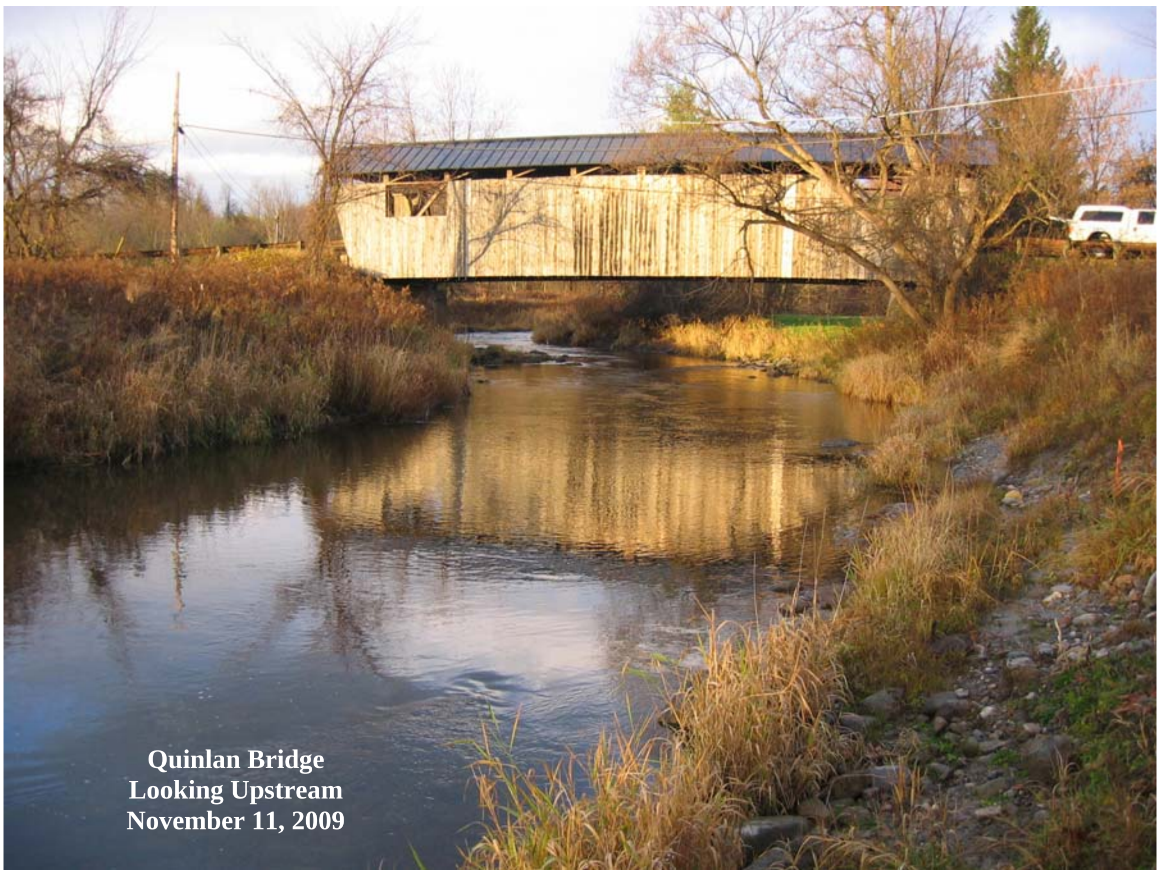
Quinlan Bridge Area Alternatives Analysis to Reduce Flood and Erosion Risks

Charlotte, Vermont

April 2010



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With support from:
VT Agency of Natural Resources
Town of Charlotte
Landowners in Vicinity of Quinlan Bridge

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Executive Summary

The Lewis Creek Association, together with its consultants South Mountain Research & Consulting and Milone & MacBroom, Inc., has completed an alternatives analysis to reduce flooding and erosion risks at the Quinlan Bridge and reconnect the channel to historic floodplains.

Project objectives included:

Goal 1. Reduce flood, erosion, and ice jam risks near Quinlan Bridge.

- Objective 1-1. Reduce flood and erosion risks during break-up ice jamming during small to moderate storms typically during spring thaw or occasionally during a January thaw.
- Objective 1-2. Improve flood relief for future non-ice large storms.
- Objective 1-3. Protect historic Quinlan Bridge.

Goal 2. Restore Lewis Creek and associated wetlands

- Objective 2-1. Re-connect the channel to historic floodplains.
- Objective 2-2. Promote natural channel stability (and naturalize local sediment and debris transport) to improve habitat.

The alternatives analysis was initiated based on past study of the river and recommendations in the *Lewis Creek Watershed: Corridor Conservation & Management Plan* (SMRC, 2010). Assessment and study were performed with input from the landowners in the immediate vicinity of the Quinlan Bridge site and the Charlotte road commissioner. Results were then presented to the Charlotte Select Board and the public. The alternatives analysis included the following elements:

1. Compilation of historic data documenting flooding at the site and the existing channel and watershed stressors;

2. A field survey of the river channel and floodplain through a 3,300-foot project area spanning the bridge, including documentation of the channel bed sediment size by pebble counts;

3. A hydrologic analysis to establish flood characteristics for this stretch of the Lewis Creek;

4. A hydraulic analysis to model flow depths and velocities, ice jam flooding, and sediment transport under existing and proposed conditions (alternatives); and

5. Evaluation of alternatives to naturalize flow and sediment transport in the study reach.

The Quinlan Bridge area experiences ice jams during spring runoff and occasionally during a January thaw approximately every 2 years. Ice jamming takes place on a sharp bend of the river upstream of the bridge and leads to minor overtopping of Spear Street. Water flows to some historic floodplains that are mostly disconnected from the river channel. The releasing ice jam and limited floodplain connection causes unusually high flow velocities at the bridge. The existing bridge has good flood capacity yet limited pressure-relief due to disconnected floodplains. Flood flows, ice and debris mostly confined to the channel hit the right bridge abutment and have led to concrete deterioration and some undermining. Additional study is needed to characterize the condition of the bridge abutments and prescribe necessary improvements.

Several of the explored alternatives reduce local flood velocities, erosion potential, and flood water surface elevations at the bridge by improving the connection to historic floodplains. Desirable methods to meet project objectives include:

- Remove 2-foot tall berm along Spear Street to the north of Quinlan Bridge;
- Enlarge small bridge under Spear Street to the west of Quinlan Bridge;
- Lower Spear Street 1.5 feet to the north of Quinlan Bridge and armor new embankment; and
- Lower Spear Street 1.5 feet to the west of Quinlan Bridge.

These alternatives have been recommended for implementation to reduce existing flooding and erosion risks at the Quinlan Bridge. Implementation could be sequenced, incorporated into on-going Town maintenance, and take advantage of available grant funds.

Local landowners support the recommended alternatives, yet concerns exist in the Town about increasing the number of times Spear Street is flooded and the length of time water would flow over the road surface. Alternative routes exist for detours during flooding, and engineering design would safeguard the road surface from scour. The recommended alternatives reduce the risks of bridge failure.

The Town expressed interest in protecting the streambank at the sharp bend approximately 400 feet upstream of Quinlan Bridge where Lewis Creek flows directly at the right bank (facing downstream). Erosion is threatening to undermine Spear Street as it drops in elevation approaching Quinlan Bridge. Riprap is recommended on the lower bank in this location – only after some degree of floodplain connection is restored along the Lewis Creek between this location and the Quinlan Bridge. If riprap installation in this location was the only mitigative action taken in vicinity of the bridge, the hydraulic force on the bridge would increase as energy that now erodes the river bank would be transferred downstream to the bridge and likely further impact the right abutment. Riprap installation at the sharp bend is thus only recommended in conjunction with some level of floodplain reconnection identified in the preferred alternatives that will begin to reduce flood velocities and erosion potential at the bridge site.

1.0 Introduction and Project History

An Alternatives Analysis was undertaken for the Lewis Creek in vicinity of the historic Quinlan Bridge at the Monkton Road crossing in Charlotte, Vermont. This location has long been a site of conflict between a dynamically adjusting river and closely-encroaching human infrastructure. The Quinlan Bridge span is less than the natural bankfull width of the Lewis Creek channel, and the bridge is oriented at a sharp angle to the Lewis Creek. Flows are constricted through the bridge span leading to upstream aggradation and scour of the bridge abutments. Encroachments in vicinity of the bridge (Spear Street, Monkton Road) are elevated above the flood plain and both laterally and vertically constrain the channel and floodplain on approach to the bridge. Ice jams regularly cause localized flooding upstream and downstream of the bridge, threaten the integrity of the abutments of this historic bridge, and subject a nearby residential property to inundation flooding and fluvial erosion hazards.

On 9 June 2009, the property owner directly northeast of the bridge, Jim Morse, invited Chris Brunelle (Stream Alteration Engineer with VT Agency of Natural Resources) to his property to review a pending application for a Stream Alteration Permit to install riprap armoring along a section of the southern bank of Lewis Creek. Mr. Morse also invited Lewis Creek Association (Marty Illick, Executive Director) and their consultant, South Mountain R&CS (Kristen Underwood) to review the site. In recent years, Mr. Morse has noticed increased erosion along his stream bank, as the southern half of a split-channel section has grown in width carrying a larger proportion of the overall flow in Lewis Creek. He is also concerned about ice damage and inundation flooding impacts to his lower lawn, that at times comes close to the house.

During on-site discussions, it was recognized that the installation of riprap armoring on the Morse property represented a small-scale and short-term “band-aid” approach to resolving the ongoing conflicts between the river and human investments. A more system-wide approach that directly addresses the reach-scale and watershed-scale stressors would be more sustainable over the long term. An alternatives analysis for the bridge vicinity was recommended, including consideration of an engineered overtopping of Spear Street.

With approval from the town of Charlotte and landowners in direct vicinity of the bridge site, Lewis Creek Association (LCA) of Charlotte, Vermont, applied for and received funding from the VT Agency of Natural Resources, Department of Environmental Conservation to carry out an alternatives analysis. The Town of Charlotte is currently overseeing repairs to the superstructure of this historic covered bridge during a separate VTrans project and was interested in identifying long-term, sustainable solutions to repeated ice jam flooding and fluvial erosion hazards in vicinity of this crossing. Landowners near the bridge also expressed support for a long-term restoration solution that reduces risk of inundation and erosion hazard flooding at this location.

A FY2010 Ecosystem Restoration Grant from the VTANR Center for Clean and Clear funded this study. LCA was assisted by its technical consultants South Mountain Research & Consulting of Bristol, VT (geomorphology) and Milone & MacBroom, Inc. of South Burlington, VT (engineering). This project involved the participation of landowners in direct vicinity of the bridge site (Morse, Sheldon-Dean, Congdon, and Town of Charlotte) as well as representatives of the Charlotte Selectboard (Cole, Stone) and the Charlotte road commissioner (Lewis). Participants were invited to meetings held at the Charlotte town hall on 26 January 2010 and 23 February 2010 to find consensus on project objectives and to provide input into the alternatives analysis.

Identified goals and objectives of the project are to:

Goal 1 Reduce flood, erosion, and ice jam risks near Quinlan Bridge.

Objective 1-1 Reduce flood and erosion risks from break-up ice jam during small to moderate storms typically during January to April thaw which sometimes but not always coincide with annual peak flow (or bankfull) conditions recorded at the Route 7 USGS gauge.

Objective 1-2 Improve flood relief for future non-ice large storms.

Objective 1-3 Protect historic Quinlan Bridge.

Goal 2 Restore Lewis Creek and associated wetlands

Objective 2-1 Re-connect the channel to historic floodplains.

Objective 2-2 Promote natural channel stability (and naturalize local sediment and debris transport) to improve habitat.

2.0 Study Site

2.1 Geographic Setting

This study focuses on the Lewis Creek channel and adjacent floodplain in vicinity of the Quinlan Bridge (Monkton Road crossing) in southeastern Charlotte (Figure 1). Quinlan Bridge is located within 50 feet to the east of the Monkton Road intersection with Spear Street. The upstream drainage area of the river at this location is approximately 71 square miles. Landowners in direct vicinity are identified in Appendix A.

2.2 Geomorphic Setting

Regionally, the study section of the Lewis Creek is located at the transition from a semi-confined valley to a much broader alluvial valley. The area and distribution of hydric soils in vicinity of the Quinlan Bridge site suggest that in pre-colonial times, the Lewis Creek may have meandered farther to the north and west of the current bridge site, with a greater radius of curvature (Figure 2).

Beds of north-northeast trending Monkton Quartzite bedrock cut across the channel in at least five separate locations of the channel upstream of the Quinlan Bridge. Channel-spanning bedrock is also exposed approximately one third of a mile upstream in vicinity of the Scott Pond Dam. The configuration of the exposed bedrock upstream of the Quinlan Bridge contributes to a pronounced meander of the channel and local widening.

Over past centuries, human structures have been installed that constrain the channel in vicinity of the Quinlan Bridge. As a result of periodic flood damages this infrastructure has been reinforced and protected through costly channel management, streambank armoring, and berms.

- Roads were constructed along the river prior to the mid-1800s and have effectively cut off access to portions of the natural floodplain and wetlands. Encroachments include Spear Street (paved) along the north side of the channel and Lewis Creek Road (gravel) along the south side of the channel upstream of the Quinlan Bridge. The height of both roads has been raised over the years, resulting in more pronounced entrenchment of the channel. Spear Street has been bermed along the southeast side upstream of the Quinlan Bridge. Streambank armoring has been installed along both banks of the channel upstream of the bridge.

- A bridge has spanned the channel at Monkton Road since at least the early 1800s. The existing covered bridge was constructed c.1850 following loss of the previous bridge in a flood. The Quinlan Bridge is undersized with respect to the bankfull width and oriented at a sharp angle to the Lewis Creek channel. Local folklore indicates that, following the 1850 washout of the bridge site, a second channel was blasted to the north of the original channel upstream of the bridge to create a straighter approach. In recent years, the original channel has widened and deepened and now directs flow perpendicularly at the right bank of the river (facing downstream). The Town of Charlotte recently installed riprap armoring along the streambank in this location.

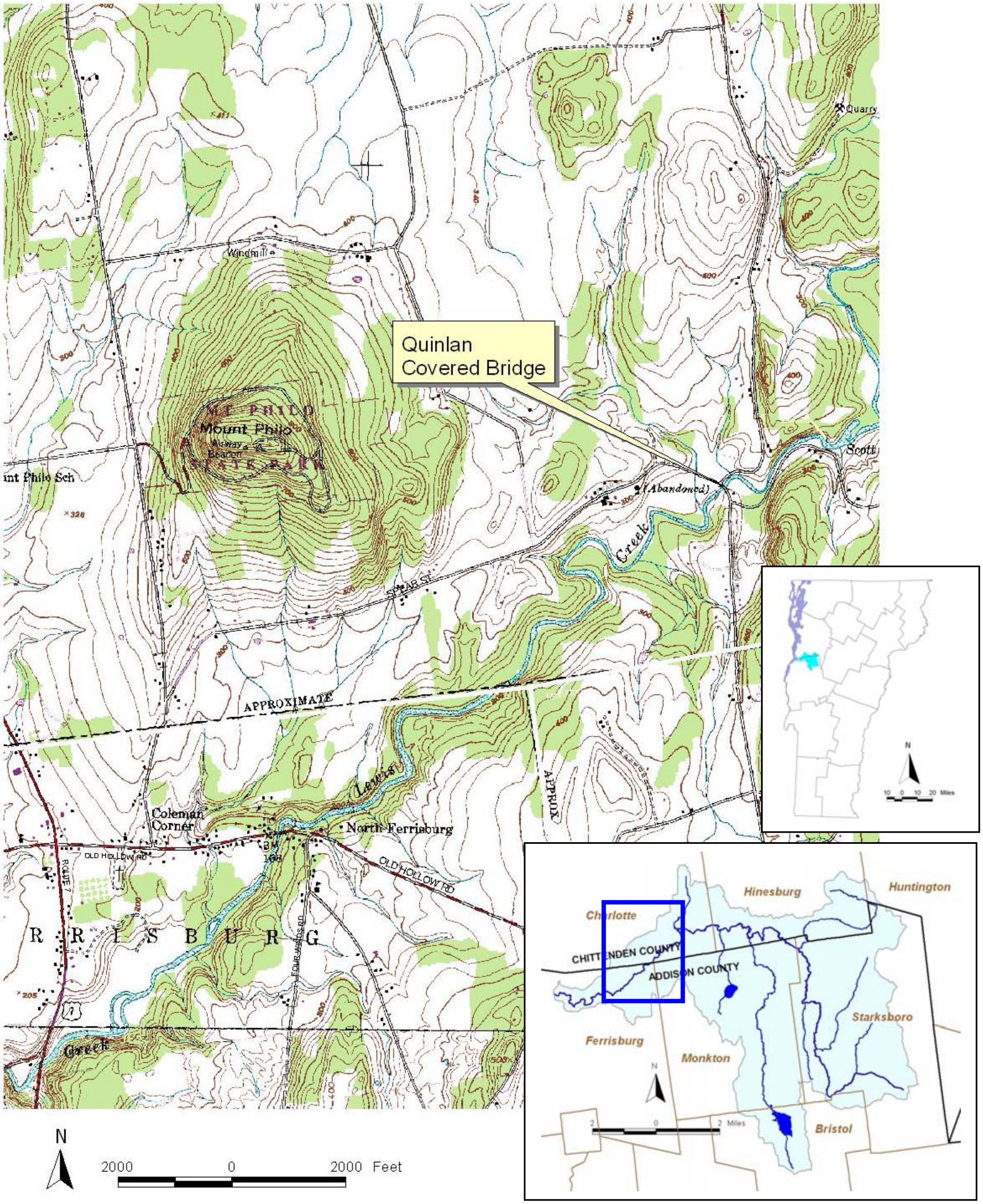


Figure 1. Site Location Map: Quinlan Covered Bridge Area on Lewis Creek in Charlotte, VT.

