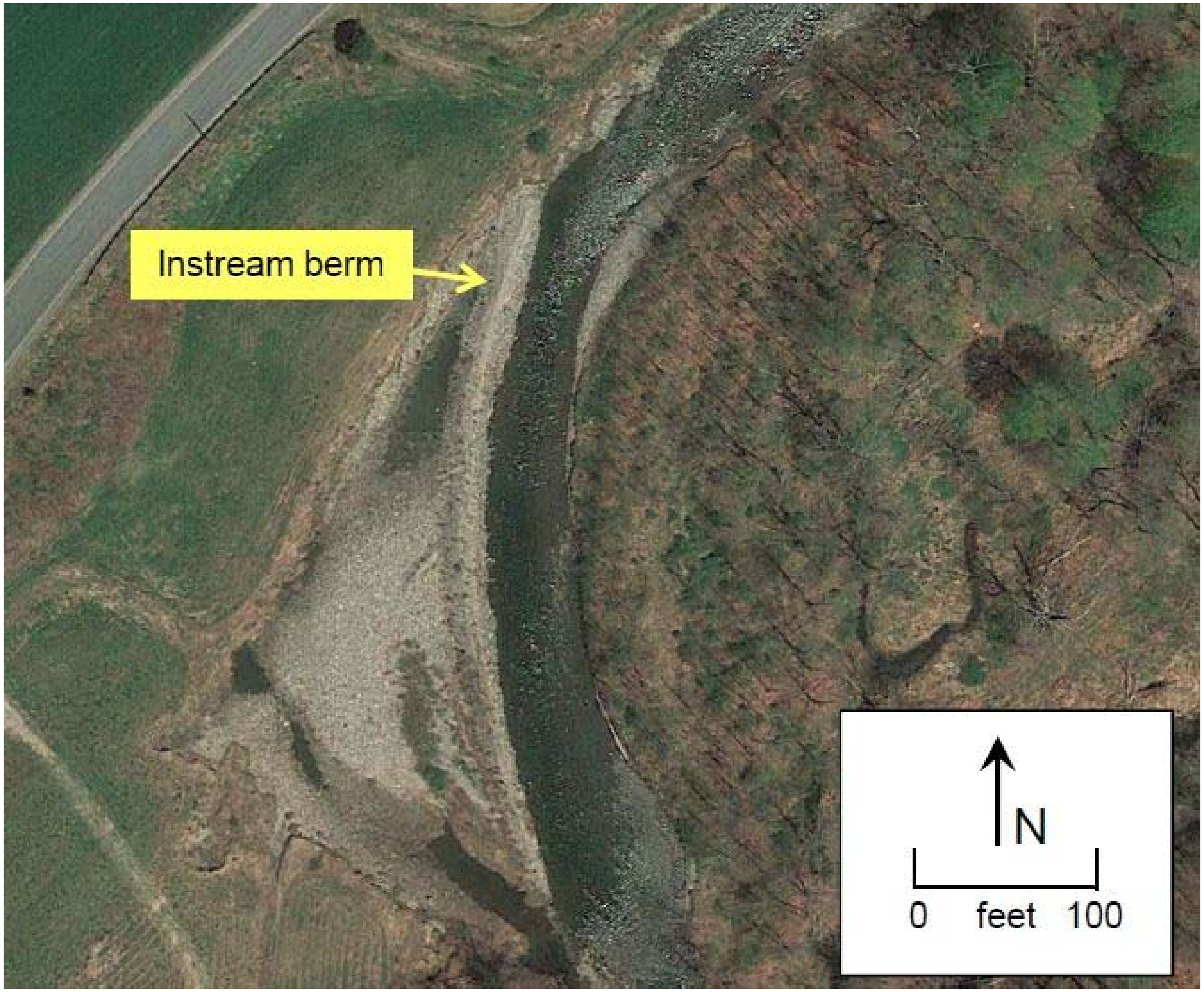


Figure 8. A berm constructed in the channel following Tropical Storm Irene cuts off the outer portion of a meander carved during the flood.

Figure 9. A side channel flows against the valley wall, marking the former position of the main channel of the North River mainstem.

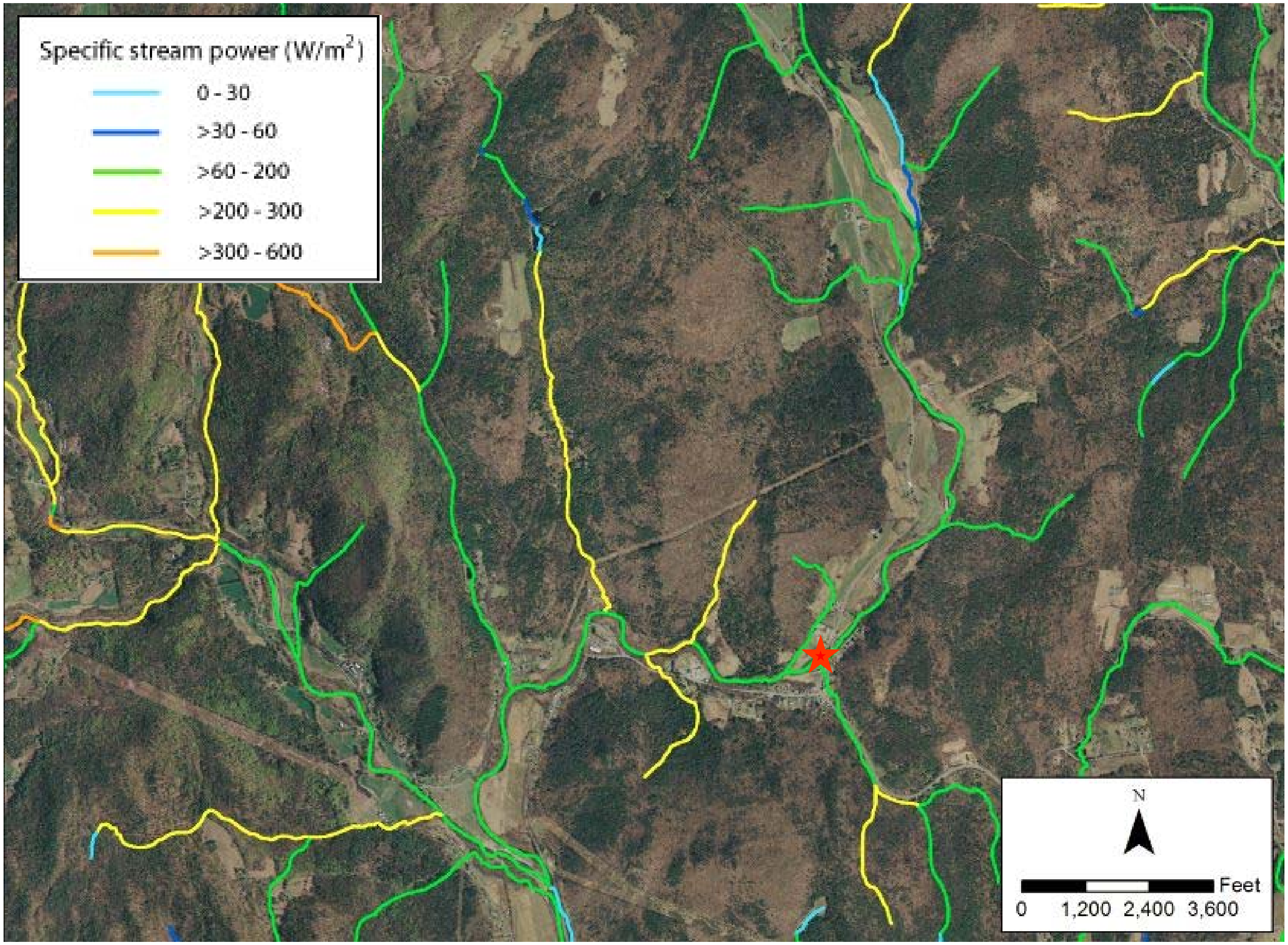


Figure 10. Map of stream power for river segments in a portion of the North River Watershed. From Milone and MacBroom (2017). Red star marks location of Colrain Elementary School for orientation.