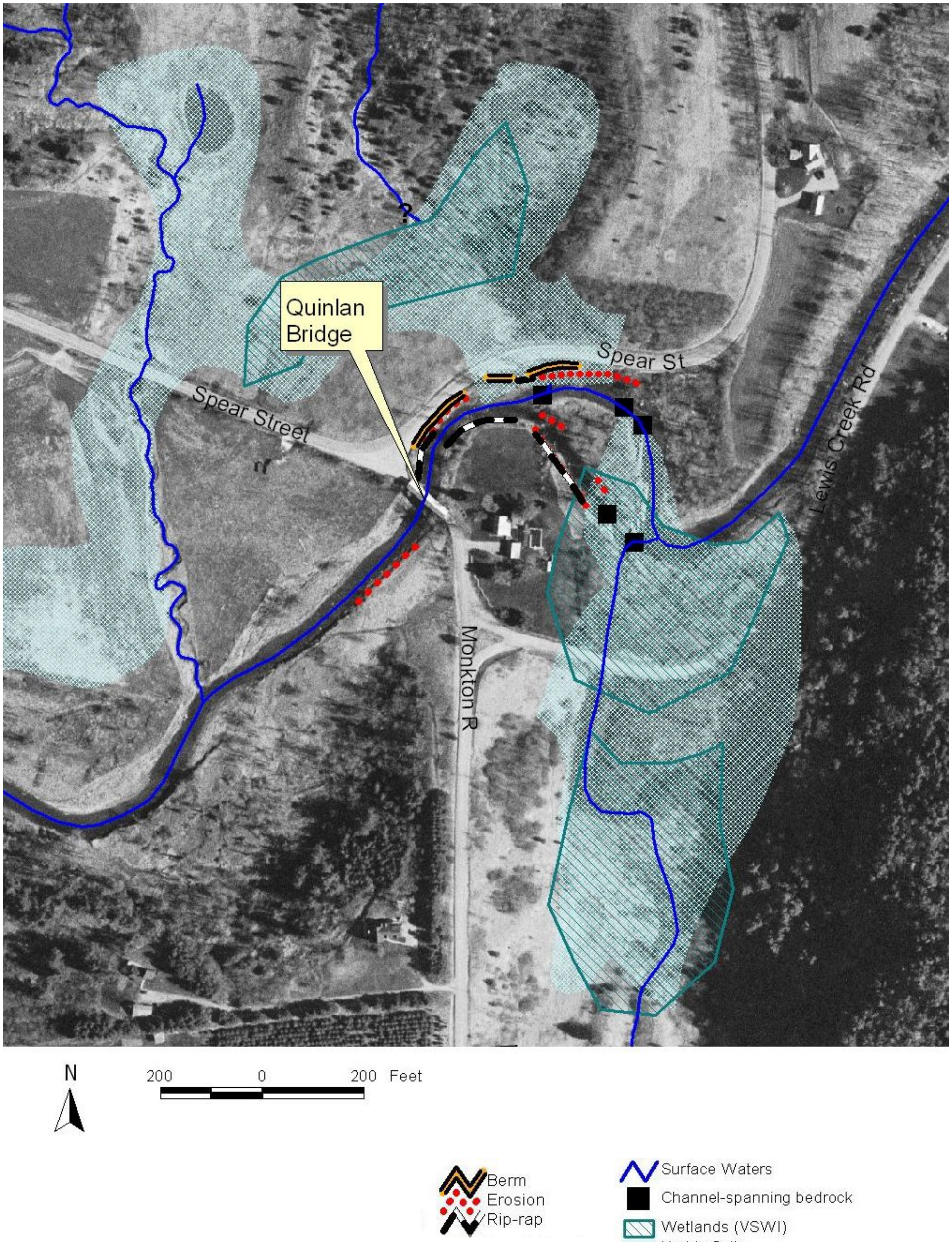


Figure 2. Quinlan Bridge Vicinity Map

- As early as the middle 1800s a dam was present in vicinity of the current Scott Pond Dam to support various mill enterprises (Rann, 1886; Beers, 1869; Walling, 1857). Past configurations of the dam were reportedly higher in elevation and impounded a greater upstream area (VTANR, 1992; USGS, 1905). Following a period of dis-repair during which the dam was breached, the site was rehabilitated in 1992 and 1994, resulting in the current structure that operates as a run-of-river structure with a minimal upstream impoundment. At present, the dam is maintained as a barrier to the upstream migration of sea lamprey (USFW et al, 2001). It is possible that "hungry water" effects of the Scott Pond Dam led to channel incision (i.e., channel down-cutting) below the dam site, as sediments were generally impounded above the dam. It is also possible that channelization or gravel extraction measures along this section of channel have historically contributed to increased incision – although no specific reference to such channel management was obtained in a limited historical review. The linear nature of the channel in this reach is in part associated with the bedrock-controlled valley.

Channel and bank erosion in the Lewis Creek have been accelerated by the human encroachments. The channel has lost most of the connection to the floodplain along the left bank 800 feet upstream of the bridge where channel-contiguous wetlands may historically have offered more flow and sediment attenuation. The channel has also lost most of the connection to the floodplain along the right bank 250 feet upstream of the bridge. The entrenched condition of the channel results in concentrated flow leading to higher velocity and thus more potential for erosion along Morse lands and at the Quinlan Bridge site.

Watershed-scale stressors over recent centuries are likely contributing to increased flooding at the Quinlan Bridge site, including:

- Changing climate patterns: Average annual precipitation in the Northeastern United States has increased approximately 3.3 inches over the period from the year 1900 to 2000. The frequency and number of intense precipitation events (defined as more than two inches of rain in a 48-hour period) has also increased, particularly in the last quarter of the 19th century (UNH Climate Change Research Center, 2005). The magnitude and frequency of large storms appears to be increasing throughout much of Vermont and New England (Collins, 2009).

- Changes in land use in the upstream watershed, including increasing development and density of road and driveway networks contributing untreated stormwater runoff to the channel; and loss of upstream wetlands through ditching, tiling and conversion to agricultural fields and pasture (SMRC, 2010).

2.3 History of Flooding

A recent flood history at the study site is evident from review of records at the United States Geological Survey continuously-recording flow gauge (Station #04282780) on the Lewis Creek, located nearly 4 miles downstream of Quinlan Bridge near the Route 7 crossing. This gauge measures flow from an approximate drainage area of 77 square miles, and has recorded daily flows dating back to 1990. The maximum peak flow recorded during this period was 4,030 cubic feet per second (cfs) on 20 May 2006; corresponding to an approximate 25-year to 50-year storm (Olson, 2002).

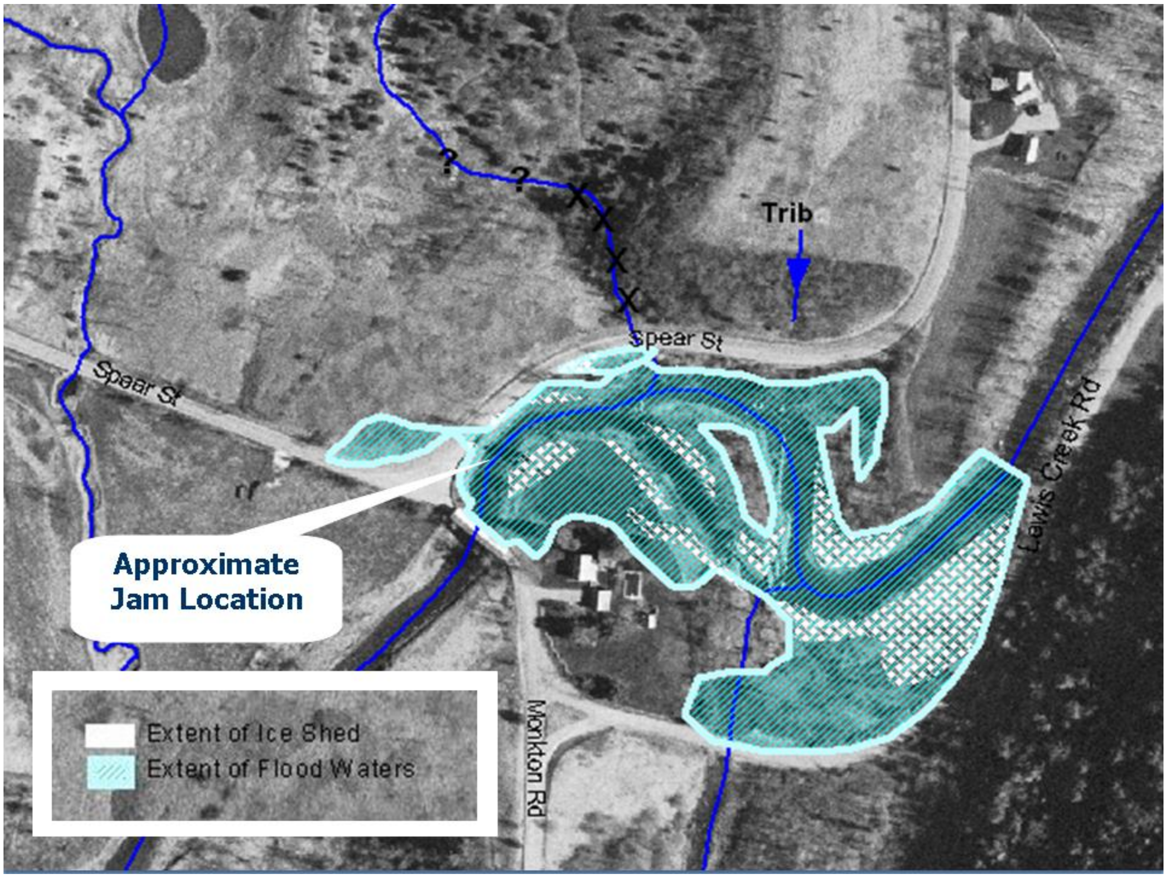
Historical records indicate larger flood events occurring in years prior to establishment of this USGS gauge, including the floods of 1938, 1936, 1927 and 1913. The 1927 flood was the highest flood on record in the State of Vermont (USGS, 1990; Wernecke & Mueller, 1972).

Local landowners have reported that break-up ice jam events occur in vicinity of the Quinlan Bridge every few years and result in inundation and erosion of the Morse residential lands and occasional over-topping of Spear Street. The abutments of the Quinlan Bridge are impacted during flooding and ice jams. The right (facing downstream) abutment on the north side of the channel has cracks, dislocated concrete, and undermining. The ice jam events occur during small to moderate storms, typically during thaw conditions that occur from January to April. These events often coincide with the annual to bankfull (i.e., 1- to 2-year flood) peak flow condition recorded at the Route 7 USGS gauge approximately 4 miles downstream of the Quinlan Bridge.

The Ice Jam Database maintained by Cold Regions Research & Engineering Laboratory of the U.S. Army corps of Engineers records a somewhat significant ice jam occurring on 10 March 1992. "An ice jam about 400 to 600 feet long formed on Lewis Creek at a bend and caused residential and road flooding, riverbank and bed erosion, erosion of a dirt road [Lewis Creek Rd] and structural damage to pavement [Spear St] (CRREL, 2009)." This event corresponded with the annual peak flow recorded at the USGS gauge of 2,000 cfs on 11 March 1992.

An ice jam flood event occurred during this study on 25 January 2010. A 10- to 12-inch-thick layer of ice cover had developed in upstream sections of the Lewis Creek during a two-and-a-half week period from 28 December 2009 through 13 January 2010 as temperatures remained at or below freezing and snow fell almost daily (National Weather Service, 2010). For the next week, daily high temperatures climbed slightly above freezing, followed by five more days of sub-freezing temperatures and trace accumulations of snow. On 25 January 2010, temperatures warmed to the mid-50s Fahrenheit, and just over one inch of rain fell steadily throughout the day. Most of the precipitation ran off the frozen ground surfaces of the upstream watershed to the tributaries of Lewis Creek, resulting in a relatively rapid rise in water levels in the river and a sudden break-up of ice cover. USGS provisional data estimated the maximum flow at the Route 7 gauge to be just over 4,000 cfs, corresponding to a 25-to 50-year storm (Olson, 2002; peak flow estimates at the project site generated for this study). Area gauged watersheds experienced a similar flood response, ranging from a 2-yr to 25-yr event (Little Otter Creek, LaPlatte River, New Haven River; USGS, 2010).

A moderate break-up ice jam flood occurred in the vicinity of Quinlan Bridge that peaked around 8:00 PM on 25 January 2010 (Illick, 2010). The location of the jam was approximately 100 feet upstream of the Quinlan Bridge (Morse, 2010). Inundation flooding and ice shedding impacted a wide area upstream of the bridge (see Figure 3a), including the left-bank wetland along Lewis Creek Road, backwater areas to the northeast of the bifurcated channel, and extensive areas on the Morse residential property. Water and ice filled the pull-off along Spear Street to the north of the bridge, and water had just begun to overtop Spear Street approximately 125 feet upstream of the bridge before the jam released and flood levels lowered. The flood lasted for several hours.



(a)

(b)

(c)

Figure 3. Ice jam flooding event, 25 January 2010. (a) approximate extent of inundation and ice shed; (b) view downstream to Morse residence as flood waters receded on 26 January 2010; (c) view downstream along south streambank at Morse property on 28 January 2010.

3.0 Hydrology

Peak flow estimates at the project site were estimated by scaling USGS gauge data (Lewis Creek at North Ferrisburg USGS#04282780) based on drainage area (Table 1). The drainage area at the gauge is approximately 77 square miles, while the drainage area at the project site is approximately 71 square miles. Estimates were also made using regression analysis for the state of Vermont (USGS StreamStats, 2010; Olson, 2002). Flow estimates varied and peak flow estimates calculated using the USGS gauge data were selected to take advantage of the nearby real-time data.

Table 1: Estimates of Project Site Stream Flows

Storm (year)	Gauge Analysis (cfs)	Regression Analysis (cfs)
2	1,723	1,630
5	2,730	2,360
10	3,423	2,880
25	4,317	3,570
50	4,986	4,090
100	5,657	4,630
500	7,227	5,960

4.0 Hydraulic Modeling

4.1 Modeling Approach

A hydraulic analysis was conducted to simulate flow depth and velocity for the non-ice and river ice scenarios for existing conditions and the alternatives. Sediment transport analysis was also performed. Hydraulic modeling was performed with HEC-RAS Version 4.0 (USACOE, 2005). HEC-RAS was used to compute water surface profiles for one-dimensional, steady state, and gradually varied flow.

The basic computational procedure of HEC-RAS is solution of the one-dimensional energy equation. Energy losses are evaluated by friction (i.e., Manning's Equation) and contraction/expansion coefficients multiplied by the change in velocity head. The momentum equation is used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations, hydraulics of dams and bridges, and evaluating profiles at river junctions.

Sheet ice and ice jam analysis were performed in HEC-RAS following methods in the Ice Engineering Manual (USACE, 2002). Ice jam modeling follows the Mohr-Coulomb theory balancing the forces on the ice granules due to buoyancy, water drag, and gravity. Ice cover thickness was determined in the field to range between 0.75 and 1.0 feet. Ice roughness was taken as 0.03, and increased in jam locations. The specific gravity of the ice was set at 0.916.

A mobile bed sediment transport analysis was performed in HEC-RAS using quasi-steady flow, the Meyer, Peter, Muller (MPM) transport function, and the Exner 5 sorting method. A potentially mobile control volume 5 feet thick was set at each cross section in the area of flow. Bed particle gradations were entered for each sediment reach from collected pebble count data (Appendix B). An equilibrium load was used as the sediment boundary condition at the upstream end of the model so that sediment incident on the main project site originated from mobilized bedload from upstream. The change in channel bed elevation after a modeled 1- to 2-year storm was used to investigate changes in sediment transport capacity.

4.2 Geometry Set-Up

A field survey was conducted along a half-mile section of the Lewis Creek centered on the Quinlan Bridge (Monkton Rd) (Figure 1). The study section extends from just upstream of the Scott Pond Dam off Lewis Creek Road to approximately 500 feet downstream of the Quinlan Bridge (just above the confluence of a right-bank tributary draining through lands of Congdon). The survey was conducted with an engineer's transit generally in accordance with Vermont Phase 3 Stream Geomorphic Assessment protocols (VTANR, 2009). Survey data (available on CD-ROM) include a 3,360-foot longitudinal profile, twelve cross sections, Scott Pond Dam, and Quinlan Bridge (Figure 4). Seven pebble counts (Wolman, 1954) were performed to define the sediment size in the channel.

Cross sections were chosen in the field to represent major changes in channel and floodplain configuration. Contraction/expansion coefficients and friction values (i.e., Manning's N) were determined during field assessments. Roughness values for the channel ranged between 0.03 and 0.05, while floodplain roughness ranged between 0.04 to 0.08. Normal water surface elevation (i.e., the depth of flow in the channel is constant and the slope of the water surface matches the channel bottom) was used for the upstream and downstream boundary conditions.

Figure 4: Cross section locations used in hydraulic modeling.

4.3 Flow Data

Existing conditions and alternatives were initially modeled for all estimated peak flows (Table 1). Ice jam flooding focused on the 10-year storm event that was determined to be the flood size that best represents past flooding scenarios based on flood history, gauge records, model validation, and information provided by local landowners. Sediment transport analysis explored the 1- to 2-year flood to approximate a channel-forming flow (i.e., the flow that transports the most sediment over the long-term and thus largely determines the channel dimensions).

5.0 Alternatives Analysis

A wide range of alternatives was initially explored to reduce flood and erosion risks. The list of alternatives was presented to and refined by landowners adjacent to the project site, the town road commissioner, and individual members of the Charlotte Select Board during a meeting on 26 January 2010. Preliminary alternatives included:

- No action (existing conditions);
- Reconnect the Lewis Creek channel to the left-bank wetland along Lewis Creek Road upstream of the Morse residence and Quinlan Bridge;
- Reconnect the Lewis Creek channel to left-bank wetlands across Lewis Creek Road;
- Remove 2-foot tall berm along Spear Street north of Quinlan Bridge;
- Enlarge small bridge (box culvert) under Spear Street west of Quinlan Bridge;
- Install culverts under Spear Street north of Quinlan Bridge;
- Lower Spear Street to the north of Quinlan Bridge by 1.5 feet;
- Lower Spear Street to the west of Quinlan Bridge by 1.5 feet;
- Realign the Lewis Creek channel to the existing bridge opening to soften the approach angle of the channel; and
- Realign the Quinlan Bridge to the existing channel planform to increase the span between abutments and soften the approach angle of the channel.

Alternatives were initially modeled individually to understand effects on flood stages, flow velocities, ice shed, and sediment transport. Once alternatives were identified that met project objectives, combinations were modeled to narrow in on a group of preferred alternatives.