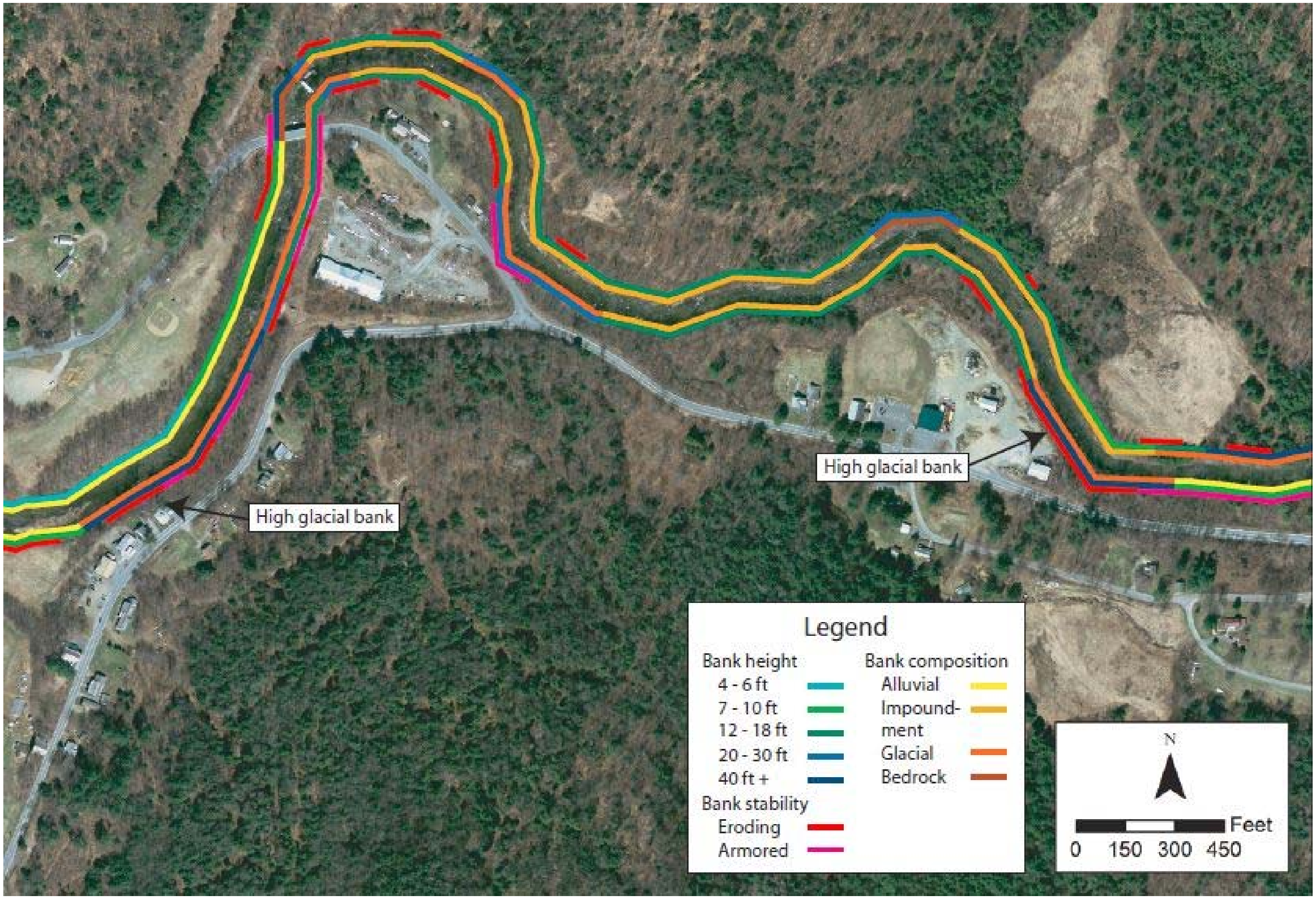


Figure 11. A map of erosion, bank height, and bank composition for a portion of the North River. From Field (2015).

APPENDIX 1

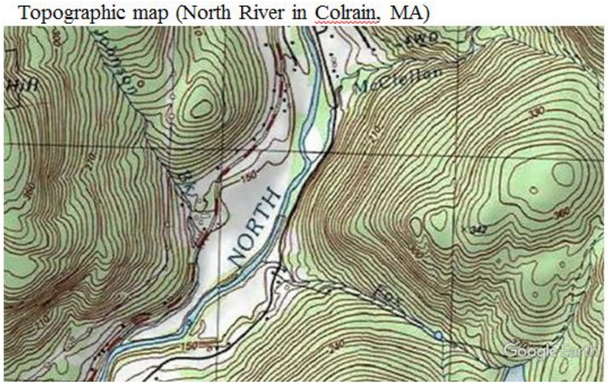
(River corridor mapping procedures)

River Corridor Mapping Procedures

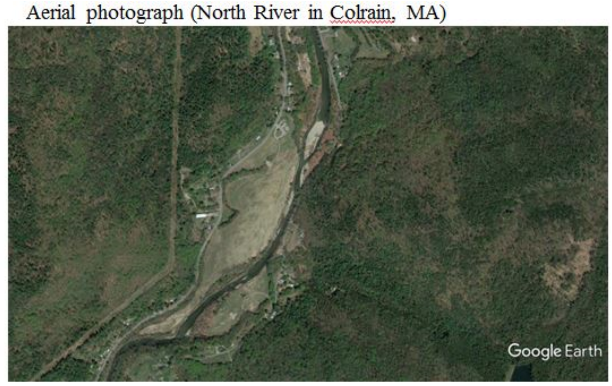
Step 1 – Gathering resources

Completing the corridor mapping requires, at a minimum, topographic maps and aerial photographs of the area of interest. Historical maps and aerials, soils and surficial geology maps, and LiDAR imagery can also be utilized but are not essential. Please refer to the accompanying *Guidance Document* for information on how to compile the resources needed to complete the corridor mapping.

Topographic map (North River in Colrain, MA)



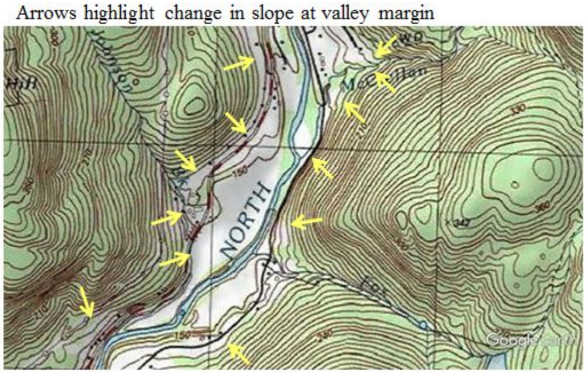
Aerial photograph (North River in Colrain, MA)



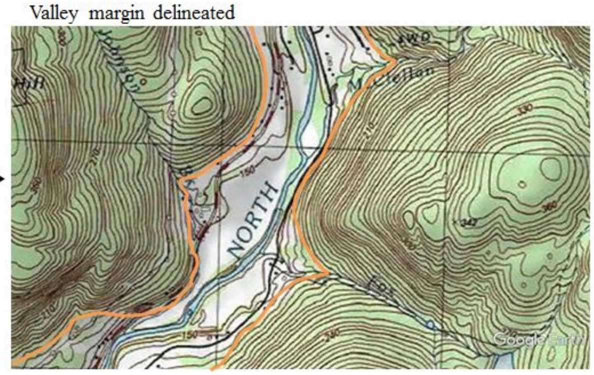
Step 2 – Delineate the valley margins

Starting with the topographic maps, delineate the margins of the valley by drawing/digitizing a line at the slope break between the flat valley floor and steeper valley sides as highlighted below:

Arrows highlight change in slope at valley margin



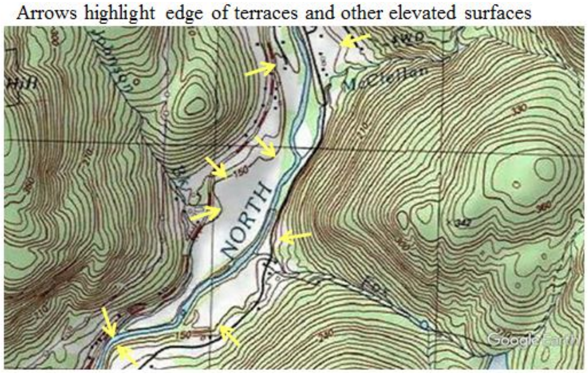
Valley margin delineated



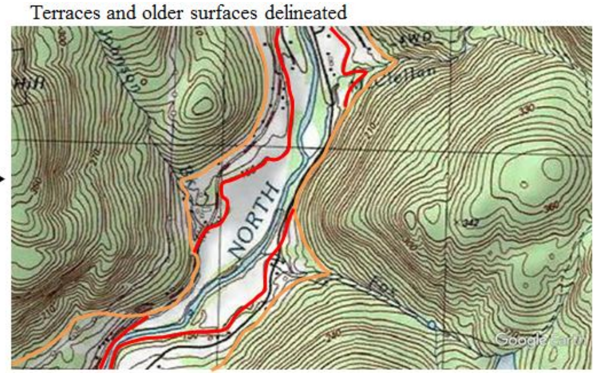
Step 3 – Delineate river terraces and other elevated surfaces

Using topographic maps, follow contour lines representing the edge of elevated surfaces that constrain flood inundation and channel migration on the valley bottom as highlighted below:

Arrows highlight edge of terraces and other elevated surfaces



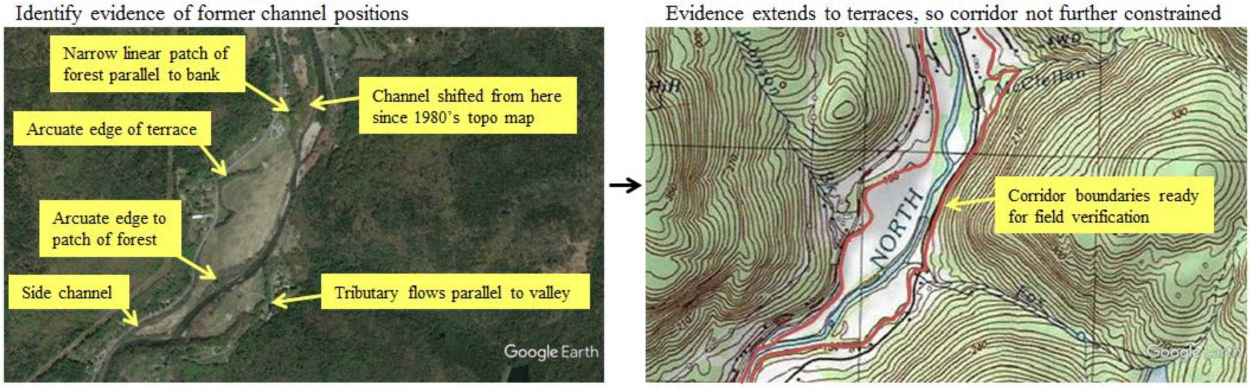
Terraces and older surfaces delineated



Step 4 – Identify evidence of former flow paths and demarcate outer limits of past channel positions

Using aerial photographs and topo maps, identify former flow paths and then demarcate the outer limits to define the river corridor. Corridor not further refined if former flow paths extend to the edge of terraces as highlighted below:

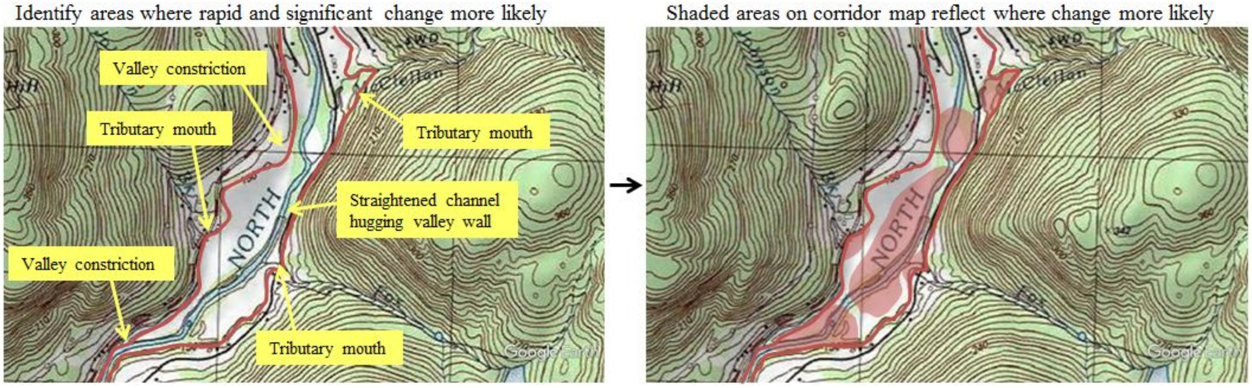
Identify evidence of former channel positions — Evidence extends to terraces, so corridor not further constrained



Step 5 – Highlight areas with greater likelihood of rapid and significant change

Rapid and significant change in channel position is more likely to occur: 1) upstream of valley constrictions where flood flows are impounded, 2) adjacent to artificially straightened channels prone to reforming meanders, and 3) at tributary mouths where sudden inputs of sediment can occur. Highlighting these areas can help in understanding the cause of persistent problems, prioritizing lands for conservation, and emergency response planning:

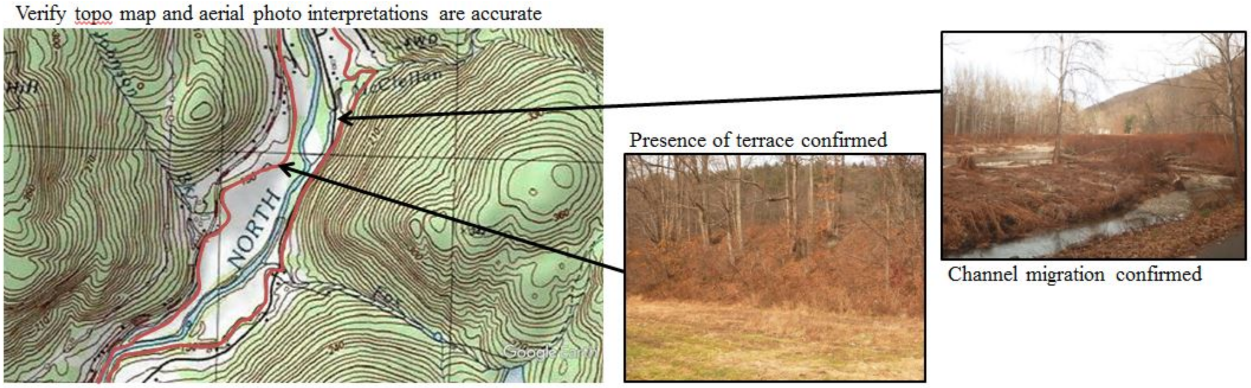
Identify areas where rapid and significant change more likely — Shaded areas on corridor map reflect where change more likely



Step 6 – Field verification of corridor boundaries

Visiting sites in the field can clear up uncertainties on the location of the valley wall, the presence of terraces, and other elevated surfaces, and evidence for former flow paths as highlighted below:

Verify topo map and aerial photo interpretations are accurate



APPENDIX 2

(River corridor mapping guidance)

River Corridor Mapping Guidance Document

This *Corridor Mapping Guidance* document provides additional information to assist in the completion of the corridor mapping protocol detailed in the accompanying *Corridor Mapping Procedures* document. Each of the six steps in the *Corridor Mapping Procedures* document is also listed here, so the link between documents is clear.

Step 1 – Gathering resources

The two essential resources for completing the corridor mapping procedures are topographic maps and aerial photographs, both of which are readily available online:

Aerial photographs are best accessed through Google Earth, which also contains historical images generally extending back to the 1990s. Google Earth can be downloaded at:

https://www.google.com/earth/download/ge/

USGS topographic maps can also be downloaded for viewing on Google Earth through this link:

http://www.earthpoint.us/TopoMap.aspx

For those unfamiliar with using Google Earth will find an informative user guide at:

https://static.googleusercontent.com/media/earth.google.de/de/de/userguide/v4/google_earth_user_guide.pdf

Corridor boundaries can be delineated and drawn directly on Google Earth using the "Add Path" tool.

If the user would prefer to use or view paper copies of topographic maps, they can be ordered from the USGS using this link:

http://www.omnimap.com/catalog/usgs3.htm

Historic topographic maps can also be useful in establishing former channel positions and changes that have occurred over time. Such maps for Massachusetts are available at:

http://docs.unh.edu/nhtopos/nhtopos.htm

Paper copies of the most recent aerial photographs (as well as historical aerial photographs) are generally available at the local NRCS field office serving the area of interest. A listing of local NRCS offices in Massachusetts is available at:

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ma/home/?cid=nrcs144p2_014130

A number of other additional resources can also be useful in the corridor delineation process. Spatial data for use in Geographical Information Systems software (GIS) is publicly available for download on the internet. Most States host their own website providing this data. In Massachusetts, the MassGIS website can be accessed at:

https://www.mass.gov/service-details/massgis-data-layers

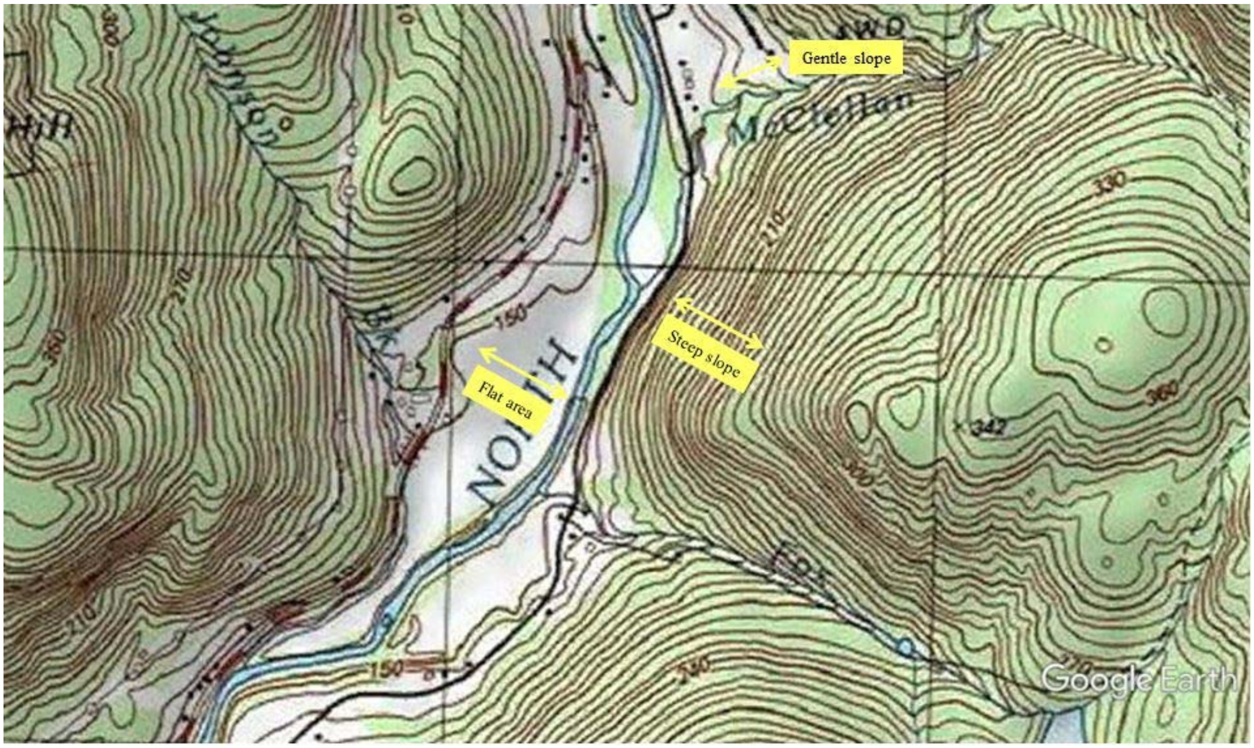
The types of information available at the website that could be useful in completing the corridor mapping procedures include: 1) ortho-rectified aerial photos as well as historic aerial photos; 2) elevation data including LiDAR and Digital Elevation Models (DEMs) along with documentation explaining how to view and utilize these data as individual tiles often need to be mosaicked, stretched, or otherwise manipulated in GIS to fully realize the data's benefits; and 3) maps of soils, surficial geology, wetlands, and other features that may be of value in identifying valley walls, river terraces, and former channel positions.

For those without GIS resources, information on purchasing GIS software and receiving training on its use from one of the most widely used platforms is available at:

https://www.esri.com/en-us/home

Step 2 – Delineate the valley margins

For those unfamiliar, topographic maps show the elevation above sea level for various points on the map using contour lines (shown in brown on map below) with points on the same contour line being at the same elevation. Adjacent contour lines are higher or lower in elevation by an amount equal to the contour interval, which in the map below is 20 ft but varies map to map depending on the amount of relief in the given area. As highlighted on the map below, several closely spaced contour lines indicates a rapid change in elevation over a short distance and thus represents a steep hill slope whereas widely spaced contour lines indicate a gentle slope and a large area with no contour lines represents a flat, or nearly flat, surface. By identifying the different amounts of spacing between contour lines across the surface, the break in slope between steep hill slopes and the flatter or gently sloping valley bottom can be delineated.