5.1 No Action (Existing Conditions)

The no action alternative is the first evaluated to understand existing conditions and verify the risks at Quinlan Bridge identified during past geomorphic assessments and corridor planning. Under current conditions, ice jams of varying degree and extent occur every few years. The location of these ice jams varies, but frequently occurs at the incised and entrenched channel cross section just upstream of the Quinlan Bridge. Lower lawn areas of the Morse residential property become inundated and covered with ice. Occasionally, flood waters and ice chunks overtop Spear Street, sometimes leading to temporary road closures and pavement buckling.

The Quinlan Bridge is relatively high above the channel, and thus has considerable flood capacity and clearance. Nevertheless, the structure does cause a rise in water surface elevation upstream of the bridge opening (i.e., backwatering) for storms larger than the 2-year flood (Figure 5). As with most crossing structures that are undersized relative to natural channel width, the downstream movement of flood water, sediment, ice, and debris is slowed at Quinlan Bridge. At the same time, contracted flows accelerate under the bridge leading to increased scour that impacts the abutments. The bridge opening width (at the 2-year flood level) is approximately 62 feet (Figure 6) while the upstream channel bankfull width is approximately 74 feet. The sloping bridge abutments lead to a low-flow channel width of approximately 50 feet that further reduces the capacity of the opening.

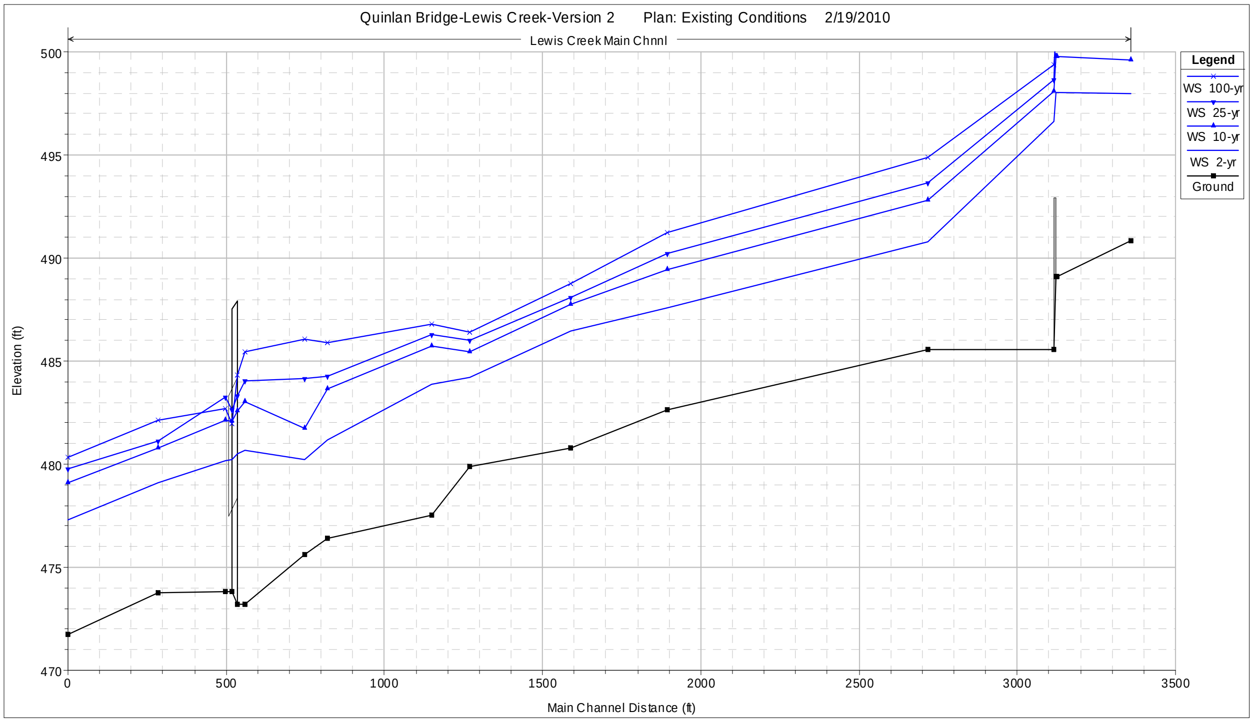


Figure 5: HEC-RAS existing conditions river profile showing the peak flood water surface elevations for the 2-, 10-, 25-, and 100-year storms.

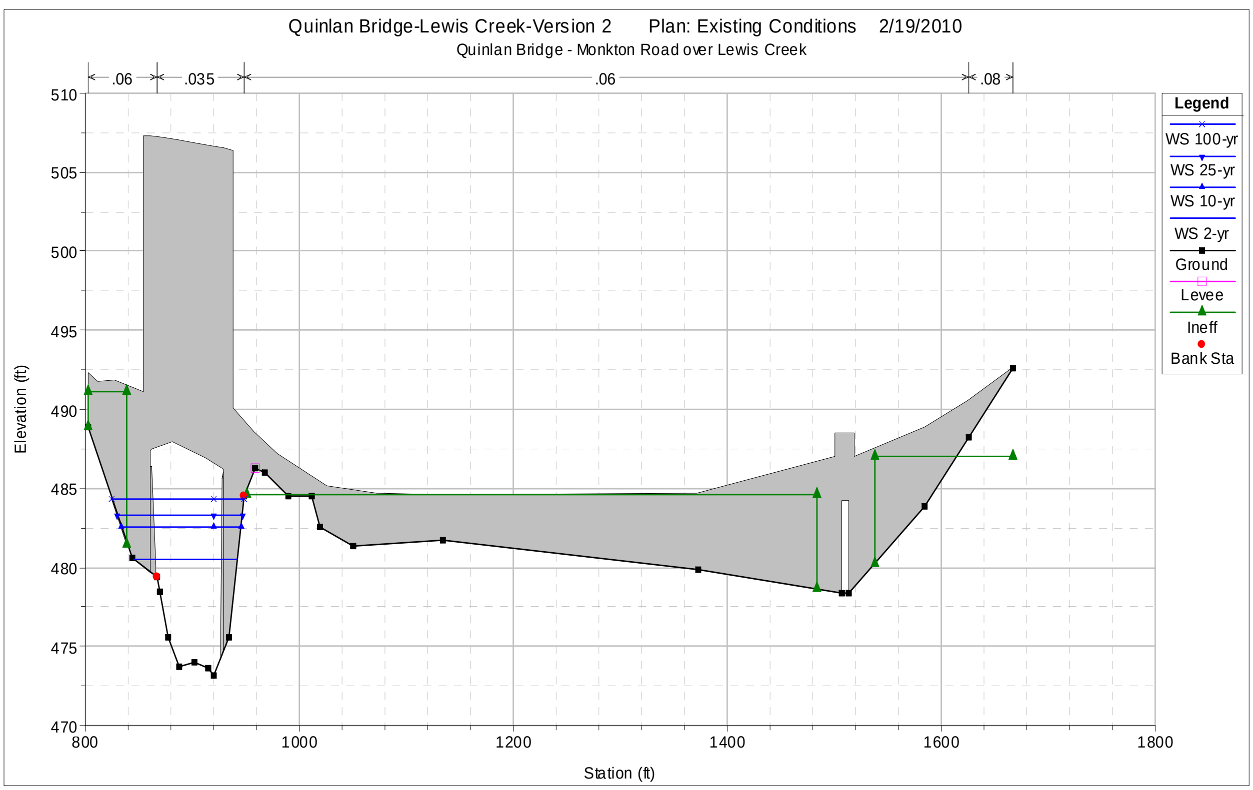


Figure 6: HEC-RAS existing conditions cross section of the upstream face of Quinlan Bridge showing water surface elevations for the 2-, 10-, 25-, and 100-year storms.

The hydraulic model shows the expected increase in water surface elevations for sheet ice cover (Figure 7) and ice jam flooding (Figure 8) beyond the non-ice flood scenario. For example, the 10-year ice jam flood has a water surface elevation upstream of Quinlan Bridge equivalent to the 50-year non-ice flood.

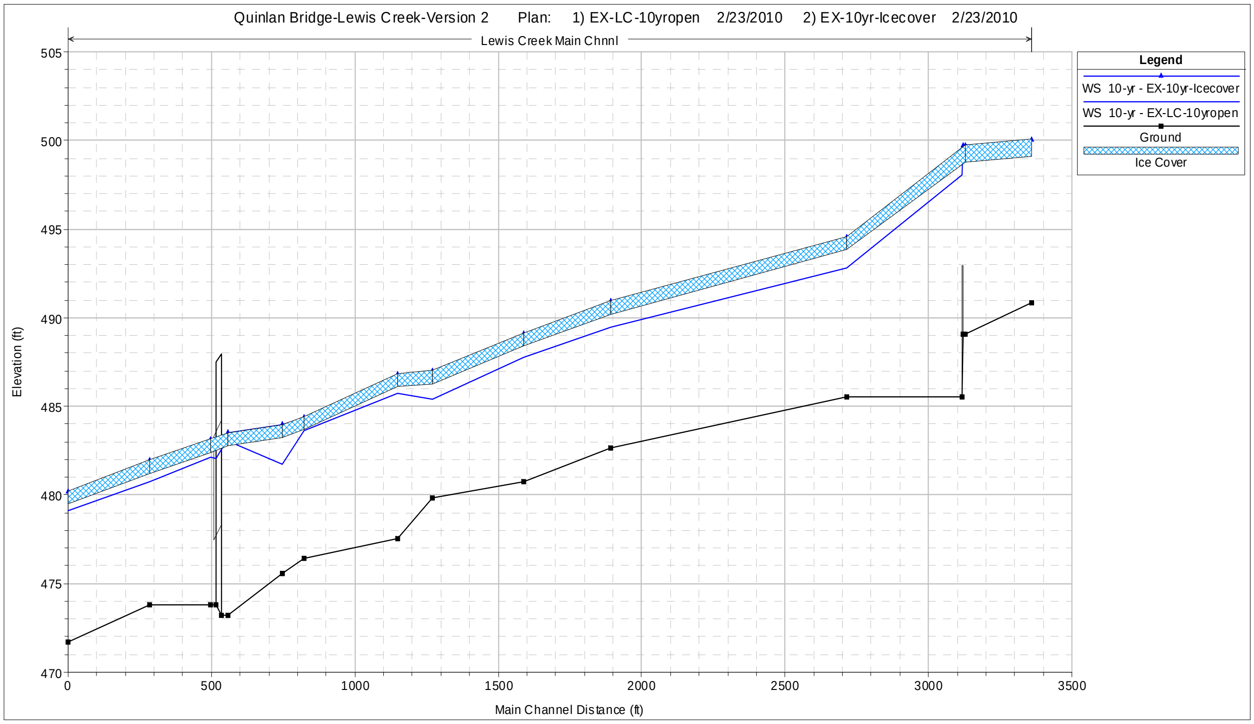


Figure 7: HEC-RAS existing conditions river profile showing the 10-year flood for sheet ice cover.

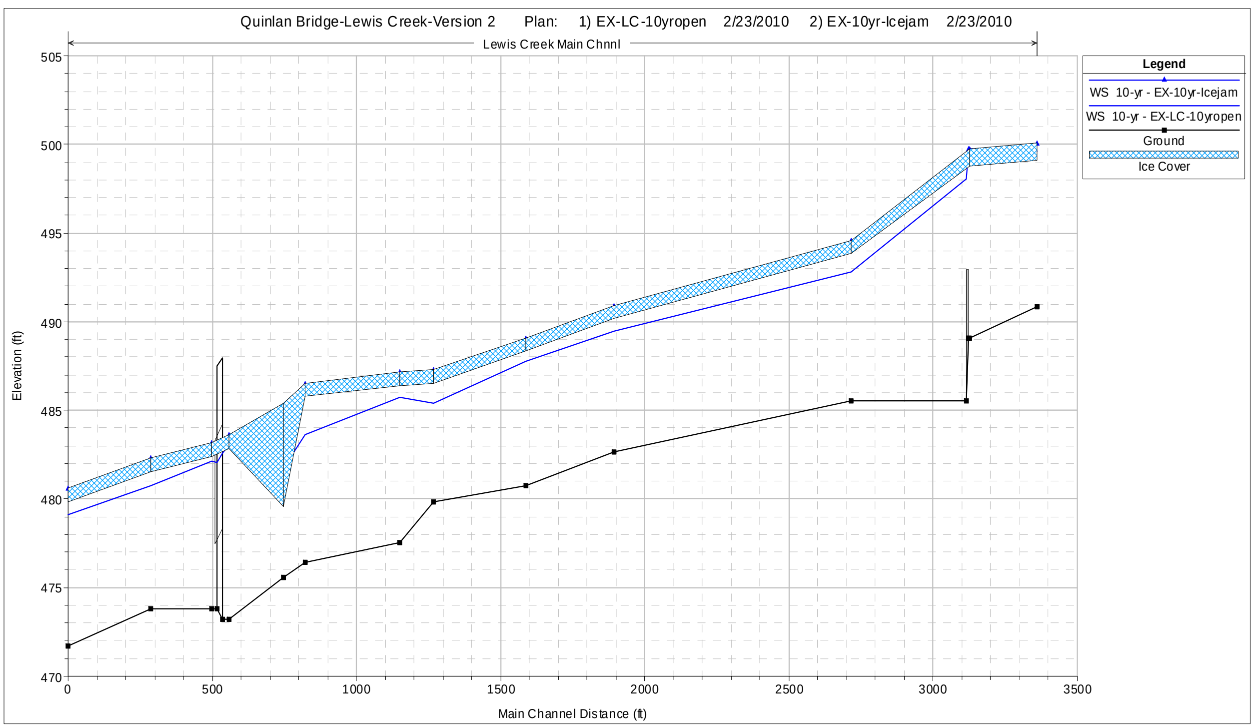


Figure 8: HEC-RAS existing conditions river profile showing the 10-year ice jam flood and the non-ice water surface elevation.

Channel cross sections upstream of Quinlan Bridge where ice jamming typically occurs contains a small berm and the Spear Street embankment that blocks flood water from accessing the lower floodplain on the opposite side of Spear Street (Figure 9). When compared to other upstream cross sections, there is less flood flow area available in this cross section due to the encroachments.

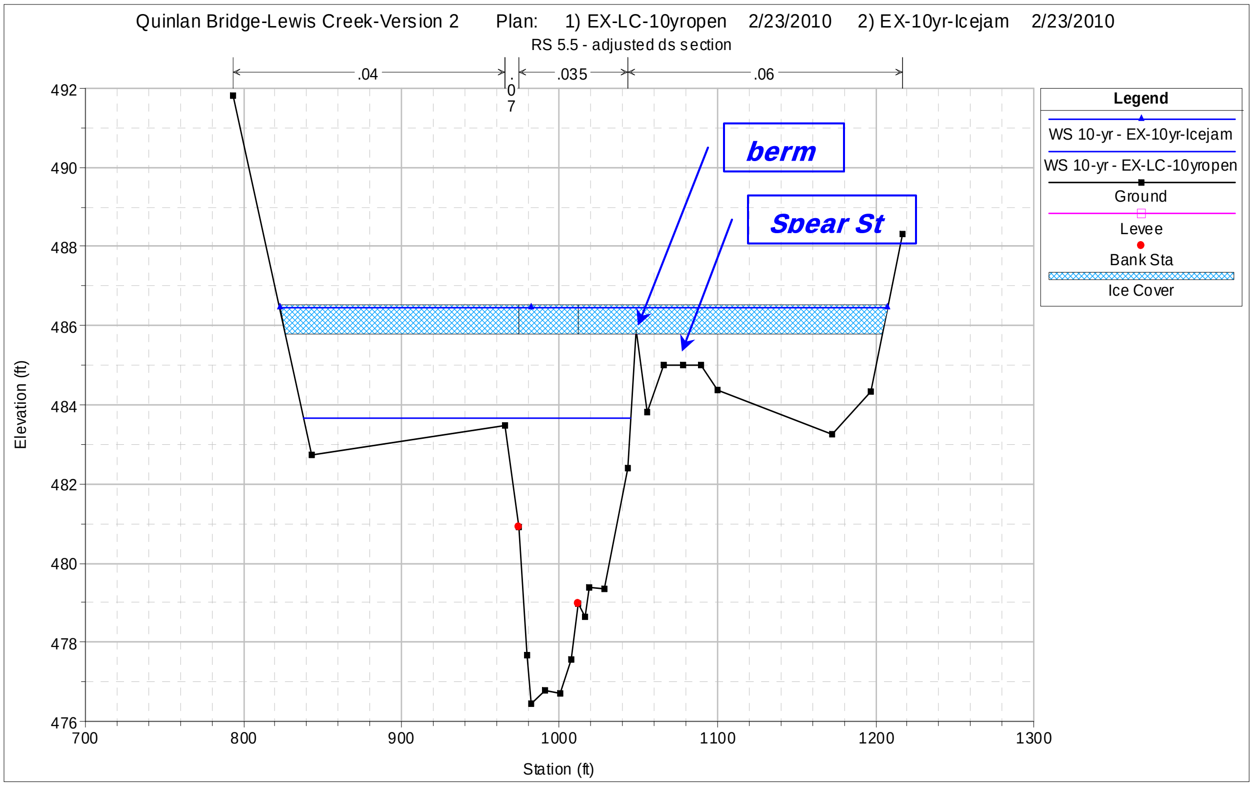


Figure 9: HEC-RAS existing conditions cross section upstream of Quinlan Bridge showing water surface elevations for the 10-year non-ice and ice jam floods. Note the small berm and Spear Street embankment on the right bank isolating the floodplain except during large floods.

Under existing conditions (No-action alternative), the available flood capacity of Quinlan Bridge and the limited existing flood-relief over Spear Street have allowed the bridge to remain in place since its last replacement in 1850. While there are no up-front costs for the no-action alternative, repair or replacement of the right bridge abutment will eventually be needed as flows will continue to impinge upon and deteriorate this structure (Figure 10). Accelerated velocities in the area will remain as will increased erosion risks with the confined channel. Existing overtopping of Spear Street will continue.

(a) *(b)*

Figure 10. Flow hitting the right abutment of Quinlan Bridge with high velocity due to the limited floodplain connection and the skewed channel approach to the bridge. (a) Turbulent flow directed at the right-bank abutment during high water on 26 January 2010; view downstream. (b) Undermining, cracking, and spalling of the concrete-capped, stone abutment visible at low flow on 4 November 2009.

5.1.1 Model Calibration and Validation

The documented 25 January 2010 ice jam flood was used to calibrate the existing conditions hydraulic model. Flooding extent and high water marks were recorded in the field and compared to modeled water surface elevations. Documented water surface elevations roughly match the estimated 50-year non-ice flood and the 10-year ice jam flood. Local and regional gauges indicated a flood of 25- to 50-year non-ice magnitude. Ice jam parameters such as roughness and flow through velocity were fine-tuned to replicate field observations.

Observations suggest that water and ice crossed Spear Street with a depth of approximately 1 +/- foot, and the hydraulic model shows 1.5 feet of overtopping after small changes to Manning's n-values at the jam location (see Figure 9).

Once these changes were made, additional observations upstream were used to validate the model. High water marks indicate that water and ice crested within 2.5 feet of Lewis Creek Road approximately 1,300 feet upstream of Quinlan Bridge (at river station 9.0). This flood elevation is confirmed in the model (Figure 11) indicating that the model is accurately representing existing conditions upstream of the bridge. The model also matches another field observation 1,050 feet upstream from Quinlan Bridge where the both the field observation and model show a peak flood level 4 feet below Lewis Creek Road (Figure 12).

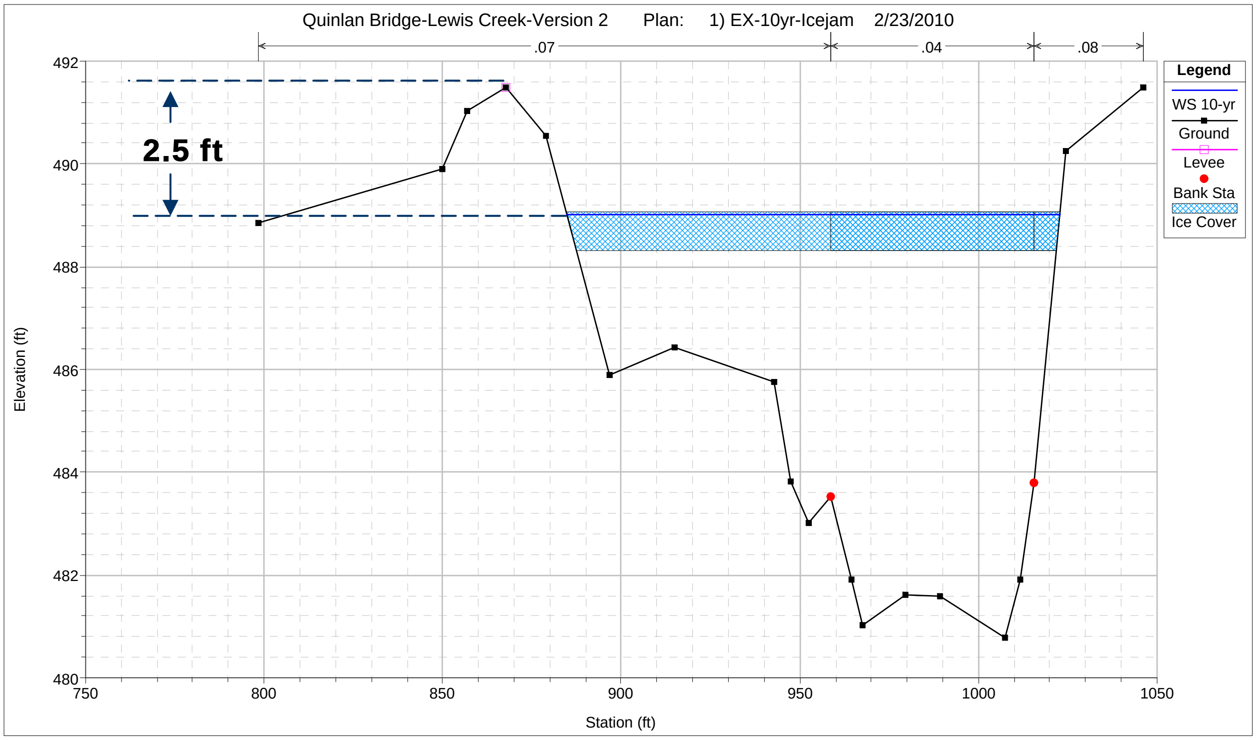


Figure 11: HEC-RAS existing conditions cross section upstream of Quinlan Bridge confirming a 2.5-foot rise from the 25 January 2010 ice jam flood to the top of Lewis Creek Road.

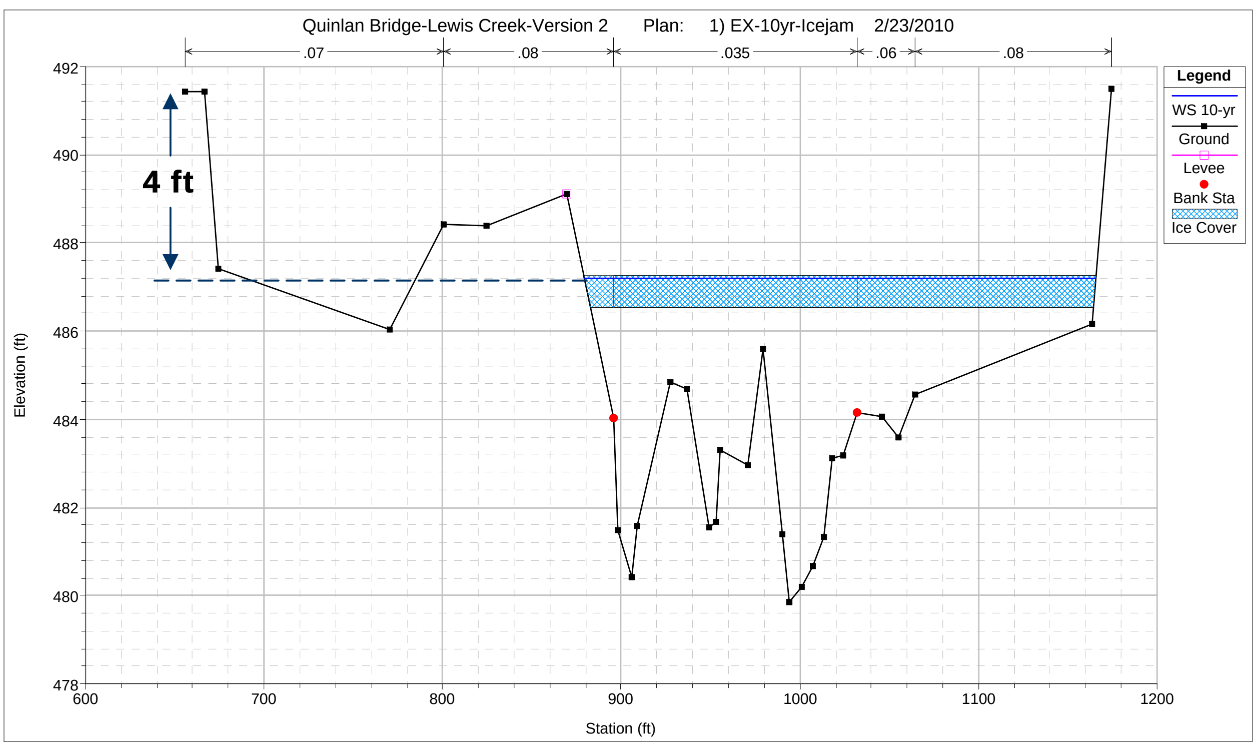


Figure 12: HEC-RAS existing conditions cross section upstream of Quinlan Bridge confirming a 4-foot rise from the 25 January 2010 ice jam flood to the top of Lewis Creek Road.

5.1.2 Sediment Transport

Sediment transport modeling indicates that sediment aggradation is taking place upstream of the Quinlan Bridge at modest rates, with the highest amount of deposition located on the meander bend where ice jamming is most common (river distance = 822 feet) (Figure 13). The accumulated sediments may be increasing the ice build up and jamming in this location. At the bridge (river distance = 534 feet), modest down-cutting (i.e., incision) is taking place. This is evident at the bridge due to the undermining of the right abutment. As is often the case, the disruption of natural sediment transport is increasing flood and erosion risks in the vicinity of Quinlan Bridge. Channel confinement is the typical cause of the pattern of upstream deposition and local scour at bridges and culverts. The sediment deposition spike located at the upstream end of the model near Scott Pond Dam (river distance = 3,116 feet) is likely an artifact of not having sediment data in the impoundment and thus is an artificial feature due to boundary conditions.

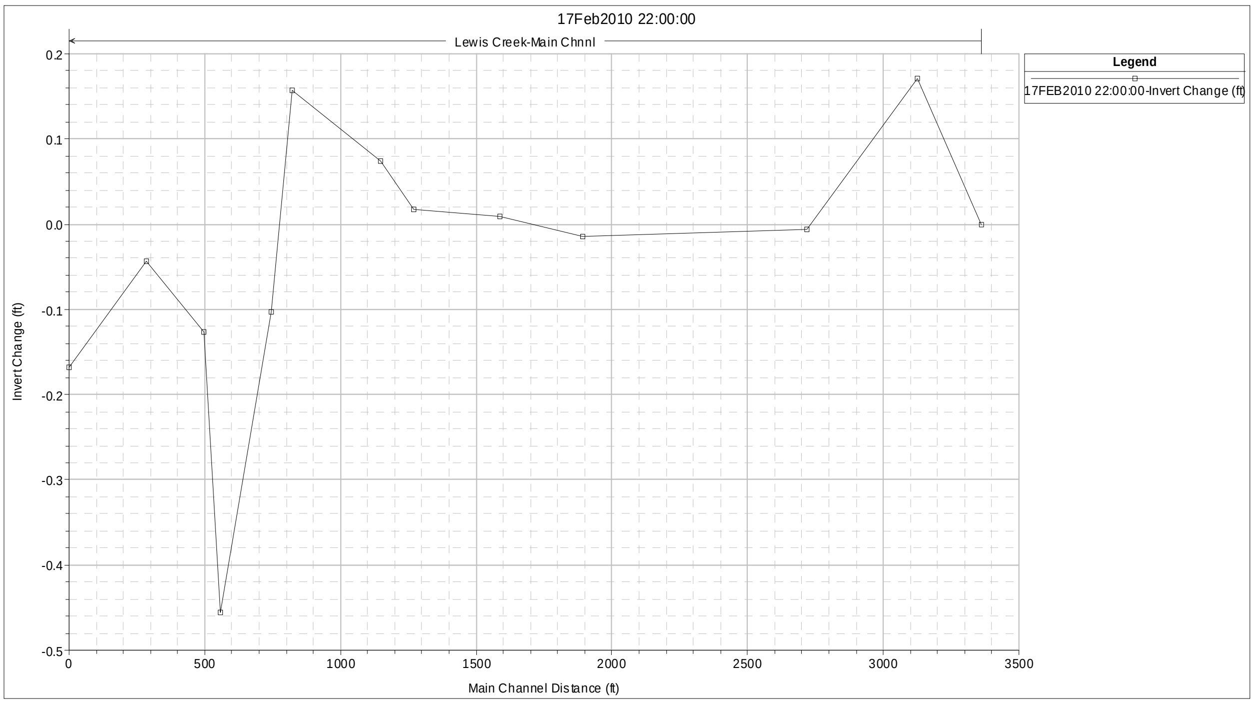


Figure 13: HEC-RAS existing conditions river profile showing the change in channel bed elevation following a modeled bankfull flood.

5.2 Reconnect the Lewis Creek channel to the left-bank wetland along Lewis Creek Road upstream of the Morse residence and Quinlan Bridge

Approximately 1.5 acres of floodplain with wetland characteristics exists along the left bank of the Lewis Creek channel along Lewis Creek Road 800 feet upstream of the Quinlan Bridge (Figure 14). Given the partly-incised condition of the channel, this adjacent wetland is only connected to the channel during higher flows. Improving the existing channel connection to this wetland area was considered to increase flow, ice, and sediment storage. A small amount of excavation in the near-bank floodplain would be required to fully connect the channel.

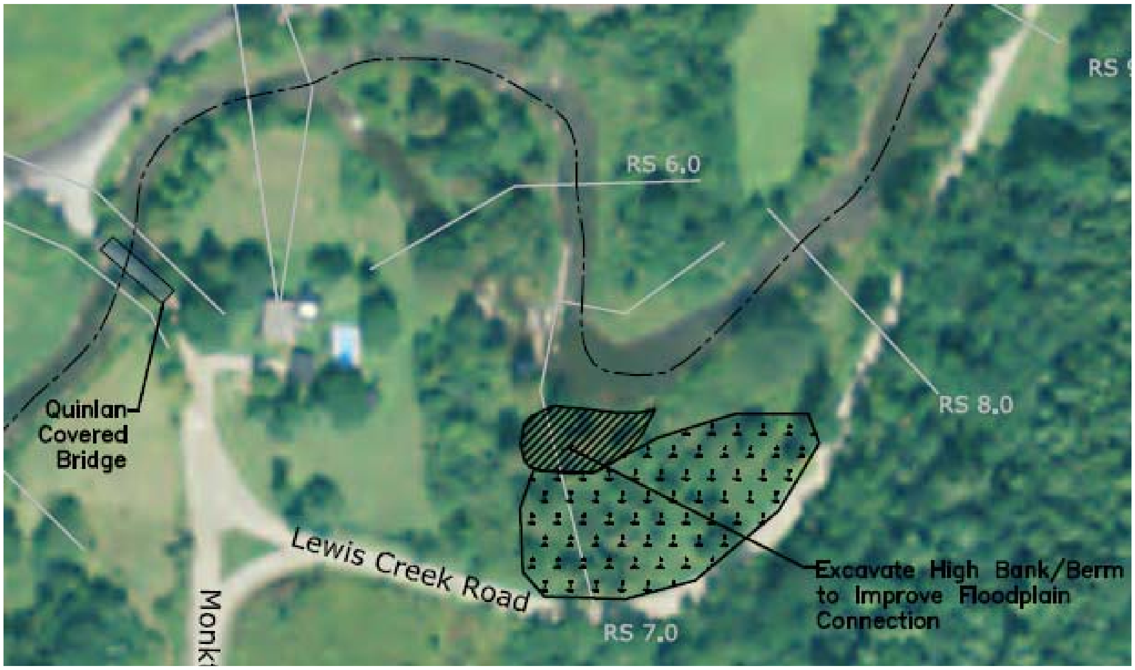


Figure 14. Alternative schematic of floodplain reconnection on the left-bank wetland north of Lewis Creek Road.

Modeling results indicate small changes to flood and ice storage following improving the connection between the left bank wetland and channel (Figure 15). The river profile has negligible changes and flood velocities drop a very small amount.

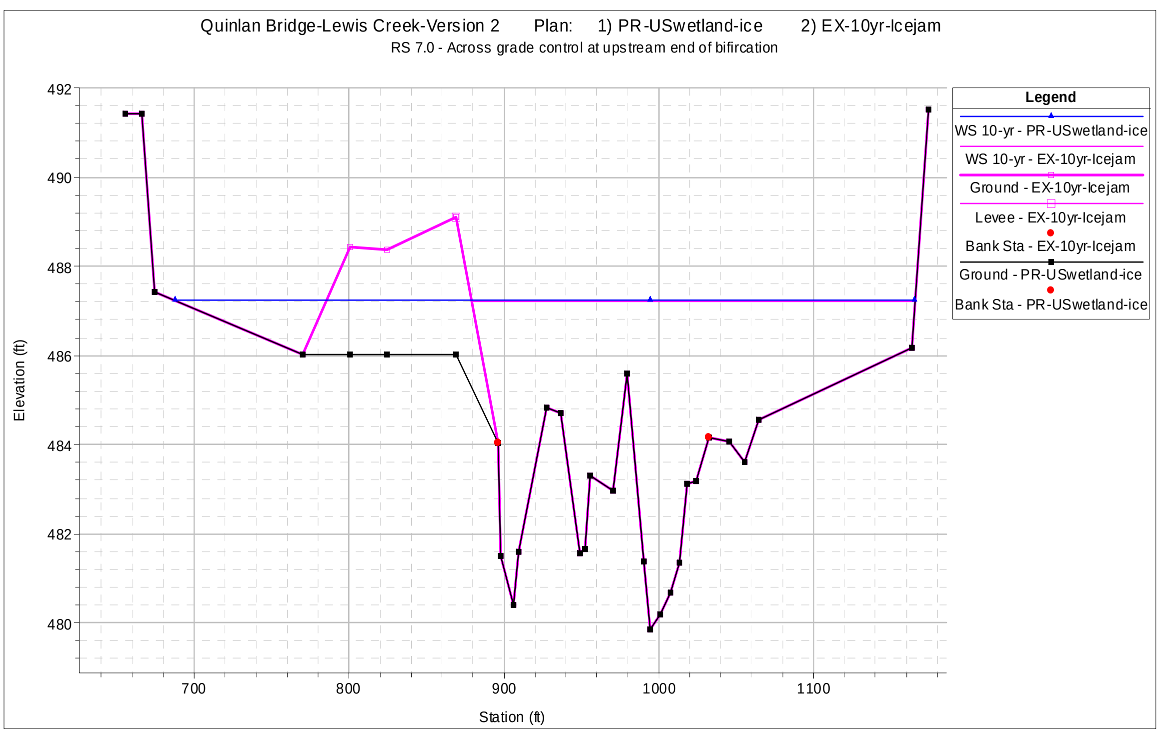


Figure 15. HEC-RAS cross section showing the earth to be removed (pink) and the existing and proposed flood elevations for the 10-year ice jam flood. Note that ice cover is not shown to simplify viewing.

The 25 January 2010 ice jam flood event illustrated that the river presently does access the subject wetland during higher flows, and ice accumulates in the wetland following ice jam flooding (Figure 16).

Figure 16. Despite a degree of channel incision, the left-bank wetland along Lewis Creek Road was accessed by flood waters and ice during the 25 January 2010 ice jam event; view downstream.

The limited benefits of this alternative do not justify the costs to implement it. The preliminary cost opinion for this alternative is $10,000 for excavation of approximately 1,000 cubic yards and installation of 10 cubic yards of riprap for scour protection (see Appendix C for cost opinion calculations). The ecological cost of excavating on the perimeter of a partially functioning wetland with well-established trees and shrubs would be relatively high compared to the benefits. In addition, there is a concern that reconnecting the wetland could increase erosion and lead to a less stable channel around the existing bedrock knob and the Morse residence. This risk is not justified by the limited benefits of the alternative and thus implementation is not recommended.