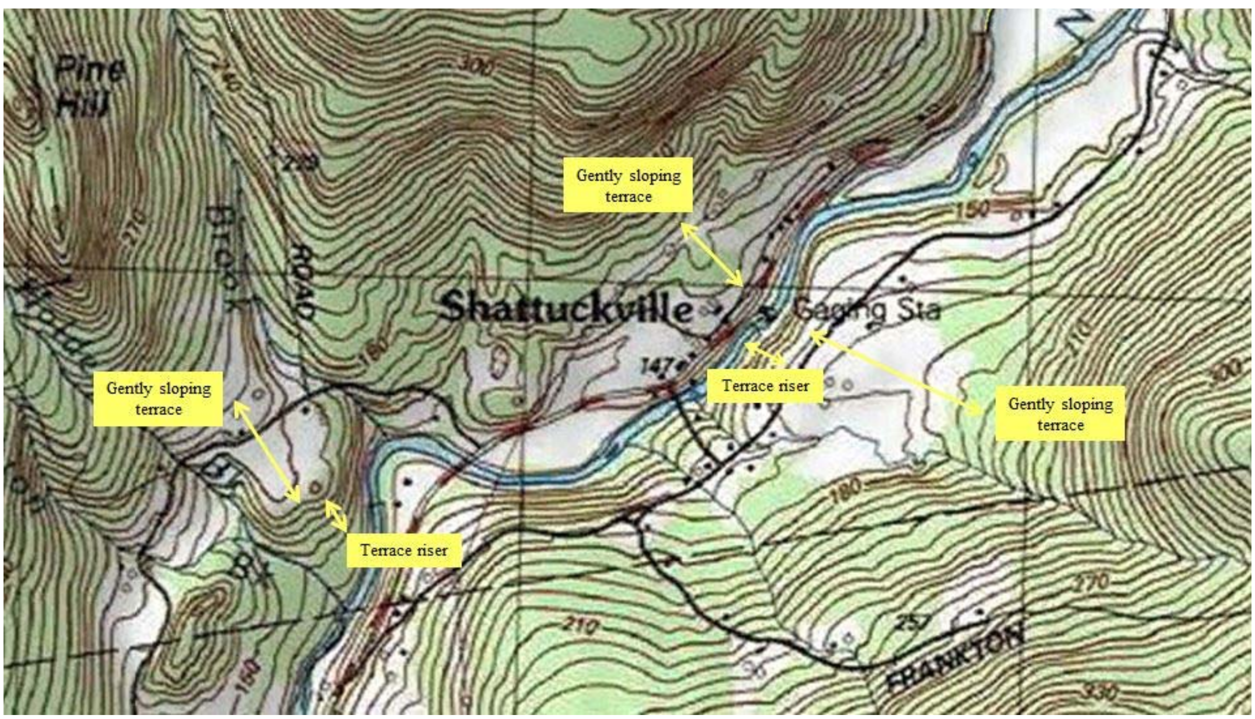
Step 3 – Delineate river terraces and other elevated surfaces

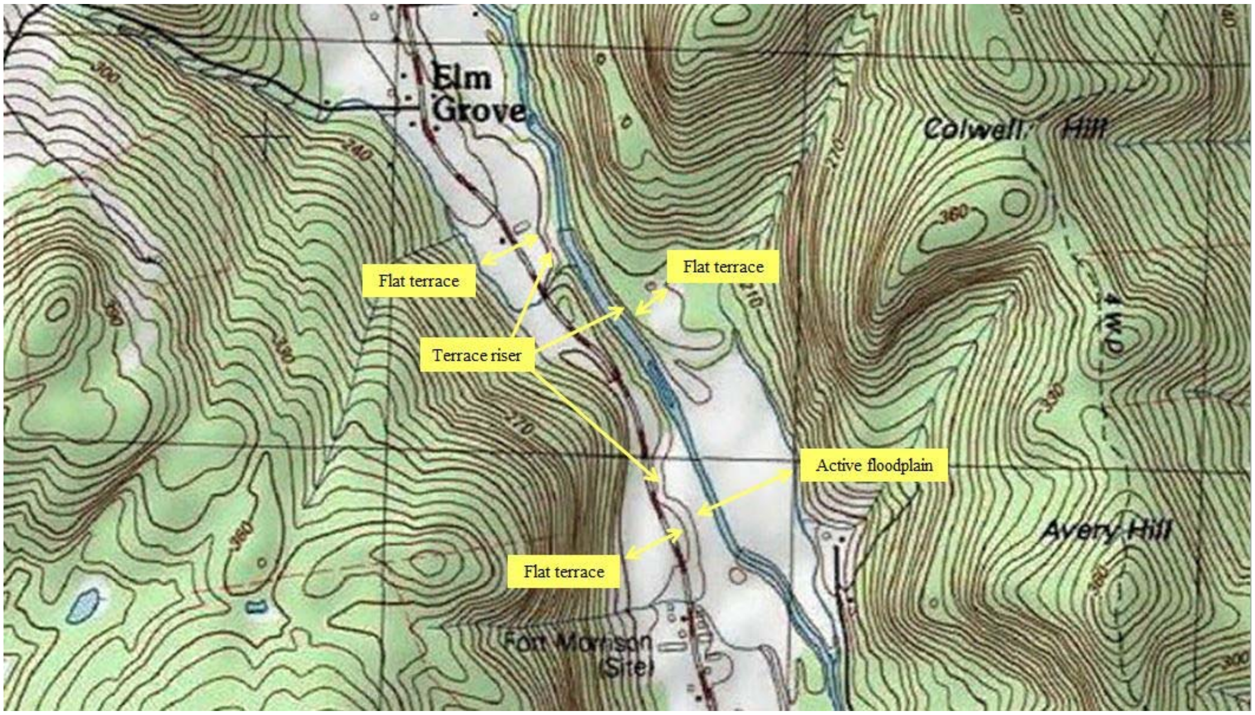
River terraces are flat to gently sloping surfaces elevated above the active floodplain that are remnants of former higher levels of the valley floor. Terraces have become isolated from modern river processes by downcutting of the river over time and are thus no longer subject to flood inundation. In many instances throughout Massachusetts elevated terrace surfaces were formed by glaciogenic processes rather than riverine processes and, thus, technically should not be referred to as river terraces, although they are similarly isolated from flood inundation. Such glaciogenic surfaces include glacial outwash terraces and kame terraces. For river corridor delineation, however, a determination of the genesis of a particular terrace is not required.

These river terraces and other elevated terraces are generally flat to gently sloping surfaces that are often high above the modern floodplain and are typically thousands of years old. The generally steep slope separating the terrace surface from the modern floodplain and river channel below is referred to as a terrace riser. Where the river flows directly against a terrace riser, a high eroding bank may develop that can add significant amounts of sediment to the river, but given its height such banks do not typically retreat rapidly and channel migration into the terrace is thus limited. Consequently, river terraces and other elevated surfaces are excluded from the delineated river corridor as both flood inundation and channel migration across their surfaces are unlikely.

River and glaciogenic terraces are typically found along the margins of valleys with the modern floodplain inset between and below terrace remnants on both sides of the valley. Terraces are identified on topographic maps as flat or gently sloping surfaces elevated above the floodplain with the two surfaces separated by a steeper terrace riser as illustrated at various places along the

North River on the maps below. In some instances, a single contour line may define the edge of a low terrace, but the presence of a terrace can be more confidently established where multiple contour lines are present between two flat surfaces on the valley floor with the higher surface closer to the steep valley side slopes representing the terrace and the lower surface more towards the center of the valley being either the floodplain or, where multiple terraces are present, a lower terrace surface. Lower terraces that are only slightly elevated above the floodplain may be more difficult to identify with topographic maps alone, although the greater resolution of LiDAR may be particularly useful for this purpose. In some instances, lower terrace surfaces may represent historically abandoned floodplain surfaces formed in association with channel incision caused by watershed and river alterations that have occurred since European settlement of the region in the past few hundred years. Failing to recognize young terraces like these and mistakenly including them within the river corridor would not be an egregious error at all, because their limited relief relative to the active floodplain and the associated low banks that result when the river flows along their edge may lead to flood inundation and channel migration during extreme flood events. A more detailed assessment utilizing hydraulic modeling would be required to establish the likelihood that such surfaces could experience flood inundation or erosion and may be advisable where critical infrastructure or proposed developments could be at risk.