5.3 Reconnect the Lewis Creek channel to left-bank wetlands across Lewis Creek Road

Approximately 4 acres of wetland are present along the left bank of the Lewis Creek channel south of Lewis Creek Road upstream of the Quinlan Bridge. An unnamed tributary to Lewis Creek drains to the north through this wetland, through a culvert under Lewis Creek Road, and ultimately to the Lewis Creek. This area was briefly considered as a possible flood storage area. Culverts could be located under Lewis Creek Road to convey flood waters (Figure 17). This alternative was dropped from further consideration due to limited floodplain area available for reconnection. Culverts alone would not shed ice and thus limit the utility of this alternative in ice jam floods. Field inspection on 28 January 2010 confirmed landowner information that this wetland area is at too high an elevation to provide improved flood and ice storage.

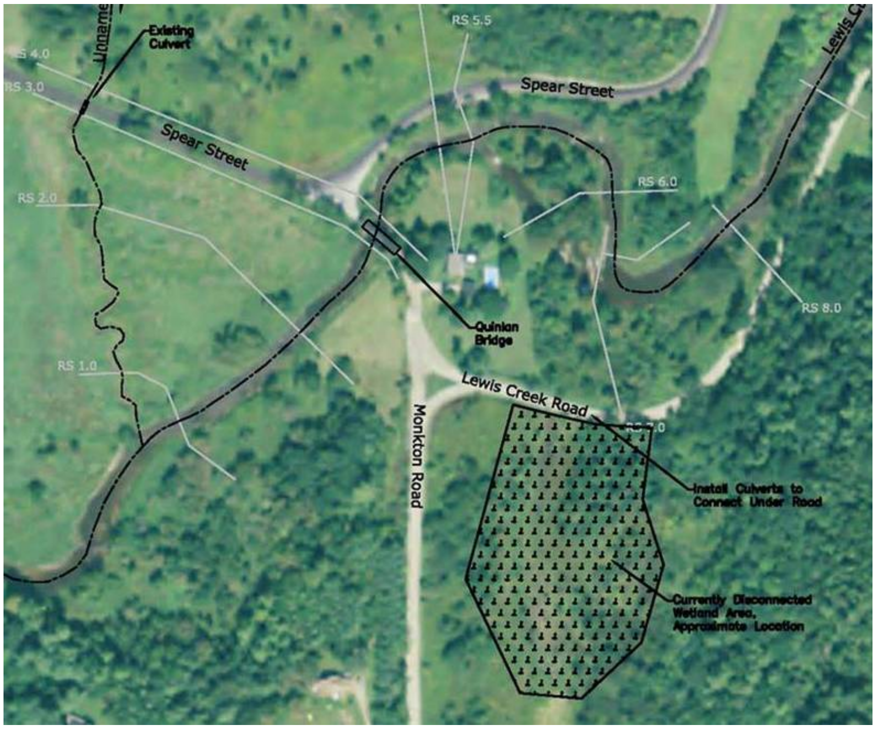


Figure 17. Alternative schematic of extended floodplain reconnection on the left-bank wetland south of Lewis Creek Road.

5.4 Remove 2-foot tall berm along Spear Street north of Quinlan Bridge

A small earthen berm exists on the river side of Spear Street to the north of Quinlan Bridge (Figure 18). The berm ranges in height from 0.5 to 2 feet and extends approximately 275 feet from the end of the existing guardrail near the Quinlan Bridge upstream to a gravel pull-off along Spear Street. Removal of this earthen berm would improve the river's connection to the floodplain area to the northwest across Spear Street, providing a small increase in ice shed and water storage during flood events (Figure 19). This low-cost alternative would lead to a small increase in the flooding over Spear Street.

Figure 18. Berm along Spear Street upstream of Quinlan Bridge.

Lowering the berm broadens the flood and ice shed area and slows the flow velocity. The lower water velocity reduces erosion approaching Quinlan Bridge, and leads to a small increase in flood water elevations of 0.3 feet (Figure 20).

The cross section view of this alternative illustrates the lowered berm and small increase to flood levels on Spear Street during ice jam flooding (Figure 21).

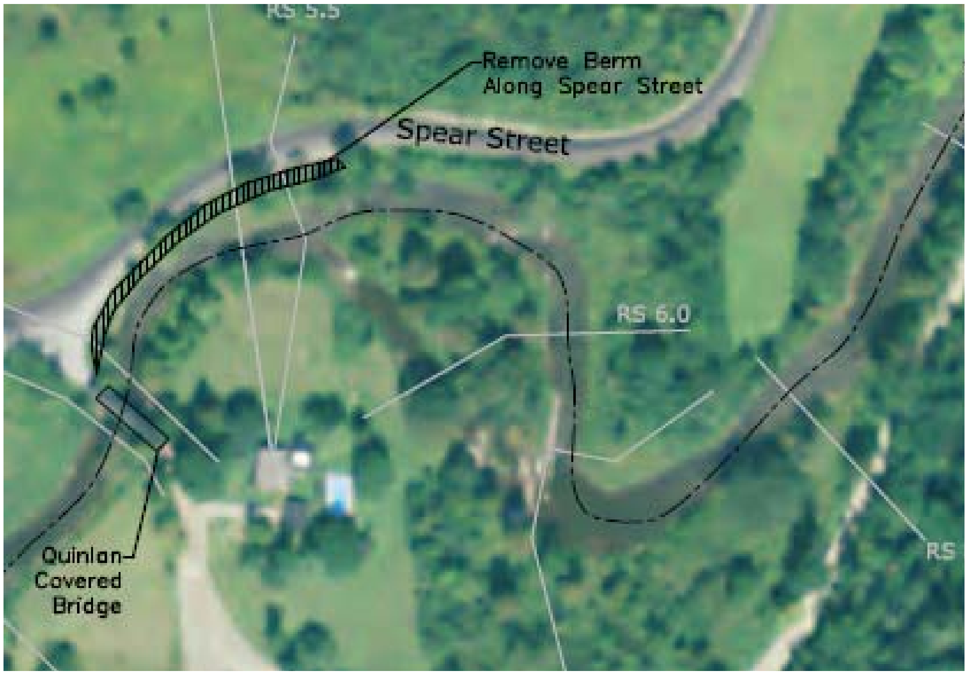


Figure 19. Alternative schematic of berm removal along Spear Street.

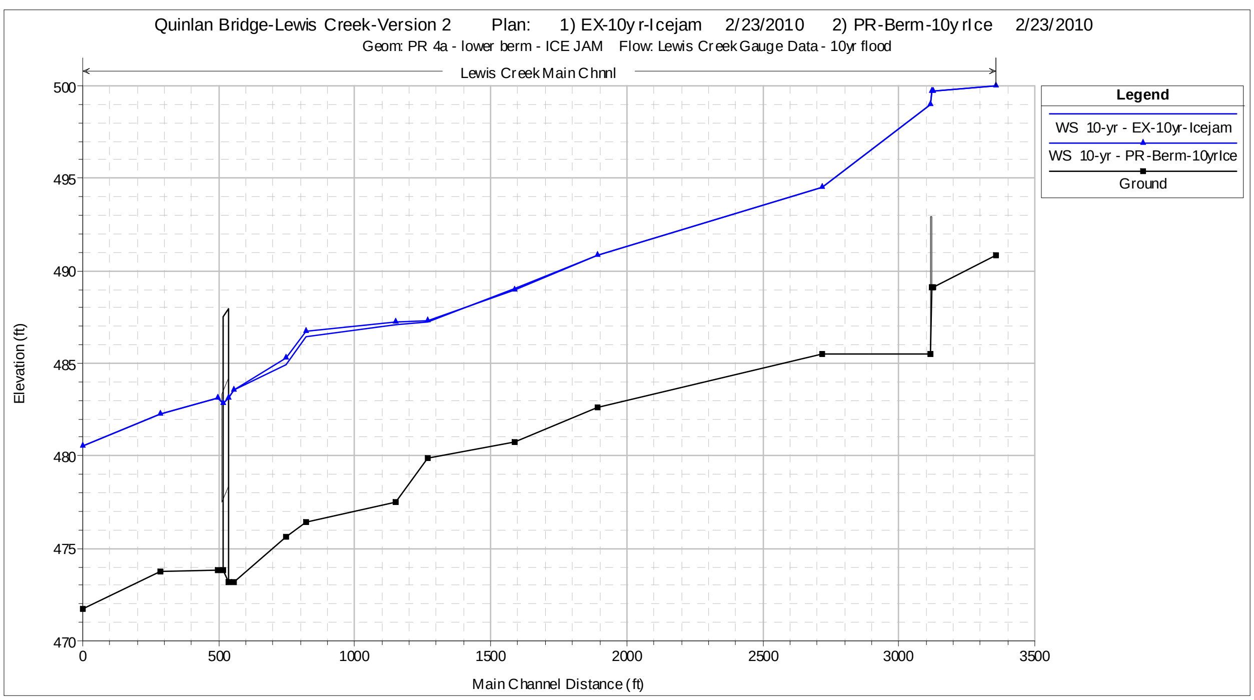


Figure 20: HEC-RAS river profile showing the existing and proposed 10-year ice jam flood for the berm lowering alternative. Note that ice cover is not shown to simplify viewing.

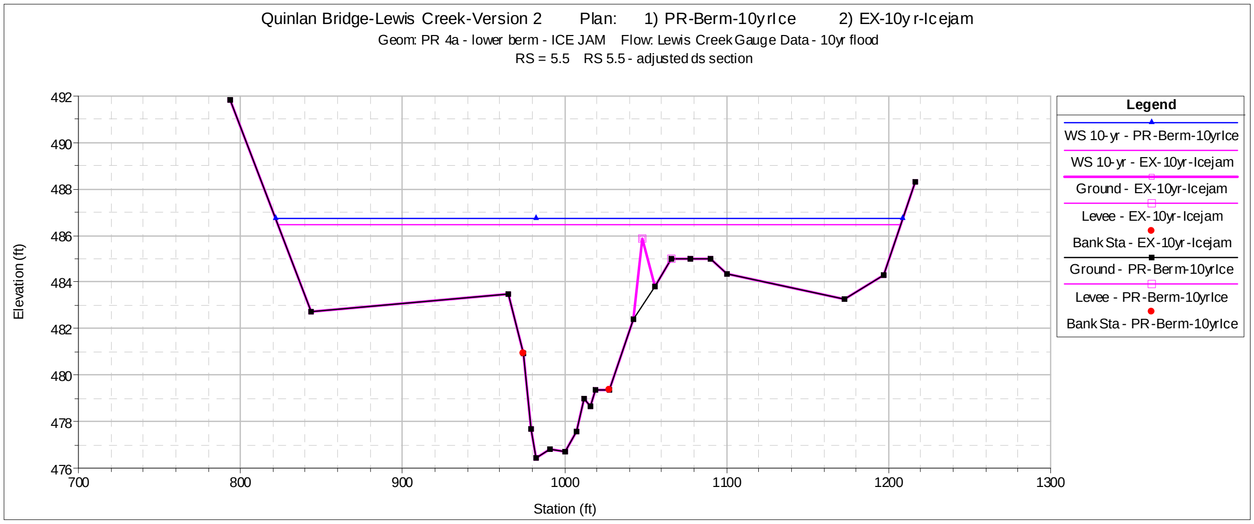


Figure 21: HEC-RAS cross section showing the existing and proposed 10-year ice jam flood for the berm lowering alternative. Note that ice cover is not shown to simplify viewing.

The preliminary cost opinion for this alternative is $5,000 for excavation of 300 cubic yards of earth including mobilization and site recovery. It is anticipated that lower costs are possible as this small task could be performed by Town work crews in a short period of time when other maintenance tasks are being performed in the area. Another project cost is the anticipated small increase to the current duration of overtopping during ice jam flooding. Typical flooding is expected to remain on the order of several hours prior to releasing.

The erosion reduction benefits, estimated cost, and small increase to flood duration suggest that removing the berm along Spear Street should be considered for implementation. Important benefits are equal to or exceed costs.

Regulatory requirements for this alternative are limited given that all work would take place outside of the bankfull channel over a very short period of time. The project area is less than an acre so a Vermont Construction General Permit is not needed.

The road commissioner and Charlotte Selectboard members noted that the berm serves as an informal traffic barrier between Spear Street and Lewis Creek. If this alternative is implemented extension of the guard rail is recommended. The ability to shed ice across Spear Street for larger ice jam floods is a central component of this alternative, so the guard rail design must allow passage of large ice chunks and flood waters.

Guard rails with wide post-spacing will allow more ice and debris to pass. Steel-backed timber posts have wide spacing that is typically 10 feet on center (as opposed to metal beam rail that is 6 feet, 3 inches on center). Wire rope railing strung on narrow steel posts will likely have the smallest cross-sectional area and could pass ice. Conversations with VTrans indicate that the weak post systems such as cable-rails may fail during a large ice flow, allow ice to pass, and require replacement after flooding. Another option is to install removable cable systems that can be pulled during anticipated ice jam events when travel along Spear Street is likely limited and the road may be temporarily not passable - as is the case during existing ice jam floods. The cost of the guard rail is currently not included in the cost opinion presented above at this conceptual design stage.

5.5 Enlarge small bridge (box culvert) under Spear Street west of Quinlan Bridge

A small unnamed tributary with upstream drainage area just over 1 square mile joins the Lewis Creek along the right bank 500 feet downstream of Quinlan Bridge. This unnamed tributary passes under Spear Street to the west of Quinlan Bridge through a three-sided concrete bridge (Figure 22). Wetlands to the north and west of Spear Street discharge to this unnamed tributary upstream of the Spear Street crossing. During flooding when Lewis Creek overtops Spear Street and accesses the floodplain to the north and west, a portion of the floodwaters drain to this unnamed tributary. Replacing this structure with a wider and taller structure would improve drainage from the floodplain lowering flood elevation and velocity in vicinity of the Quinlan Bridge. This structure is deteriorated with cracked concrete and a sagging ceiling. The bridge will need to be replaced for structural reasons.

Figure 22. Concrete three-sided bridge, Spear Street crossing of unnamed tributary approximately 600 feet west of Quinlan Bridge; view of culvert outlet.

The current bridge has a width of 6.5 feet and a height of 5.9 feet. Enlarging the structure to have a span of 10 feet and a height of 7 feet leads to very little hydraulic changes in Lewis Creek when this alternative is implemented alone. Water will likely drain out of the wetland and pass under Spear Street quicker, yet the flood profile and velocities remain as existing. The enlarged structure plays a more important role in reducing flood and erosion risks as the floodplain connection is improved by lowering the berm along Spear Street (Section 5.4) or the Spear Street road embankment (Section 5.7).

The preliminary cost opinion to replace the three-sided bridge is $80,000 including engineering, permitting, materials, and construction labor. This high-cost alternative is not justified based solely on project objectives, given the minimal benefits. However, the bridge needs replacement as it approaches the end of its engineering life span. Federal and state grants exist to improve structures for fish passage, and initial conversations by Lewis Creek Association about this alternative have interested agency personnel to explore restoration potential. The possibility of a structure replacement to increase safety and improve fish passage exists.

Regulatory requirements likely include obtaining a Vermont Stream Alteration Permit and a U.S. Army Corps of Engineer's Category 2 Vermont General Permit since Lewis Creek is a designated "River of Concern". A local permit will also likely be required for construction in a regulated floodplain. Effective regulated floodway or floodplains do not currently exist along Lewis Creek (FEMA Flood Insurance Study, Town of Charlotte, Vermont, March 1980). However, interim digital flood insurance rate maps (DFIRMS) have been generated as part of the FEMA map modernization program and the project site falls in a newly designated Zone A. In Charlotte along Lewis Creek, Zone A identifies the 100-year floodplain that has been delineated via approximate methods. This designation indicates that construction and development activities must meet regulations in place under the National Flood Insurance Program and implemented by the Town. As this and all of the proposed alternatives tend to reduce flood and erosion risks, the hydraulic model and analysis presented here can serve as the basis for illustrating the same or reduced flood risks in the Special Flood Hazard Areas. A final letter of approval for the interim DFIRMS is anticipated December 2010.

5.6 Install cross culverts under Spear Street

The use of culverts to convey flood water from Lewis Creek under Spear Street to the historic floodplain to the northwest was evaluated (Figure 23). Culverts would transfer flood water, now contained in Lewis Creek, onto the floodplain reducing the volume passing through the bridge. This alternative would not improve shedding of ice that is the primary mechanism of flooding because culvert size is limited by the small elevation change between the Spear Street road surface and the adjoining floodplain. To maintain the necessary 1.5 to 2 feet of cover over the culverts and enough structure height to carry large volumes of flood waters, deep ditches would have to be dug on the floodplain edge (Figure 24). A portion of the wetland would have to be excavated to get the water from the culverts to the three-sided bridge for conveyance downstream. The depth of required depth of excavation would limit natural floodplain functions such as storing water and slowing velocity. Concentrating flood flows in a constructed ditch may transfer erosion now occurring on Lewis Creek banks to the ditch edge and reconnected floodplain. This alternative would have a high environmental risk and be difficult to permit. Cross culverts have a very limited cross sectional flow area relative to a reconnected floodplain and would thus have limited function during large floods. Ice would likely clog the culverts during high flow events.

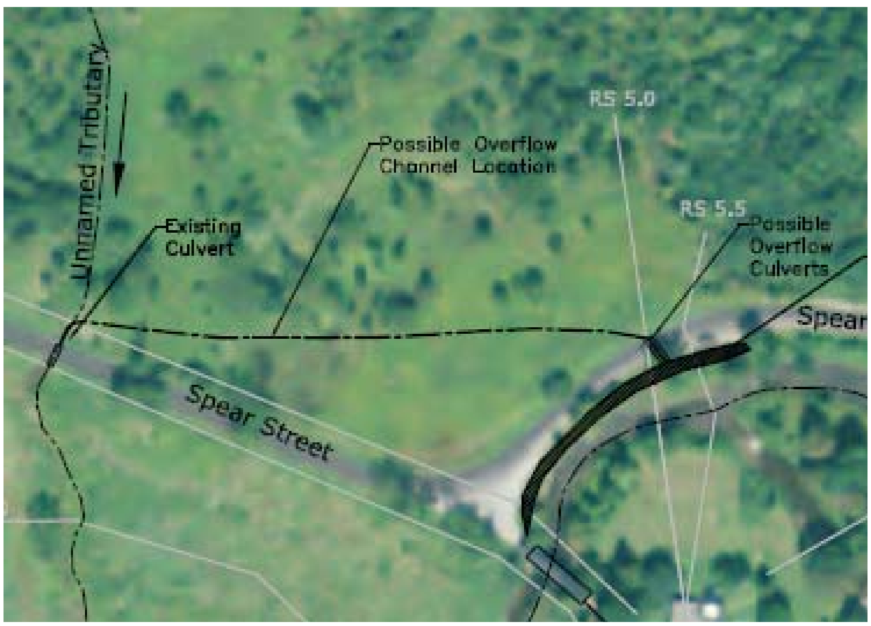


Figure 23. Alternative schematic of cross culverts under Spear Street.

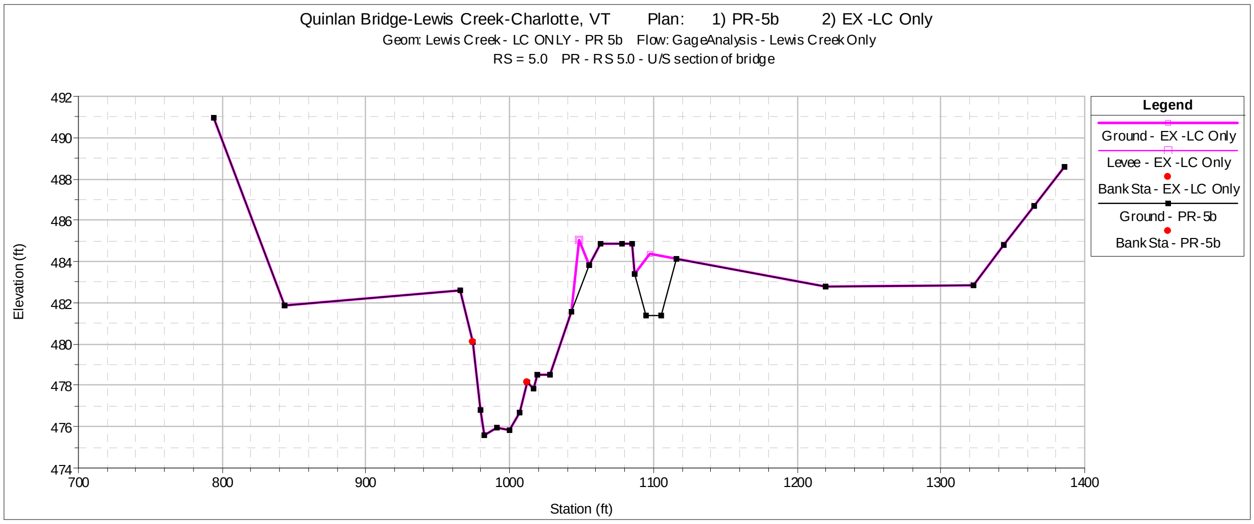


Figure 24. HEC-RAS cross section showing required ditching (pink) to get flood waters from Lewis Creek to the historic floodplain under Spear Street.

The challenging implementation with limited benefits and high environmental risk led to excluding this alternative from further consideration.

5.7 Lower Spear Street to the north of Quinlan Bridge by 1.5 feet

Over the past several decades, the elevation of Spear Street has increased by approximately 1.5 feet due to asphalt resurfacing without removal of the old road surface. The roadway is now elevated above the historic floodplain along the right bank (northwest side) of Lewis Creek. The road segment has confined the channel leading to higher water surface elevations and velocities during flooding. Increased velocities have increased erosion of the banks, channel bed, and bridge abutments. As riprap armoring is installed to protect the banks, increased velocities are being translated downstream to the bridge site leading to more potential for erosion and deterioration of the right abutment.

Lowering Spear Street to the north of Quinlan Bridge, including the existing berm (Figure 25), lowers flood levels upstream of Quinlan Bridge (Figure 26) and reduces flood velocities at the bridge.

Figure 25. Alternative schematic of lowering berm and Spear Street to the north of Quinlan Bridge.

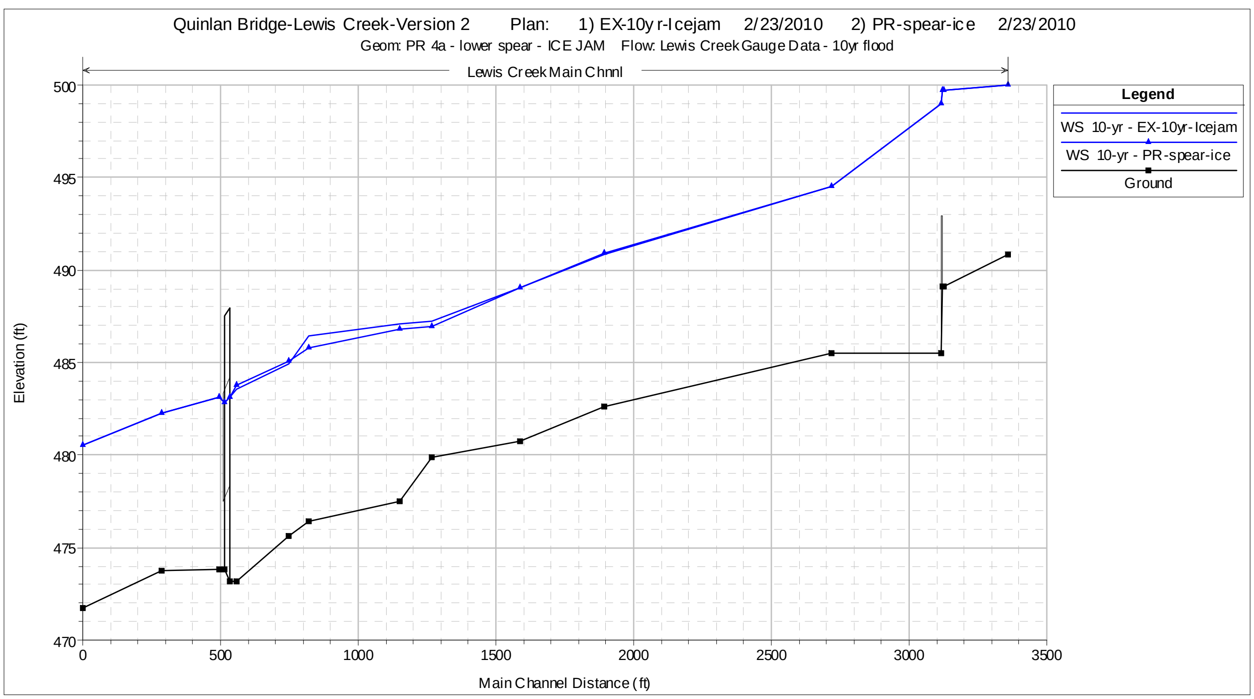


Figure 26: HEC-RAS river profile showing the existing and proposed 10-year ice jam flood for the Spear Street lowering alternative north of Quinlan Bridge. Note that ice cover is not shown to simplify viewing.

Lowering the road embankment increases the flood and ice flows out of the banks of the river (Figure 27) reducing the hydraulic force on the river and bridge.

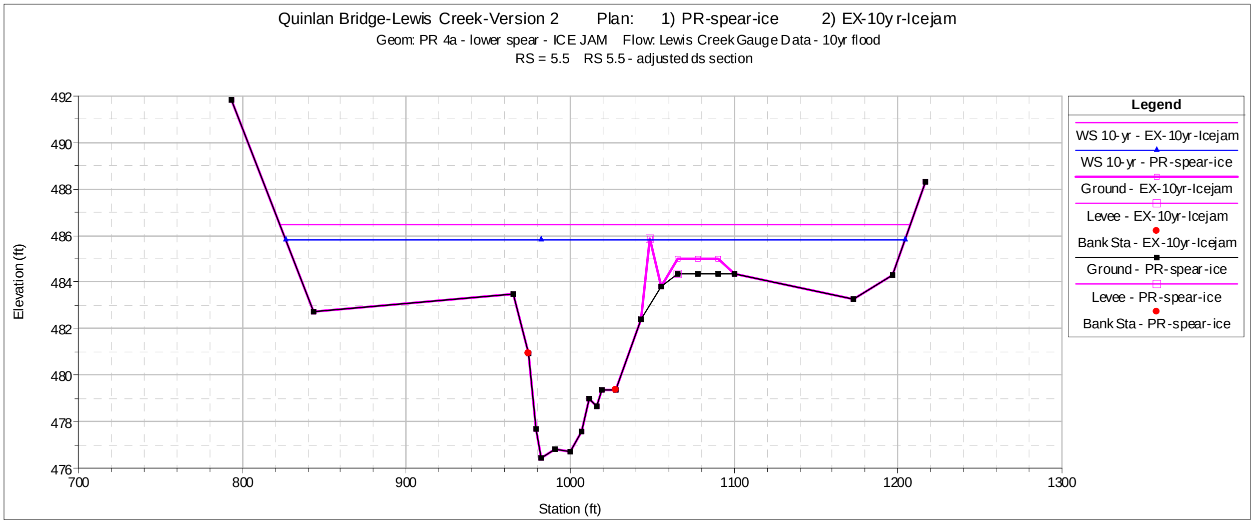


Figure 27. HEC-RAS cross section showing removed berm and lowered road embankment (pink) to get flood waters from Lewis Creek to the historic floodplain under Spear Street.

Improved connection to the floodplain and wetlands to the north and west of the bridge would provide moderate increases in ice shed and flow attenuation during flood events, dissipate the scour energy of flood flows, and reduce scour velocities at the bridge abutments. Flood waters would ultimately drain toward the unnamed tributary northwest of the bridge, and would recharge groundwater northwest of the bridge.

The preliminary cost opinion for this alternative is $50,000 based on typical road milling rates for 830 square yards, installing 700 cubic yards of riprap to protect the lowered roadway from erosion during flooding, and to repave the road surface at 190 tons of asphalt. Large cost reductions are anticipated if this alternative is implemented as part of the town's regular maintenance. The Town can reserve crushed shale from a nearby quarry to make road bed improvements that may be necessary upon lowering the embankment. Road re-paving at the project site is anticipated in 2015.

Restoring Spear Street, a town road, to its original elevation by removing 1.5 feet of old asphalt with a milling machine has limited permitting requirements. A Vermont Construction General Permit will be needed if the project disturbance area is greater than or equal to 1 acre. A state wetland clearance will be required if nearby wetlands are disturbed, yet work is only anticipated within the existing footprint of the roadway. VTrans may desire to review the plans for Spear Street.

A primary cost of this alternative is the periodic disruption of traffic flow when Spear Street overtops. It is expected that the frequency of road closures and length of time flooding occurs would increase above the existing conditions. Alternative routes would need to be used while flood waters recede and ice is cleared off of Spear Street.

The flood and erosion hazard reduction benefits while improving the floodplain connection makes lowering Spear Street an alternative worth considering for implementation. Initial feedback from landowners adjacent to the project site and the town road commissioner suggested that this alternative would not change the existing flood scenario substantially and is possibly desired since the road surface would be returned to its former height. At the subsequent Selectboard meeting (8 March 2010), the alternative was questioned by several members of the public having concerns about traffic safety when flooding overtops the roadway. The hydraulic analysis indicates that this alternative is beneficial for reducing flooding and erosion at Quinlan Bridge. Town members must decide if lowering Spear Street is an acceptable change to reduce flood and erosion risks in the bridge vicinity, or if the current threats of on-going bank erosion, upstream sediment aggradation, and bridge scour are acceptable.

5.8 Lower Spear Street to the west of Quinlan Bridge by 1.5 feet

The Spear Street segment to the west of Quinlan Bridge is also elevated above the floodplain due to the buildup of asphalt during road resurfacing without milling (Figure 28). Lowering this road segment by 1.5 feet is also a potential mitigation action to be implemented in combination with or after lowering of the north Spear Street segment (Figure 29). Flood flows could access the wetland and then drain back to Lewis Creek more rapidly across the west portion of Spear Street.

This alternative was identified to lower flood elevations upstream of the bridge (Figure 30). Modeling results indicate that flood velocities are lower at the bridge due to a large increase in cross sectional flow area. A 1-foot rise in water surface elevation takes place at the bridge due to the slower flows, yet erosion potential is reduced. Allowing for overtopping of roadway approaches is a common method to reduce flood pressure on structures.

Figure 28. Spear Street west of Quinlan Bridge; view to the east toward the bridge site.

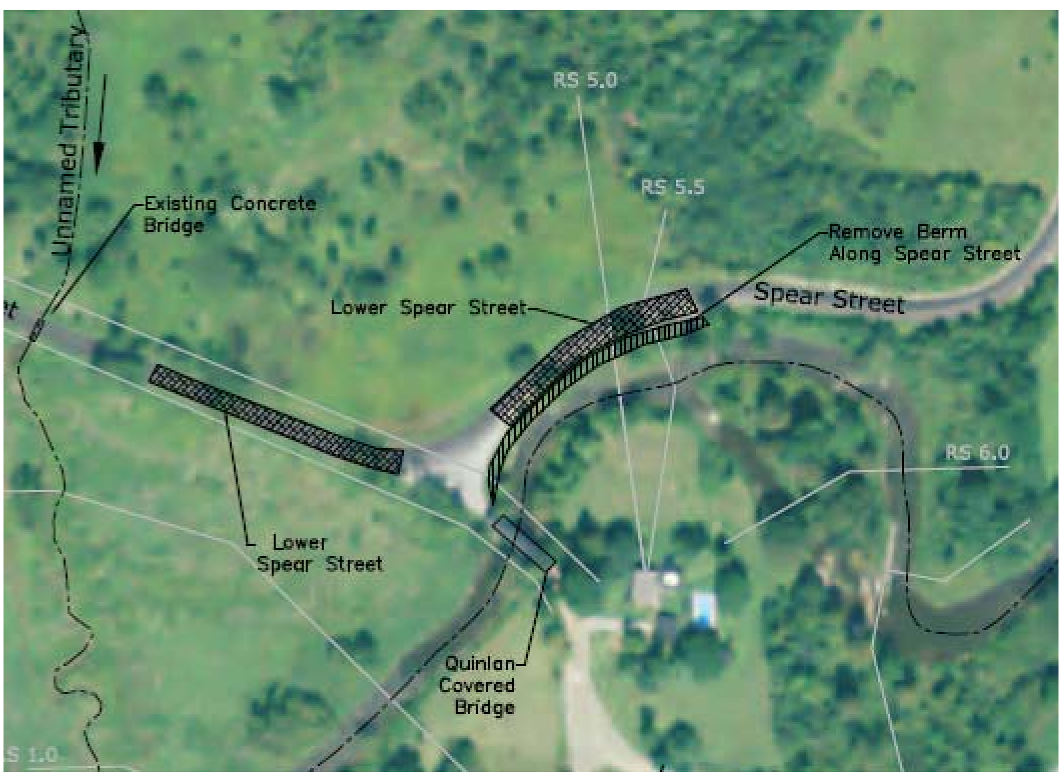


Figure 29. Alternative schematic of lowering berm and Spear Street to the west of Quinlan Bridge.

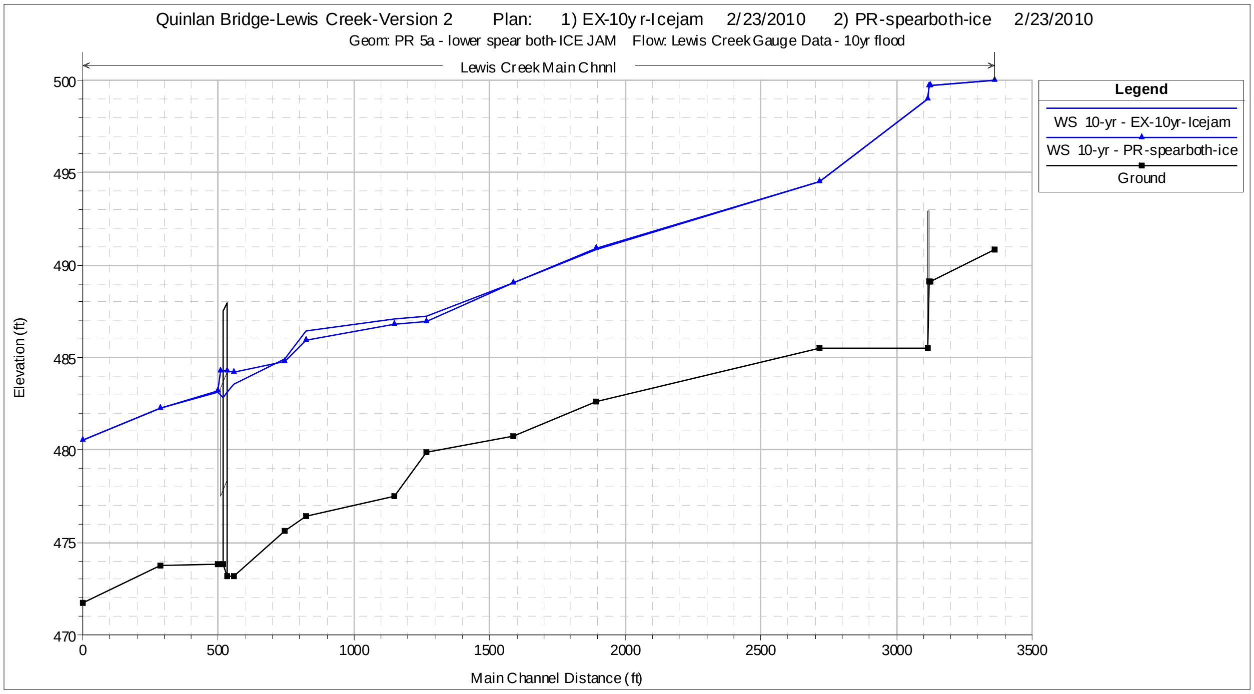


Figure 30: HEC-RAS river profile showing the existing and proposed 10-year ice jam flood for the Spear Street lowering alternative west of Quinlan Bridge. Note that ice cover is not shown to simplify viewing.

The preliminary cost opinion for lowering the western portion of Spear Street is $30,000 that includes 920 square yards of asphalt milling, 50 cubic yards of riprap, and 210 tons of asphalt. Again, substantial cost savings are anticipated if this work is coordinated with scheduled road resurfacing in 2015.

The limited permitting requirements are the same as for the previous alternative.

As with lowering the northern portion of Spear Street, benefits of this alternative lead to suggesting its implementation, yet the public must decide if this approach is acceptable. Lowering both the north and west portions of Spear Street will close more of the roadway, yet it is anticipated that floods will recede faster as a more direct flow path would exist across Spear Street and back to Lewis Creek.