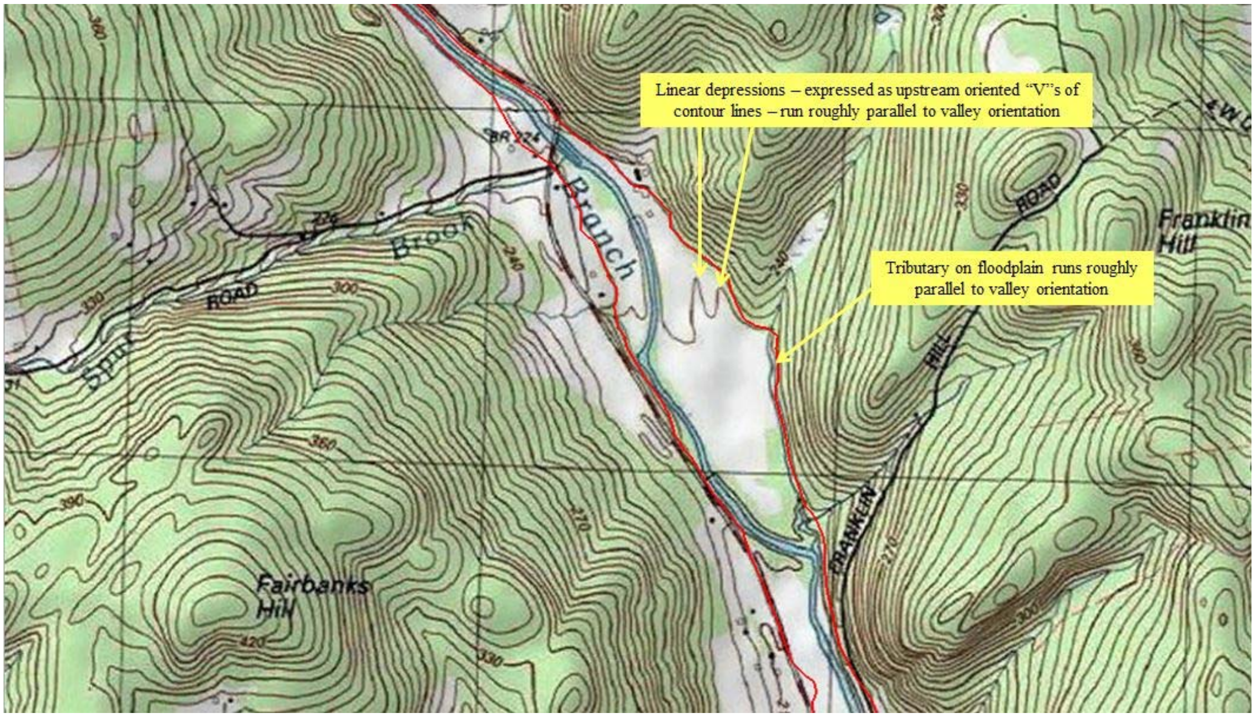




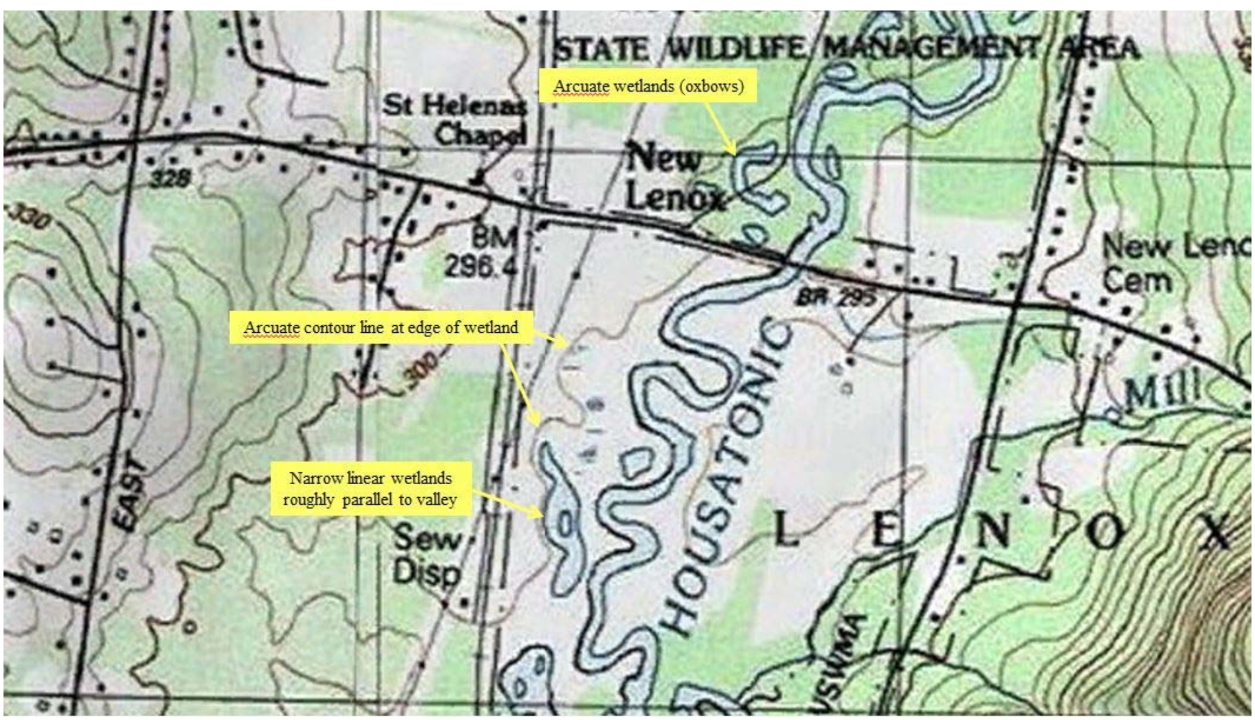
Step 4 – Identify evidence of former flow paths and demarcate outer limits of past channel positions

River channels can naturally migrate slowly over time (or rapidly) through bank erosion that is often offset by an equal amount of deposition on the opposite bank. The entire river channel can also shift rapidly, typically during a large flood, to a new portion of the floodplain in a process known as an avulsion, whereby a new channel is carved into the floodplain. Typifying, but not fully embodying, this type of process is the formation of oxbows, or abandoned meanders, created when a new channel is carved across the inside of a meander bend. Past channel positions have also been abandoned due to human activities such as artificial channel straightening with the former flow path often still visible on aerial photographs and topographic maps. Furthermore, straightened channels themselves can be abandoned when blocked with wood, sediment, or ice with new meander bends rapidly carved across the floodplain during large floods or the former pre-straightened channels are reoccupied. Below are a series of aerial photos and topographic maps from the North River and elsewhere throughout New England illustrating a variety of features that can be used to identify former channel positions and artificially straightened channels. Further methods for identifying former channel positions is provided in Steps 5 and 6 below along with a description of the hazardous processes associated with their formation.

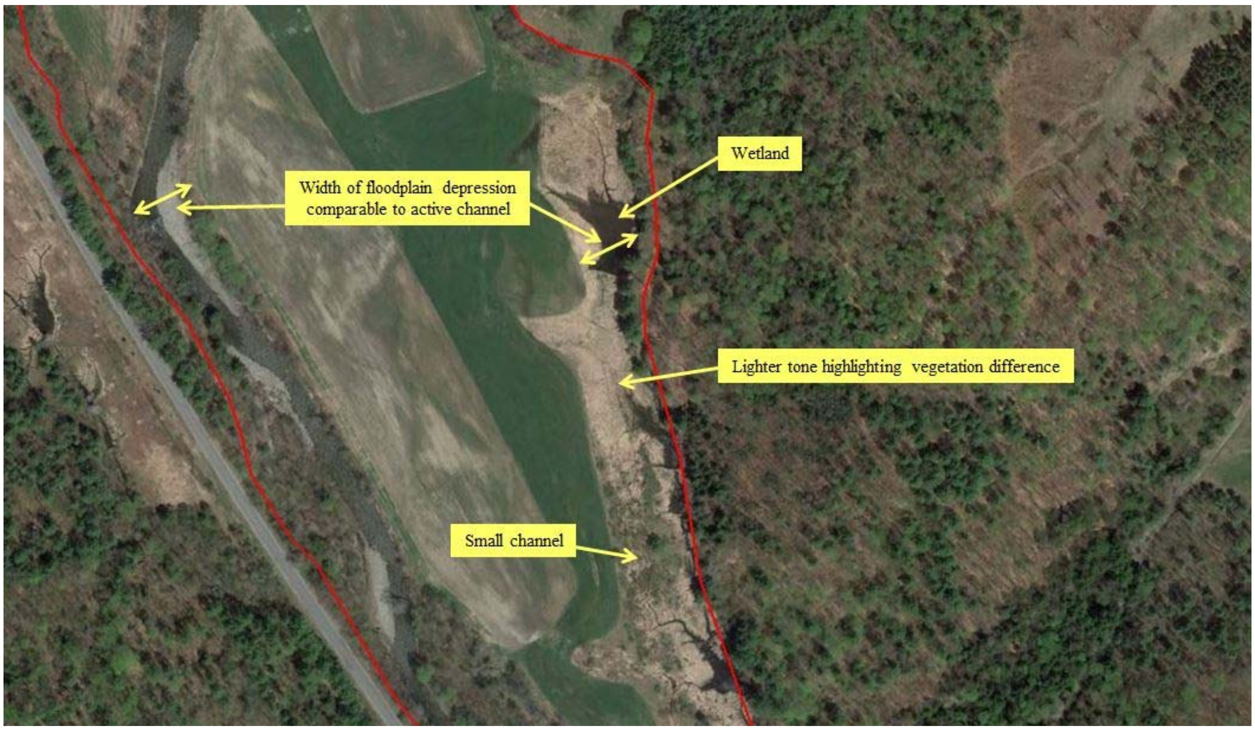
Several features can be used on topographic maps to identify former channel positions. In the example below from the North River tributaries and linear depressions on the floodplain are suggestive of former channel positions and provide evidence that the channel has extended across the entire floodplain between the valley side slope to the east and river terrace to the west. Consequently, the river corridor boundaries (shown in red) are drawn along the terrace riser and valley side.



Although not present in the North River corridor, the topographic map below of the Housatonic River in Lenox, MA illustrates a few other features that can be useful in identifying former channel positions. In this example, the evidence of former channel positions occupies only a portion of the floodplain, so would define the corridor boundaries rather than the edge of terraces or valley sides.