5.9 Realign the Lewis Creek channel to the existing bridge opening to soften the approach angle of the channel

Realignment of Lewis Creek was considered to straighten the approach to the bridge (Figure 31) was identified as an alternative. This alternative was briefly considered and modeled, but ultimately dropped due to likely increased risks at the Quinlan Bridge and Morse property. Straightening the channel would increase flood and erosion risks due to higher flow velocities associated with a steeper channel. Slope increases for straighter channels as they become shorter for the same drop in elevation. Costs of such an alternative would be very high, create an extreme ecological disturbance, and be complicated to permit. Site constraints would require that the channel be shifted approximately 50 feet to the southeast toward the Morse residence.

This type of channel modification introduces additional risk of erosion hazards by moving the river farther from its equilibrium path. During flood events the river would likely re-meander to attempt to achieve its equilibrium slope and reconnect to historic floodplains.

Figure 31: Alternative schematic of channel realignment upstream of Quinlan Bridge.

5.10 Realign the Quinlan Bridge to the existing channel planform to increase the span between abutments and soften the approach angle of the channel

This alternative initially appears to be consistent with project goals and objectives, however little would be done to reduce scour velocities along the banks and bed of the incised channel. The high cost of bridge abutment replacement is a strong deterrent for this alternative. Considerable financial and technical resources have recently been invested to improve the structural integrity of the superstructure of the Quinlan Bridge. This separate project is based on the bridge in its current alignment, and does not address the integrity of the abutments or channel erosion potential.

5.11 Preferred Alternatives

Review, discussion, and additional modeling of preliminary alternatives (summarized in Appendix D) indicated that four alternatives provide the most benefits with acceptable costs to reduce flood and erosions risk at Quinlan Bridge (Table 2 and Figure 32). The four alternatives are recommended for implementation in the following sequence while being incorporated into town maintenance to reduce costs.

- Remove 2-foot tall berm along Spear Street to the north of Quinlan Bridge
- Enlarge small bridge under Spear Street to the west of Quinlan Bridge
- Lower Spear Street 1.5 feet to the north of Quinlan Bridge and armor new embankment
- Lower Spear Street 1.5 feet to the west of Quinlan Bridge

The combined alternatives lower upstream flood levels (Figure 33) and reduce flood velocities approaching Quinlan Bridge, while improving connection of the Lewis Creek channel to its historic floodplain and naturalizing local transport of sediment and debris.

This study identified two recommendations for action outside the specific scope of the project: (1) repair of the right abutment of Quinlan Bridge and (2) armoring of the right bank at the sharp bend upstream of the bridge where erosion is threatening to undermine Spear Street. The bank has moved in the last 5 years and appears to be scoured by ice buildup. The mechanisms creating these two problems would be reduced with implementation of the preferred alternatives. It is recommended that armoring the upstream bank only be performed after some level of floodplain connection is restored (e.g., removing the small berm along Spear Street), to not increase flood and erosion risks at the bridge.

Also, during this project a discussion emerged about re-routing Spear Street away from Lewis Creek and the eroding steep bank to improve traffic safety. Bedrock and steep slopes in this area would limit the feasibility of re-routing the road farther to the north and west without blasting and substantial earth work.

Concerns have been expressed by the public about increasing the inundation on Spear Street during ice jam flooding. The no-action alternative may be preferred if the majority of people would rather accept the risk of future bridge failure and erosion of the road embankment than allow roadway overtopping during ice jam flooding. The preferred alternatives would also alleviate hydraulic force on the bridge and nearby channel during a very large non-ice storm that has not occurred for some time. This analysis, however, indicates a more natural, stable, and safer channel with floodplain re-connection alternatives in place.

Table 2: Four Preferred Alternatives for Implementation

SEQUENCE #	EROSION AND FLOOD REDUCTION COMPONENTS*	BENEFITS	COSTS	IMPLEMENTATION
1	Remove 2-foot tall berm along Spear Street to the north of Quinlan Bridge	Improve floodplain connection to provide increase in ice shed and water storage area to reduce pressure on bridge. Flood velocities decrease on bend approaching bridge that reduce erosion potential along Spear Street.	Approximately 1 day of excavation time. Periodic road closures during peak flooding will continue until ice jam releases and flood recedes.	Short and simple construction effort would be performed by Town crew in 2010. Site stabilization with seed and mulch, and shrubs.
2	Enlarge small bridge under Spear Street to the west of Quinlan Bridge	Replace deteriorating small bridge to improve drainage from floodplain. The structure would be designed to improve passage of aquatic organisms and wildlife.	Grant funding would be sought from federal and state agencies. Structure, installation, engineering, and permitting could cost approximately $80,000.	Seek to improve the small bridge and allow for 1 to 2 years of settling prior to regularly scheduled road resurfacing in 2015.
3	Lower Spear Street 1.5 feet to the north of Quinlan Bridge and armor new embankment	Improve floodplain connection to provide increase in ice shed and water storage area. Flood water surface elevations lower along Spear Street. Flood velocities and erosion potential decrease at bridge.	Roadway closures could increase during peak flooding until ice jam releases and flood recedes. Cost of road milling is approximately $10,000. Cost of armor to protect lowered roadway and embankment along river is approximately $30,000.	Roadway surface would be lowered during regularly scheduled resurfacing in 2015. Schedule may want to be expedited if material from the Town pit is to be used for possible road base improvements prior to the pit closing in 3 years. Posts or guard rail design able to pass ice to be installed 25 feet upstream from existing guard rail.
4	Lower Spear Street 1.5 feet to the west of Quinlan Bridge	Improves storage and conveyance around bridge to provide greater velocity and erosion potential reduction at bridge. Flood water surface elevations lower along Spear Street.	Roadway closures could increase during peak flooding until ice jam releases and flood recedes. Lowering both sides of Spear Street would require traffic detours during peak flooding. Cost of road milling is approximately $10,000. Cost of armor to protect lowered roadway and embankment is approximately $2,000.	Roadway surface would be lowered during regularly scheduled resurfacing in 2015. Schedule may want to be expedited if material from the Town pit is to be used for possible road base improvements prior to the pit closing in 3 years.

*Although not part of this project, two additional flood protection measures were brought up during landowner meetings that are recommended for implementation. Following removal of the berm along Spear Street, riprap is recommended upstream where Lewis Creek flows directly into the tall eroding roadway embankment. The riprap should only be placed on the lower bank and extended up the bank to cover the regular winter ice level plus 1 foot. In addition, some structural deficiencies were noted on the right abutment of Quinlan Bridge. Spalled and cracked concrete are apparent and it appears that some undermining may be taking place. An assessment and restoration of the right abutment are recommended to protect the bridge.

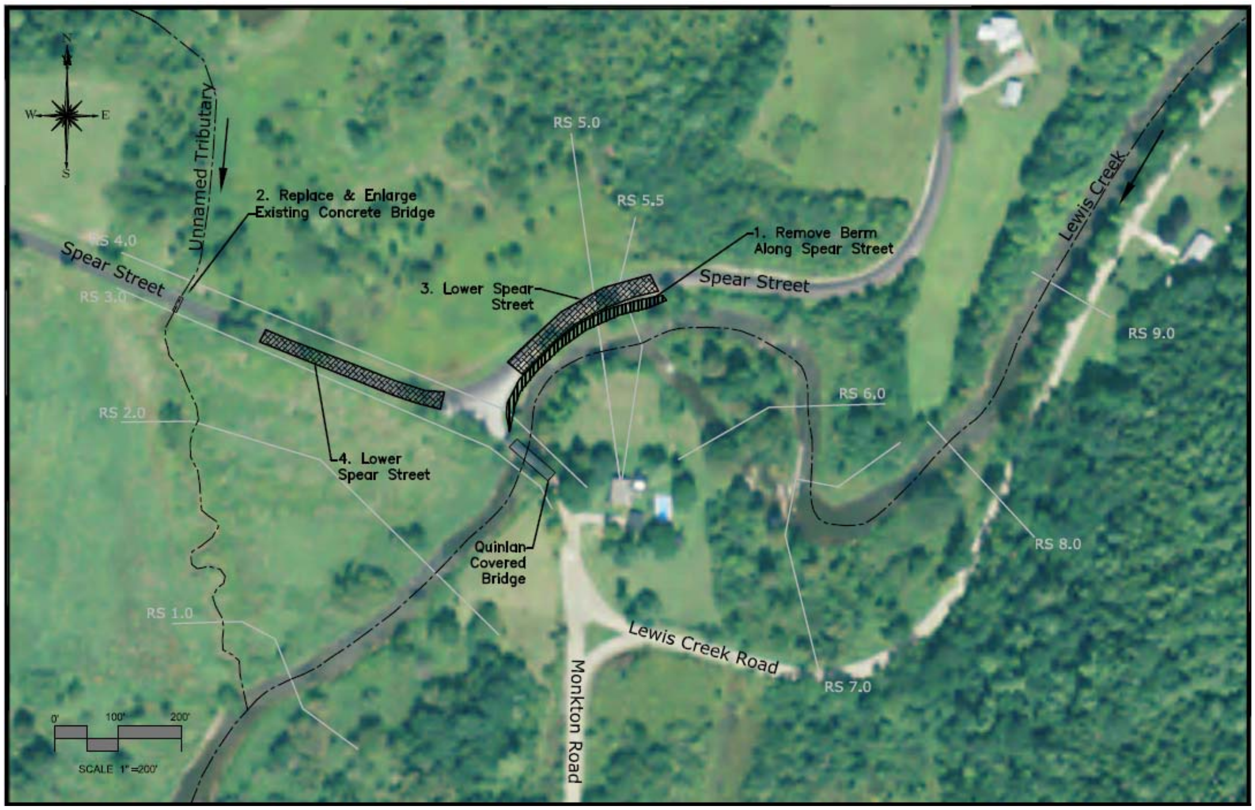


Figure 32: Alternative schematic for combination of four preferred alternatives.

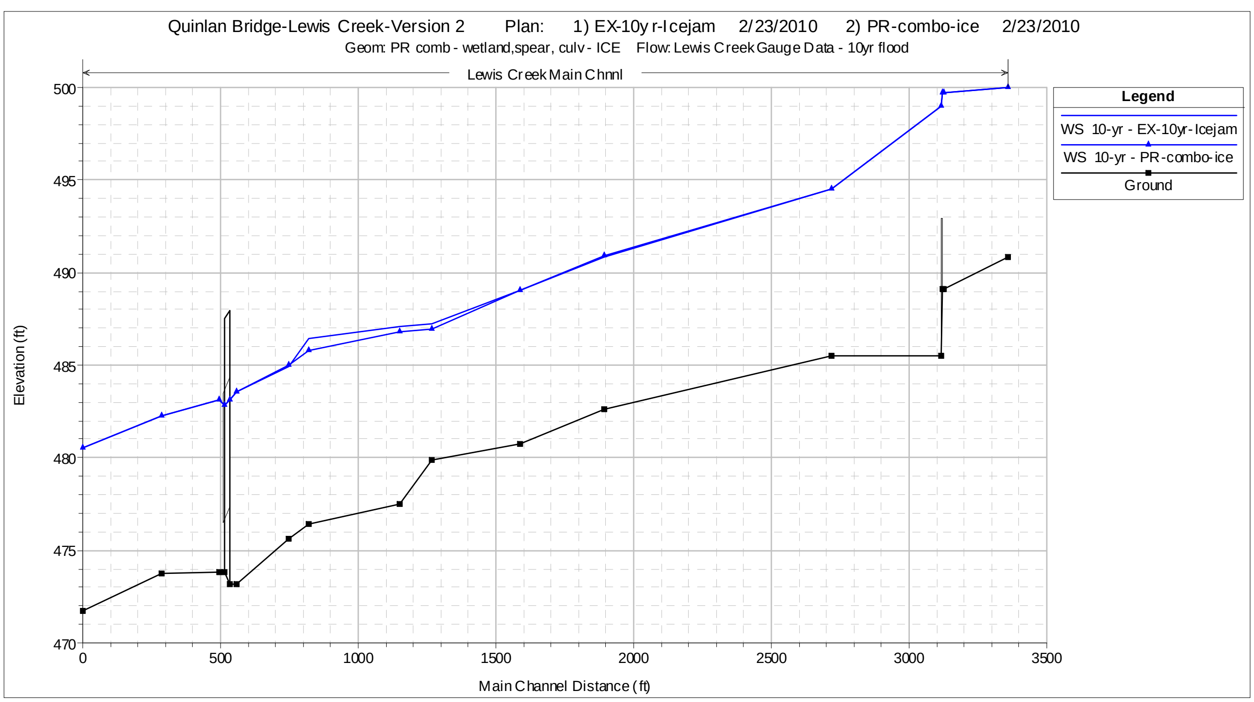


Figure 33: HEC-RAS river profile showing the existing and proposed 10-year ice jam flood for the four preferred alternatives combined. Note that ice cover is not shown to simplify viewing.

6.0 Road Forward

Landowners at the project site are willing to allow for reconnection of historic floodplains. This land should be protected using river corridor conservation easements to allow for implementation of the four preferred alternatives in the near or distant future. The easements will ensure that no structures are placed in the floodplain to be at risk of damages due to inundation or erosion.

This report documents benefits of the preferred alternatives using a hydraulic assessment of conceptual designs. Preliminary and final designs are needed to implement the alternatives. Designs range from simple for the berm removal to more involved for a replacement three-sided bridge over the tributary.

Prior to additional work, design consensus is needed from the Charlotte Select Board and public regarding implementation of four preferred alternatives. Additional meetings are planned to facilitate information exchange.

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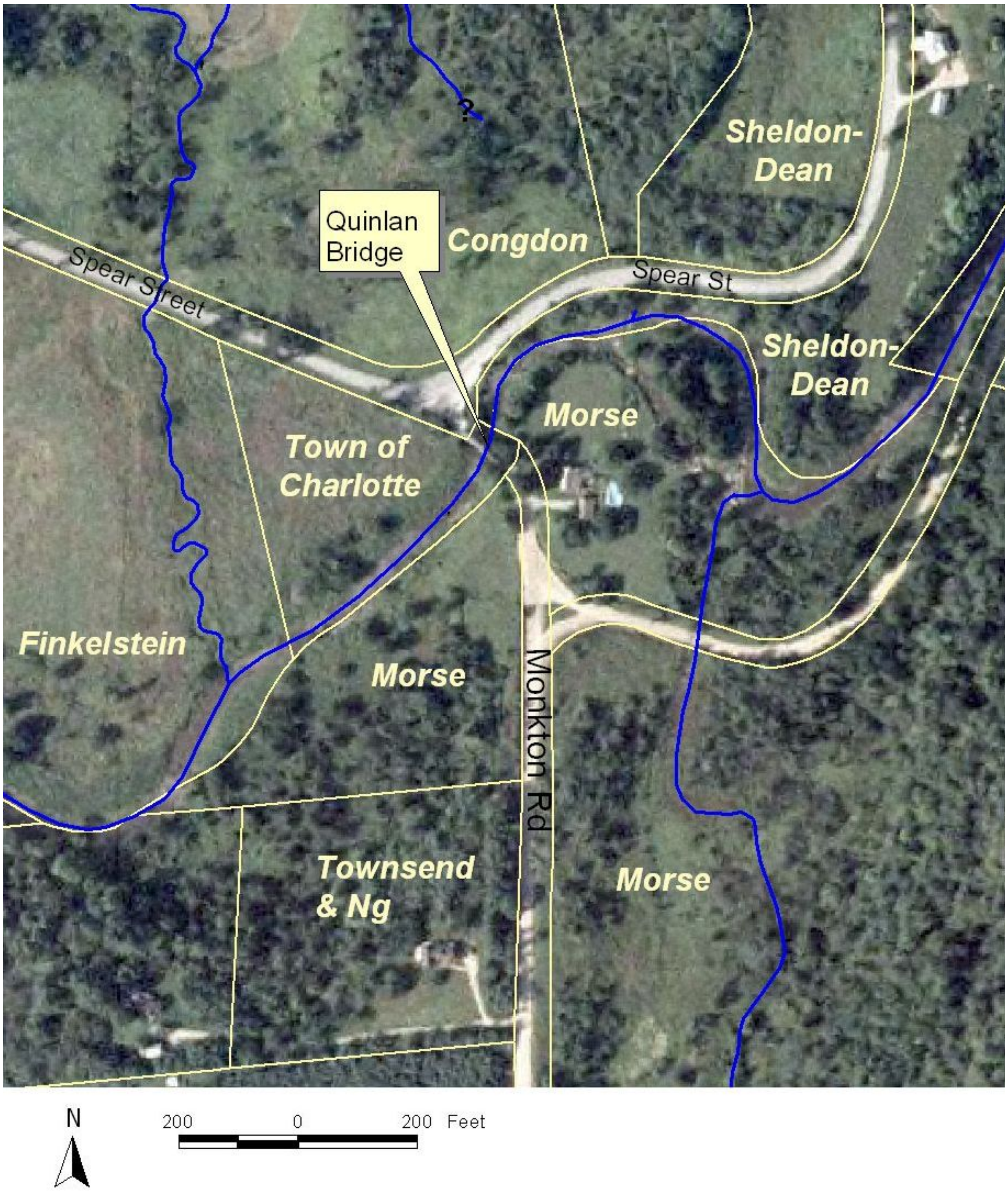
Appendix A: Landowners Near the Quinlan Bridge Site



Appendix B: Pebble Count Data

Project/Sample Information	
Project	Quinlan Bridge
Stream	Lewis Creek
Location	Charlotte
Sample ID	XS1
Sample Date	Nov-09
Sampled By	KU
Sample Method	Wolman pebble count

Sample Site Descriptions by Observations	
Channel type	riffle
D100 (mm)	
Colluvium	
Debris	
Other	