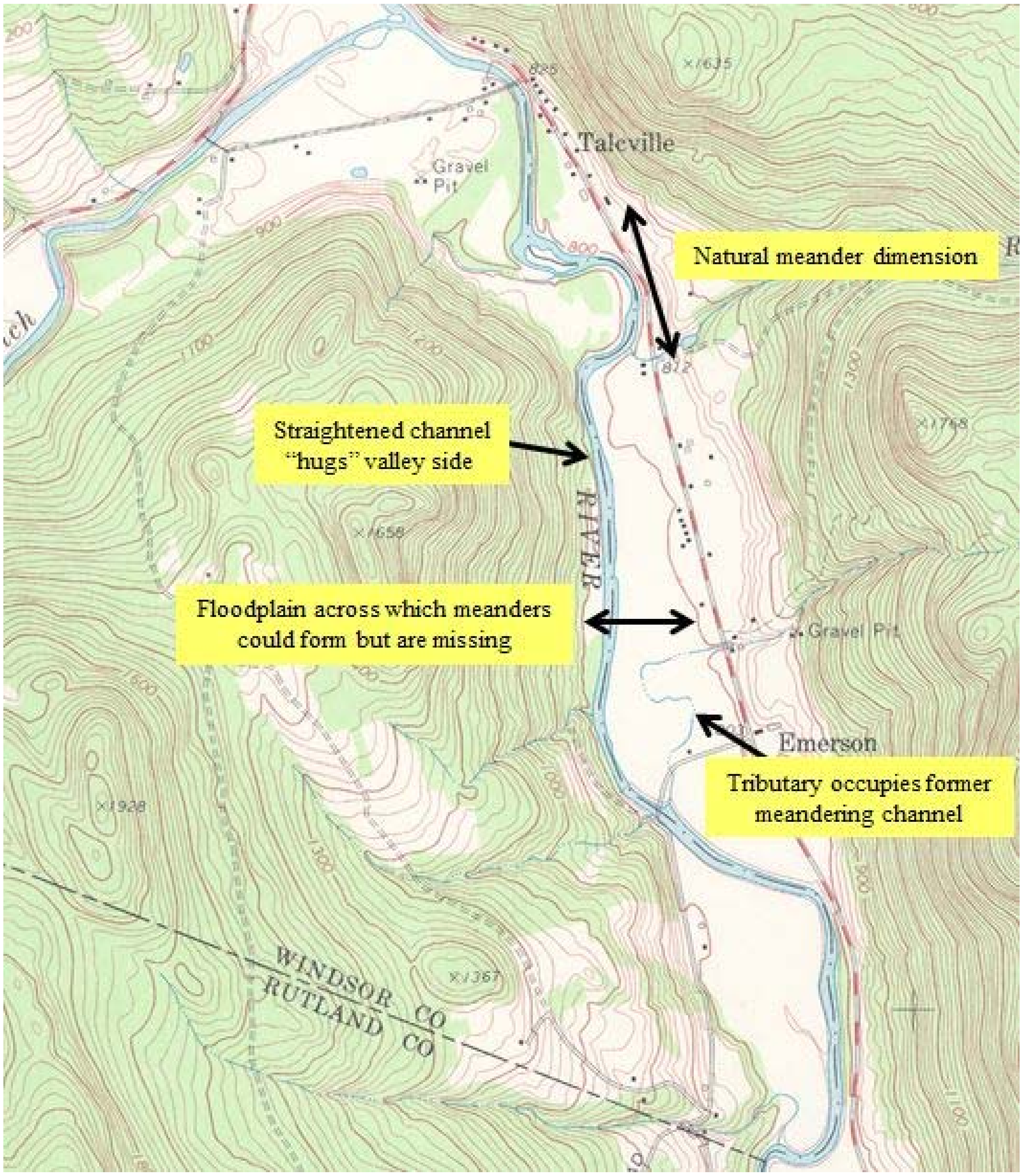
Additionally, many of the same features (e.g., oxbows) can be observed on aerial photographs to identify former channel positions. Other features not observable on topographic maps but present on aerial photographs can reinforce the findings from topographic maps or identify former channels not discernible from topographic maps alone. The aerial photograph below zooms in on that portion of the topographic map of North River above where the tributary is flowing parallel to the valley orientation along the eastern valley margin. The aerial photograph confirms the presence of a former channel position as evidenced by a difference in vegetation compared to the rest of the floodplain and the presence of wetlands and small stream channels across the broad depression whose width is comparable to the active channel of the North River. LiDAR or field verification would further confirm the presence of an old channel by revealing that this area is in a slight depression compared to the rest of the floodplain.



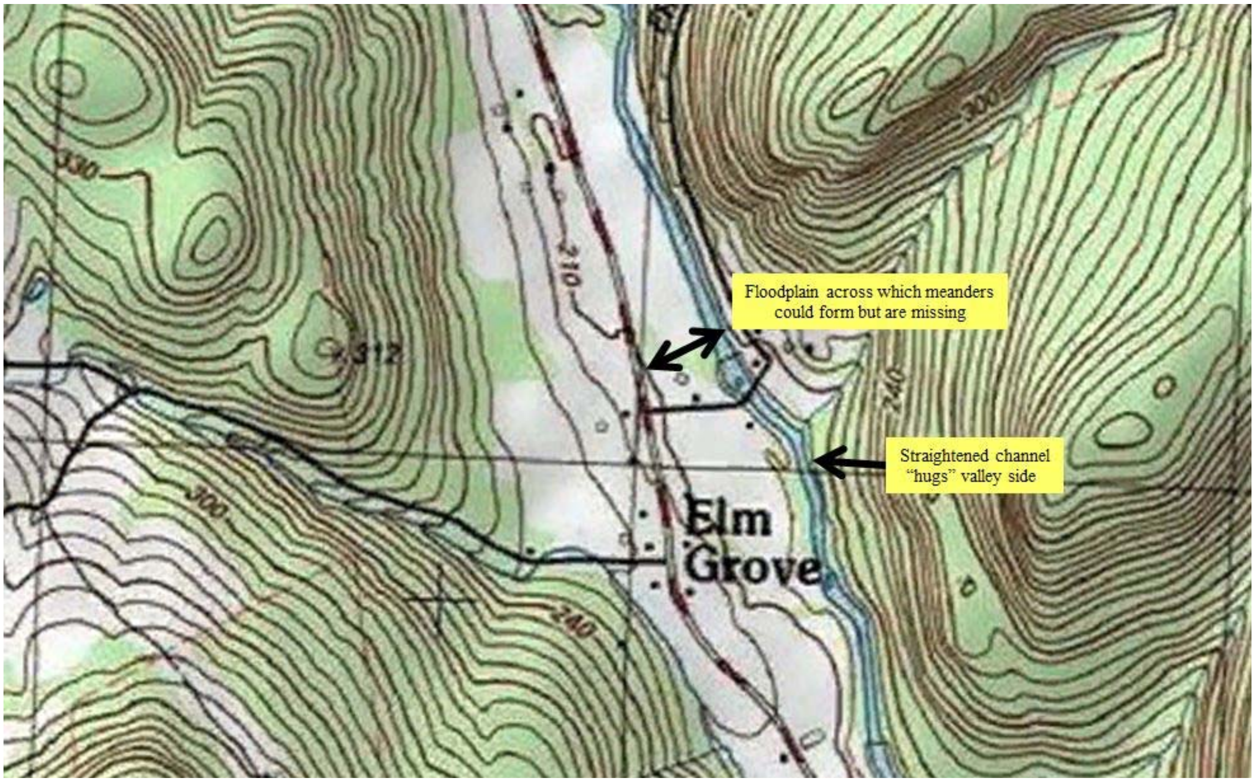
The aerial photograph of the North River below shows a wide gravel bar that is forested with trees largely of a uniform size (and age) suggesting relatively recent colonization of the bar. Such evidence suggests the channel has recently shifted (or been moved through human intervention) from this location, a supposition borne out by the topographic map (not shown here) that shows the channel occupying this area in the 1980s.

The aerial photo below of the North River shows a narrow linear patch of forest that represents a former channel position that is continuous with a narrow linear grassy swale on the other side of Route 112 that is part of the same former channel but is cutoff from overflow from the active channel by the highway. The home at the north end of the swale highlights how homes within the river corridor, even those on the other side of the highway from the active river channel, are potentially at risk during extreme flood events. The highway itself, that cuts across this former channel, is also at risk from channel migration during a large flood.

Evidence for artificial channel straightening is most readily observed and appreciated on topographic maps as illustrated below from a section of the White River in Chester, VT where three hallmarks of artificially straightened channels are present: 1) missing meanders, 2) channels that “hug” the valley sides, and 3) presence of the former channel cutoff by the straightening.



Elsewhere, such as on the North River as shown below, only one or two of these hallmarks might be evident but nonetheless strongly suggests that straightening has occurred – often decades if not centuries in the past:

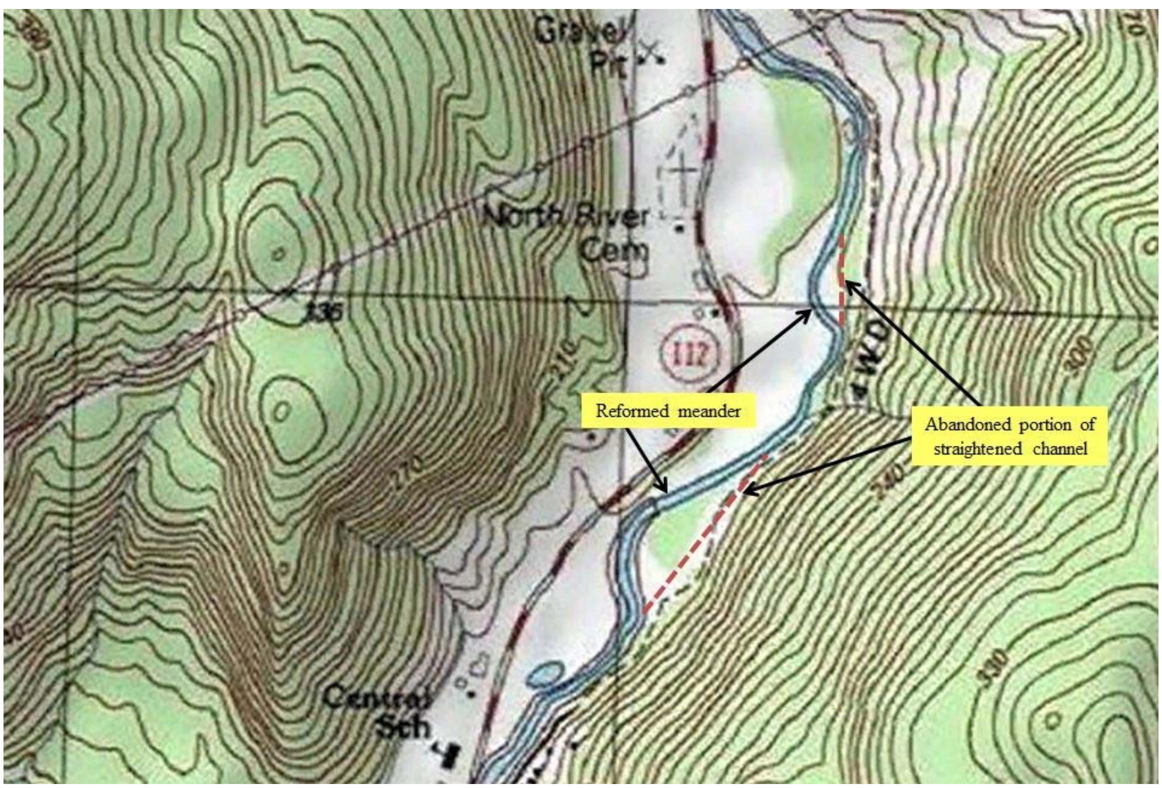


Step 5 – Highlight areas with greater likelihood of rapid and significant change

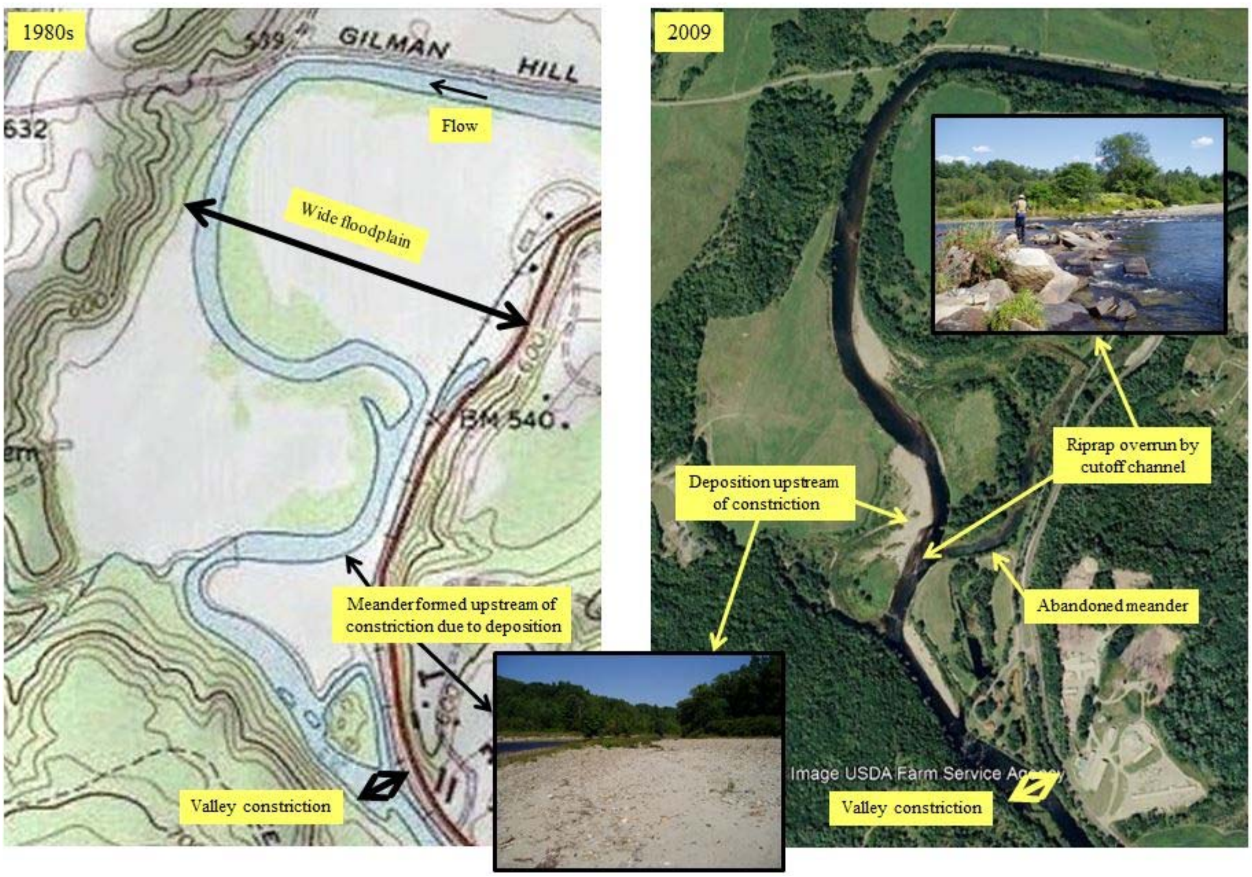
Illustrated and explained below is why hazardous processes (e.g., channel migration) are most likely to be associated with straightened channels, valley/channel constrictions, and tributary confluences. Consideration is also given to the implications of such processes on infrastructure protection and restoration/land conservation priorities.

Artificially straightened channels are prone to the reformation of meanders when they become clogged with wood, sediment, or ice as highlighted in the figure below of the Batten Kill in Arlington, VT. A log jam clogged the straightened channel and flow broke out onto the floodplain with enough force to carve a new meander. Overnight the channel migrated across the full width of the corridor, leaving the front yard of one riverside landowner under attack by the river that literally hours before was over 250 ft away. Roads, bridges, homes, and other infrastructure are similarly at risk of channel migration where channels remain in a straightened configuration. Recognizing beforehand where such hazards are more likely to occur by identifying the location of straightened channels can improve emergency preparedness and land use planning.

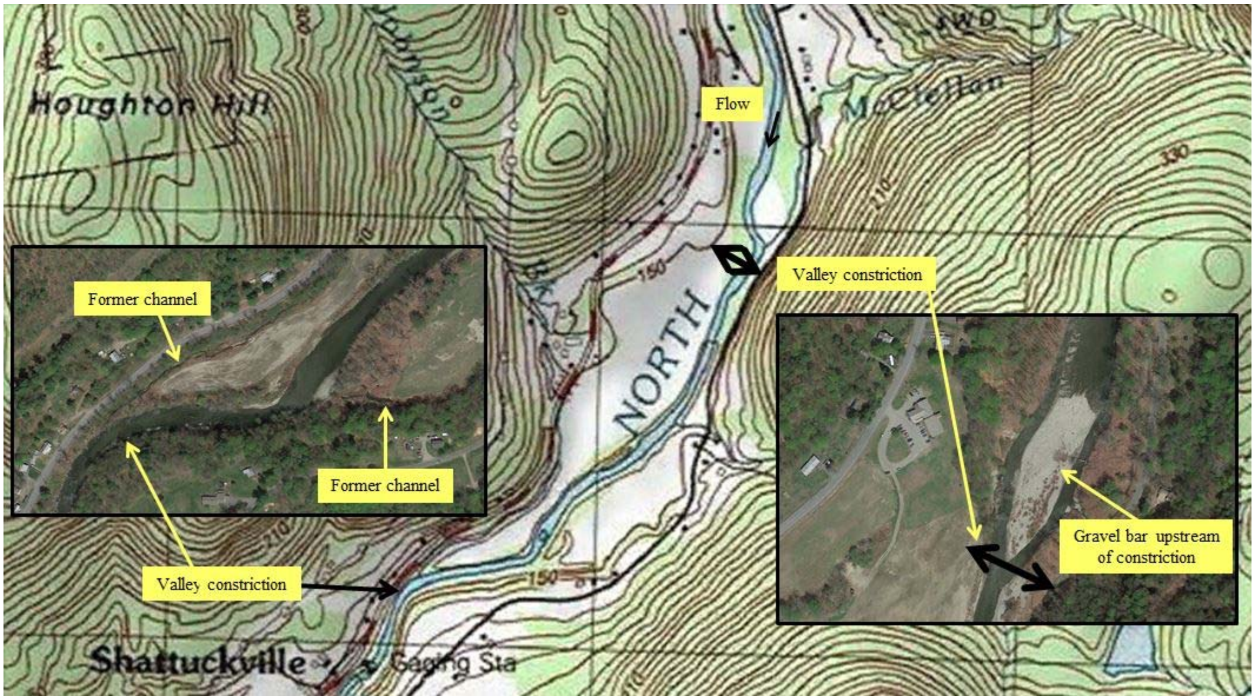
Elsewhere in New England, including on the North River as shown below, meanders have also reformed along straightened channels. These reformed meanders can be identified by their characteristic asymmetric shape (as in the Batten Kill example above) and represent priority areas for land conservation, because the quality of aquatic habitat is higher in meandering sections compared to straightened reaches. Furthermore, ensuring that the reformed meanders can continue to evolve slowly within a protected area reduces the chances of other meanders reforming rapidly in adjacent areas where the channel may remain in a straightened condition.



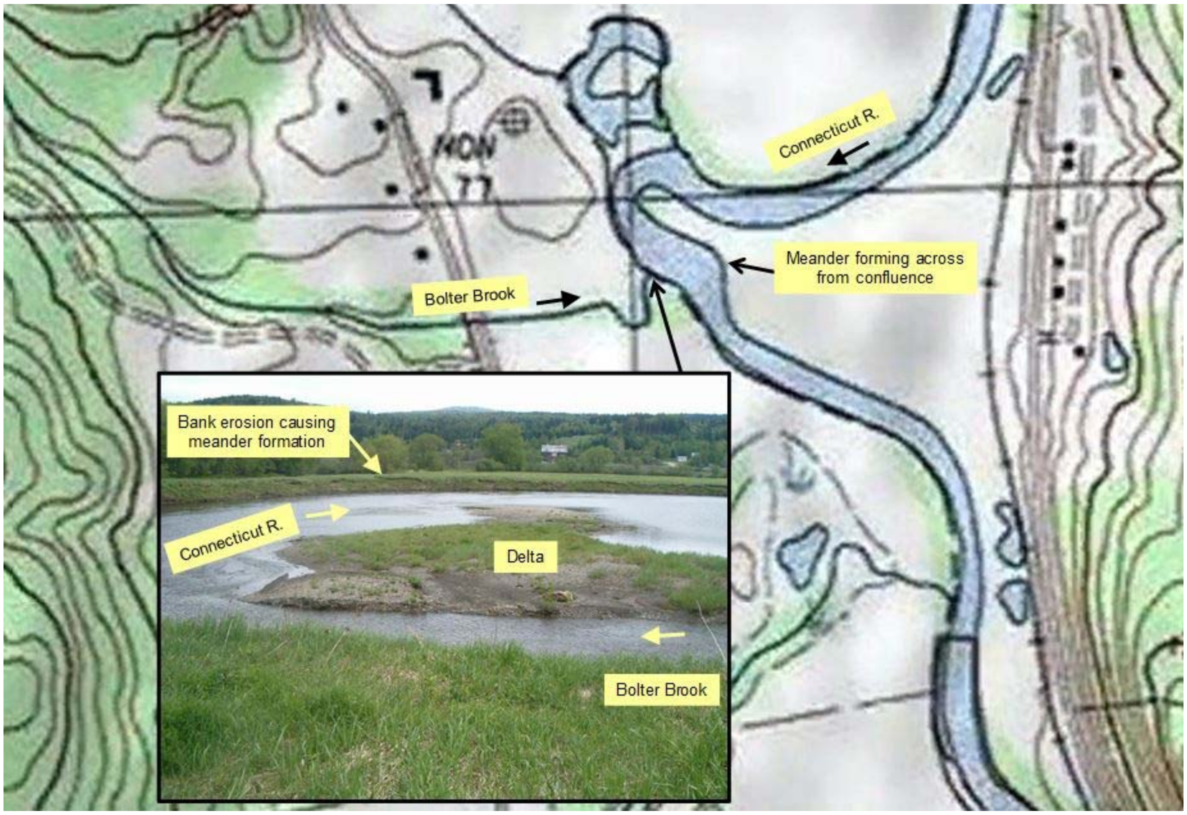
Rapid and significant channel change can also occur just upstream of valley and channel constrictions where backwatering during floods can cause rapid sediment deposition within the channel and channel migration as the flow is diverted into the river's banks. In the figure below from the Ammonoosuc River in Bath, NH, a large meander was first formed before the 1980s and then cutoff between the 1980s and 2009 because of large volumes of sediment infilling the channel that was deposited upstream of the significant valley constriction. In the process of cutting off the meander, the river overran a bank that had been protected with riprap (now a riffle of large stone crossing the river), highlighting the potential risk to infrastructure that exists in the vicinity of valley and channel constrictions.



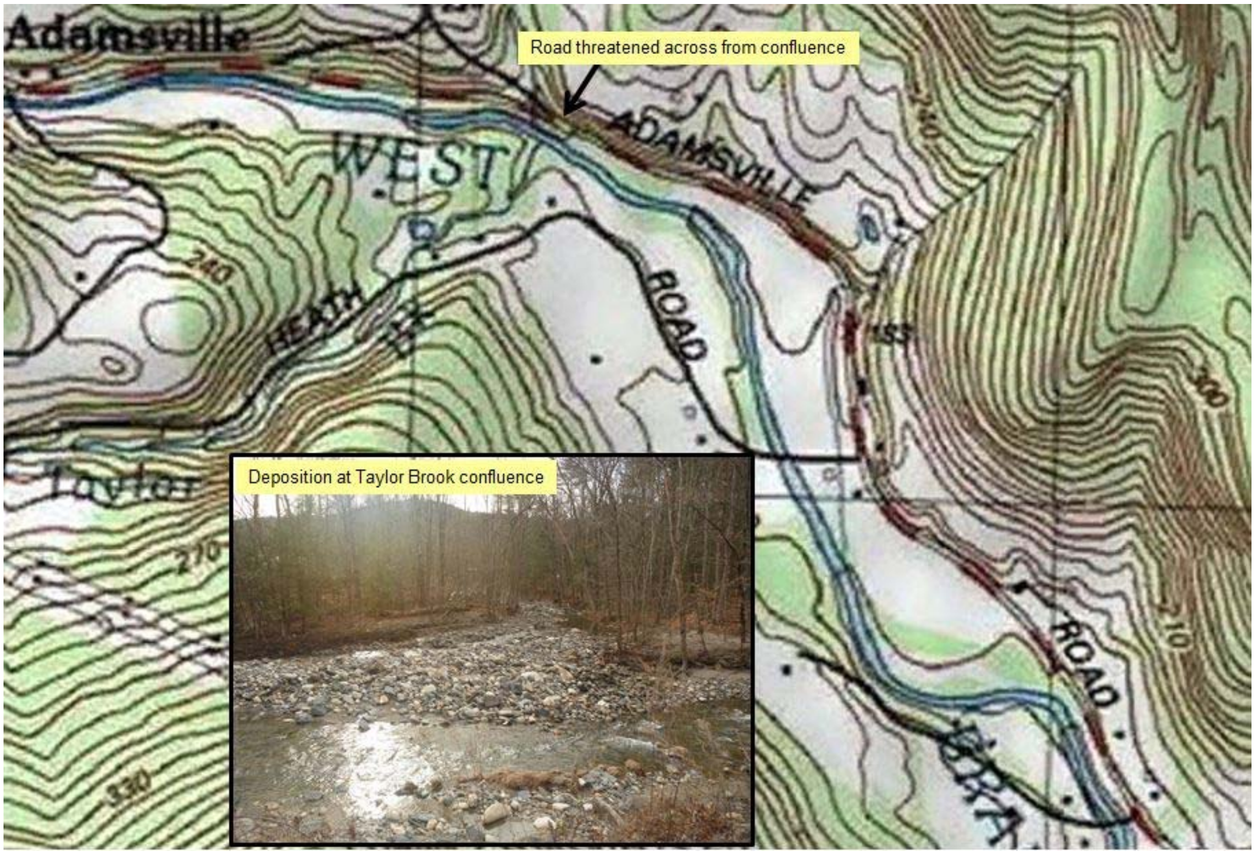
The example from the North River below underscores how common valley constrictions are along rivers and streams throughout New England and how such constrictions can be readily identified with topographic maps (as well as LiDAR). Identifying valley constrictions can be used to locate at-risk infrastructure in areas immediately upstream where severe deposition and channel migration are most likely to occur during a severe flood. These areas should be considered priority areas for land conservation as deposition, channel migration, and associated hazards are likely to persist for millennia at most valley constrictions. All bridges and culverts must also be considered potential channel constrictions. How constrictive these stream crossings are is difficult to ascertain without field verification, but when the crossing structure is much narrower than the channel width then deposition upstream can cause bank erosion and overtopping of the road surface itself (see Step 6 below).



A third setting where rapid and significant channel change can occur is at tributary confluences where the influx of sediment can divert flow into the bank opposite of the tributary mouth, leading to erosion, channel migration, and ultimately the formation of meander bends as exemplified below at the confluence of Bolter Brook and the Connecticut River in Canaan, VT.

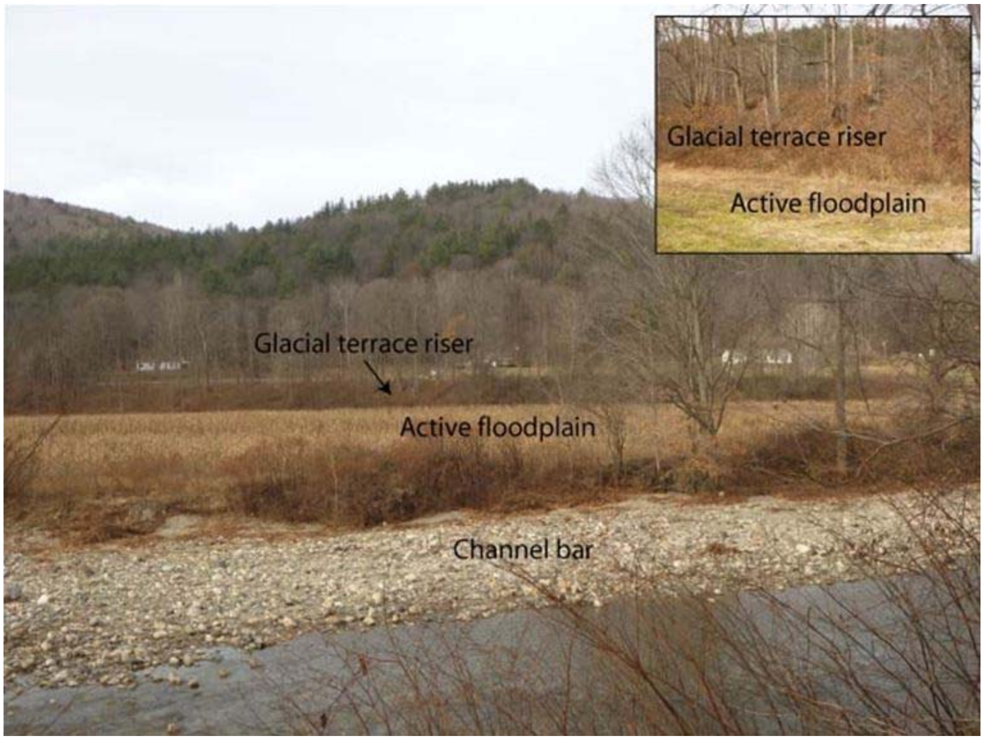


Noting the location of tributary confluences provides an indication of where significant deposition and channel migration might occur, a valuable tool in identifying at-risk infrastructure in the river corridor. Tributary confluences where significant sediment accumulation is occurring or could occur in the future represent priority areas for land conservation. In the North River watershed as shown below, the confluence of Taylor Brook and the West Branch is a site of significant sediment accumulation that could cause channel migration and threaten Adamsville Road across from the tributary mouth during a future large flood.



Step 6 – Field verification of corridor boundaries

Field verification is essential to confirm the findings from remotely sensed data. The field verification is useful in confirming: 1) the location of river terraces, 2) the presence of former channel positions, and 3) areas with a greater likelihood of rapid and significant change. In the photograph below of the North River, the position of terraces relative to the channel and active floodplain can be confirmed and the location of the corridor boundaries verified:



The position of former channels can be confirmed by noting the presence of larger depressions that once conveyed the river's full flow but now only receive minor flow from tributaries or as a side channel off of the new main flow path as exemplified below from the North River where reactivation of the former flow path (now side channel) could threaten Call Road during a large flood:

In addition to identifying at-risk infrastructure near straightened channels, valley/channel constrictions, and tributary confluences as illustrated in Step 5 above, field verification can also identify high eroding banks where the river is impinging on steep terrace risers that are generally located in narrow sections of the valley downstream of constrictions. Not only can infrastructure on top of the eroding bank be threatened but downstream areas can also experience significant sediment deposition and channel migration due to the large volumes of sediment generated from the high eroding bank as illustrated from the North River below:

APPENDIX 3

(River corridor maps of the North River – see accompanying digital files)

APPENDIX 4

(Fluvial erosion hazard maps of the North River – see accompanying digital files)