Particle Name	Size Limits (mm) lower	upper	Tally	Count	Percent Passing	Cumulative % Finer
silt/clay	0	**0.063**		14	12.8	12.8
very fine sand	0.063	**0.125**			0.0	12.8
fine sand	0.125	**0.250**		11	10.1	22.9
medium sand	0.250	**0.500**		1	0.9	23.9
coarse sand	0.500	**1**		1	0.9	24.8
very coarse sand	1	**2**			0.0	24.8
very fine gravel	2	**4**		1	0.9	25.7
fine gravel	4	**5.7**			0.0	25.7
fine gravel	5.7	**8**		1	0.9	26.6
medium gravel	8	**11.3**		3	2.8	29.4
medium gravel	11.3	**16**			0.0	29.4
coarse gravel	16	**22.6**		2	1.8	31.2
coarse gravel	22.6	**32**		7	6.4	37.6
very coarse gravel	32	**45**		8	7.3	45.0
very coarse gravel	45	**64**		11	10.1	55.0
small cobble	64	**90**		17	15.6	70.6
medium cobble	90	**128**		14	12.8	83.5
large cobble	128	**180**		11	10.1	93.6
very large cobble	180	**256**		5	4.6	98.2
small boulder	256	**362**		2	1.8	100.0
small boulder	362	**512**			0.0	100.0
medium boulder	512	**1024**			0.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	109	100.0	-

Particle Distribution (%)	
silt/clay	13
sand	12
gravel	30
cobble	43
boulder	2
bedrock	0

Particle Sizes (mm)	
D16	0
D35	28
D50	**54**
D84	130
D95	201

(Bunte and Abt, 2001)

F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	5.5
D5	0.5

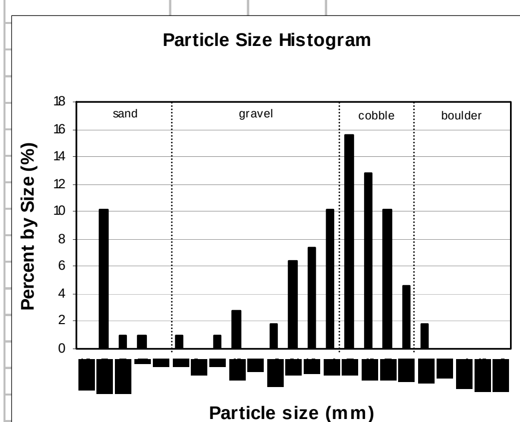
(Fuller and Thompson, 1907)

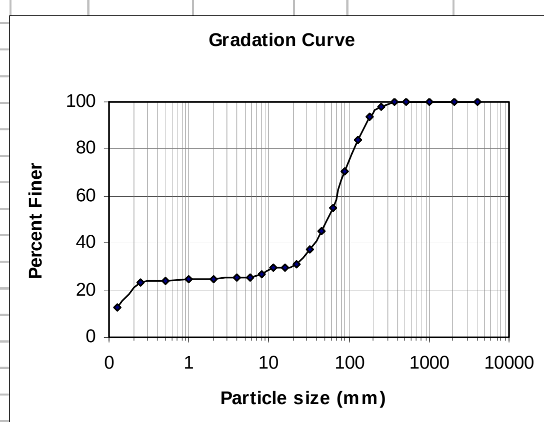
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information	
Project	Quinlan Bridge
Stream	Lewis Creek
Location	Charlotte
Sample ID	XS2
Sample Date	Nov-09
Sampled By	KU
Sample Method	Wolman pebble count

Particle Distribution (%)	
silt/clay	5
sand	2
gravel	19
cobble	69
boulder	6
bedrock	0

Sample Site Descriptions by Observations	
Channel type	riffle
D100 (mm)	
Colluvium	
Debris	
Other	

Particle Sizes (mm)	
D16	24
D35	96
D50	**126**
D84	201
D95	308

(Bunte and Abt, 2001)

Particle Name	Size Limits (mm) lower	upper	Tally	Count	Percent Passing	Cumulative % Finer
silt/clay	0	**0.063**		5	4.6	4.6
very fine sand	0.063	**0.125**			0.0	4.6
fine sand	0.125	**0.250**			0.0	4.6
medium sand	0.250	**0.500**		1	0.9	5.6
coarse sand	0.500	**1**		1	0.9	6.5
very coarse sand	1	**2**			0.0	6.5
very fine gravel	2	**4**		2	1.9	8.3
fine gravel	4	**5.7**			0.0	8.3
fine gravel	5.7	**8**		2	1.9	10.2
medium gravel	8	**11.3**		2	1.9	12.0
medium gravel	11.3	**16**		2	1.9	13.9
coarse gravel	16	**22.6**		2	1.9	15.7
coarse gravel	22.6	**32**		2	1.9	17.6
very coarse gravel	32	**45**		3	2.8	20.4
very coarse gravel	45	**64**		5	4.6	25.0
small cobble	64	**90**		7	6.5	31.5
medium cobble	90	**128**		21	19.4	50.9
large cobble	128	**180**		31	28.7	79.6
very large cobble	180	**256**		15	13.9	93.5
small boulder	256	**362**		3	2.8	96.3
small boulder	362	**512**		2	1.9	98.1
medium boulder	512	**1024**		2	1.9	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	108	100.0	-

F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	12.9
D5	1.3

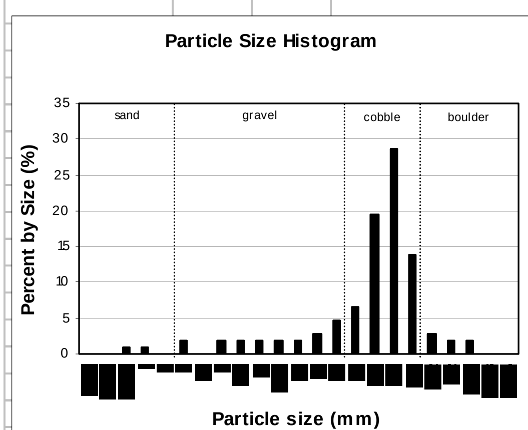
(Fuller and Thompson, 1907)

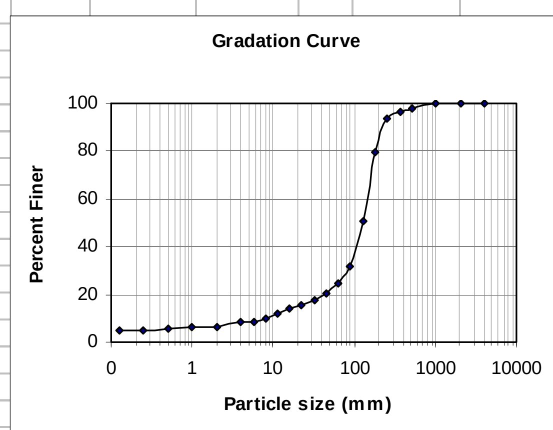
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information	
Project	Quinlan Bridge
Stream	Lewis Creek
Location	Charlotte
Sample ID	XS5
Sample Date	Nov-09
Sampled By	KU
Sample Method	Wolman pebble count

Particle Distribution (%)	
silt/clay	10
sand	1
gravel	22
cobble	55
boulder	12
bedrock	0

Sample Site Descriptions by Observations	
Channel type	riffle
D100 (mm)	
Colluvium	
Debris	
Other	

Particle Sizes (mm)	
D16	27
D35	71
D50	**108**
D84	234
D95	405

(Bunte and Abt, 2001)

	Size Limits (mm)				Percent	Cumulative
Particle Name	lower	upper	Tally	Count	Passing	% Finer
silt/clay	0	**0.063**		10	9.9	9.9
very fine sand	0.063	**0.125**			0.0	9.9
fine sand	0.125	**0.250**			0.0	9.9
medium sand	0.250	**0.500**			0.0	9.9
coarse sand	0.500	**1**		1	1.0	10.9
very coarse sand	1	**2**			0.0	10.9
very fine gravel	2	**4**			0.0	10.9
fine gravel	4	**5.7**		1	1.0	11.9
fine gravel	5.7	**8**			0.0	11.9
medium gravel	8	**11.3**		2	2.0	13.9
medium gravel	11.3	**16**			0.0	13.9
coarse gravel	16	**22.6**			0.0	13.9
coarse gravel	22.6	**32**		4	4.0	17.8
very coarse gravel	32	**45**		4	4.0	21.8
very coarse gravel	45	**64**		11	10.9	32.7
small cobble	64	**90**		8	7.9	40.6
medium cobble	90	**128**		18	17.8	58.4
large cobble	128	**180**		14	13.9	72.3
very large cobble	180	**256**		16	15.8	88.1
small boulder	256	**362**		5	5.0	93.1
small boulder	362	**512**		6	5.9	99.0
medium boulder	512	**1024**		1	1.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	101	100.0	-

F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	11.1
D5	1.1

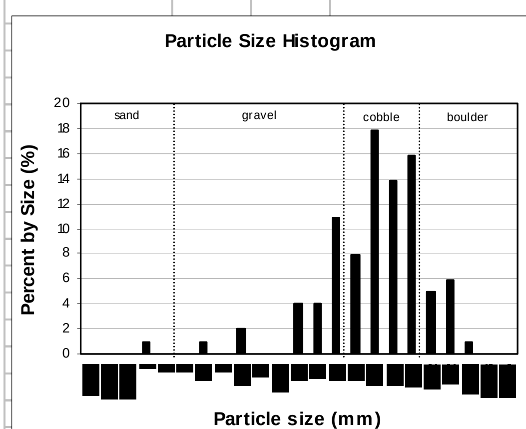
(Fuller and Thompson, 1907)

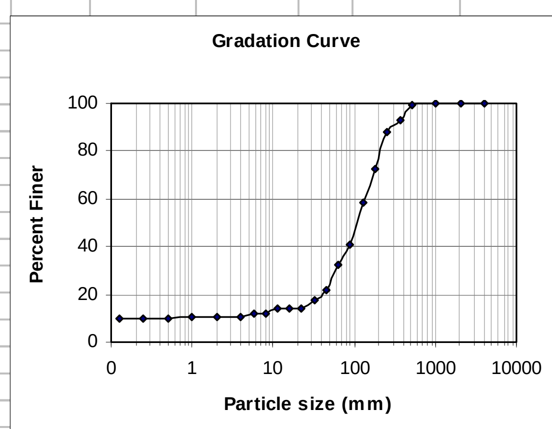
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information	
Project	Quinlan Bridge
Stream	Lewis Creek
Location	Charlotte
Sample ID	XS8
Sample Date	Nov-09
Sampled By	KU
Sample Method	Wolman pebble count

Particle Distribution (%)	
silt/clay	9
sand	1
gravel	33
cobble	50
boulder	7
bedrock	0

Sample Site Descriptions by Observations	
Channel type	riffle
D100 (mm)	
Colluvium	
Debris	
Other	

Particle Sizes (mm)	
D16	12
D35	42
D50	**81**
D84	183
D95	317

(Bunte and Abt, 2001)

Particle Name	Size Limits (mm) lower	upper	Tally	Count	Percent Passing	Cumulative % Finer
silt/clay	0	**0.063**		9	8.7	8.7
very fine sand	0.063	**0.125**			0.0	8.7
fine sand	0.125	**0.250**		1	1.0	9.7
medium sand	0.250	**0.500**			0.0	9.7
coarse sand	0.500	**1**			0.0	9.7
very coarse sand	1	**2**			0.0	9.7
very fine gravel	2	**4**			0.0	9.7
fine gravel	4	**5.7**		3	2.9	12.6
fine gravel	5.7	**8**		1	1.0	13.6
medium gravel	8	**11.3**		2	1.9	15.5
medium gravel	11.3	**16**		3	2.9	18.4
coarse gravel	16	**22.6**		3	2.9	21.4
coarse gravel	22.6	**32**		6	5.8	27.2
very coarse gravel	32	**45**		10	9.7	36.9
very coarse gravel	45	**64**		6	5.8	42.7
small cobble	64	**90**		11	10.7	53.4
medium cobble	90	**128**		20	19.4	72.8
large cobble	128	**180**		11	10.7	83.5
very large cobble	180	**256**		10	9.7	93.2
small boulder	256	**362**		3	2.9	96.1
small boulder	362	**512**		3	2.9	99.0
medium boulder	512	**1024**		1	1.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	103	100.0	-

F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	8.3
D5	0.8

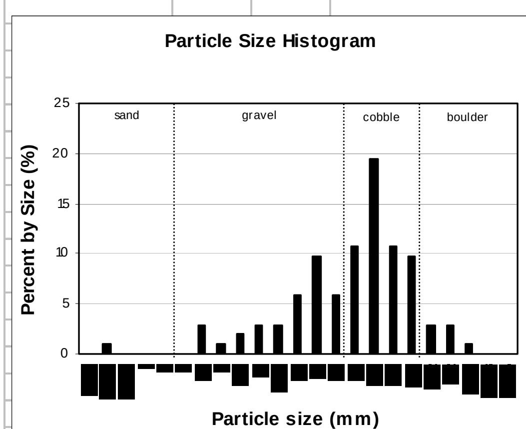
(Fuller and Thompson, 1907)

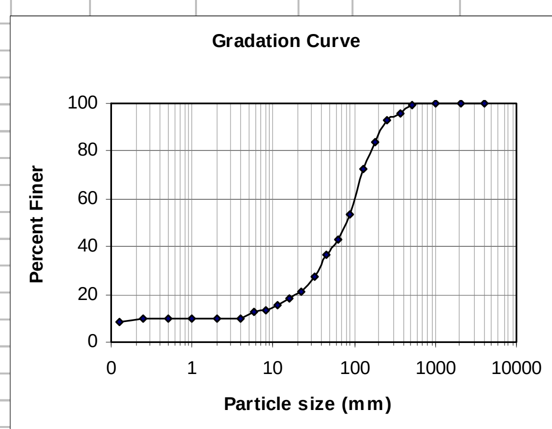
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information		Particle Distribution (%)	
Project	Quinlan Bridge	silt/clay	5
Stream	Lewis Creek	sand	2
Location	Charlotte	gravel	26
Sample ID	XS9	cobble	55
Sample Date	Nov-09	boulder	12
Sampled By	KU	bedrock	0
Sample Method	Wolman pebble count		

Sample Site Descriptions by Observations		Particle Sizes (mm)	
Channel type	run	D16	11
D100 (mm)		D35	68
Colluvium		**D50**	**99**
Debris		D84	226
Other		D95	408

(Bunte and Abt, 2001)

	Size Limits (mm)				Percent	Cumulative
Particle Name	lower	upper	Tally	Count	Passing	% Finer
silt/clay	0	**0.063**		6	5.4	5.4
very fine sand	0.063	**0.125**			0.0	5.4
fine sand	0.125	**0.250**		1	0.9	6.3
medium sand	0.250	**0.500**			0.0	6.3
coarse sand	0.500	**1**			0.0	6.3
very coarse sand	1	**2**		1	0.9	7.1
very fine gravel	2	**4**		5	4.5	11.6
fine gravel	4	**5.7**		1	0.9	12.5
fine gravel	5.7	**8**		2	1.8	14.3
medium gravel	8	**11.3**		2	1.8	16.1
medium gravel	11.3	**16**		3	2.7	18.8
coarse gravel	16	**22.6**		1	0.9	19.6
coarse gravel	22.6	**32**		3	2.7	22.3
very coarse gravel	32	**45**		4	3.6	25.9
very coarse gravel	45	**64**		8	7.1	33.0
small cobble	64	**90**		14	12.5	45.5
medium cobble	90	**128**		18	16.1	61.6
large cobble	128	**180**		16	14.3	75.9
very large cobble	180	**256**		14	12.5	88.4
small boulder	256	**362**		5	4.5	92.9
small boulder	362	**512**		7	6.3	99.1
medium boulder	512	**1024**		1	0.9	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
			Total	112	100.0	-

(Wenthworth, 1922)

F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	10.2
D5	1.0

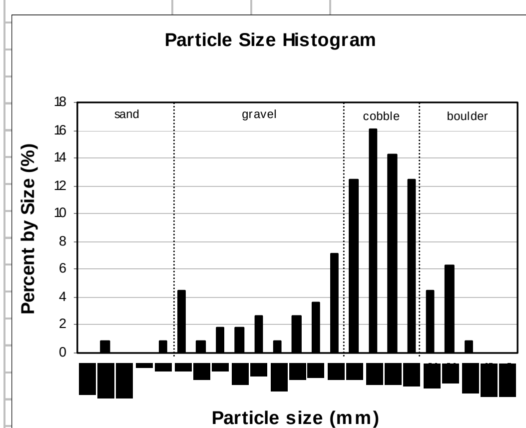
(Fuller and Thompson, 1907)

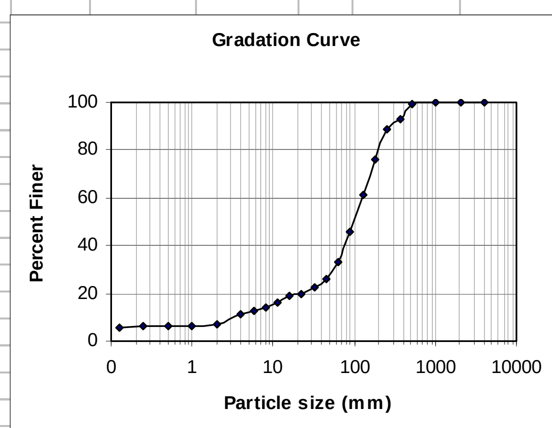
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information			Particle Distribution (%)	
Project	Quinlan Bridge		silt/clay	5
Stream	Lewis Creek		sand	5
Location	Charlotte		gravel	37
Sample ID	XS10B		cobble	41
Sample Date	Nov-09		boulder	12
Sampled By	KU		bedrock	0
Sample Method	Wolman pebble count			

Sample Site Descriptions by Observations			Particle Sizes (mm)	
Channel type	run		D16	7
D100 (mm)			D35	36
Colluvium			**D50**	**71**
Debris			D84	228
Other			D95	404
			(Bunte and Abt, 2001)	

	Size Limits (mm)				Percent	Cumulative
Particle Name	lower	upper	Tally	Count	Passing	% Finer
silt/clay	0	**0.063**		6	4.9	4.9
very fine sand	0.063	**0.125**			0.0	4.9
fine sand	0.125	**0.250**			0.0	4.9
medium sand	0.250	**0.500**		1	0.8	5.7
coarse sand	0.500	**1**		3	2.4	8.1
very coarse sand	1	**2**		2	1.6	9.8
very fine gravel	2	**4**		5	4.1	13.8
fine gravel	4	**5.7**		1	0.8	14.6
fine gravel	5.7	**8**		3	2.4	17.1
medium gravel	8	**11.3**		1	0.8	17.9
medium gravel	11.3	**16**		2	1.6	19.5
coarse gravel	16	**22.6**		7	5.7	25.2
coarse gravel	22.6	**32**		10	8.1	33.3
very coarse gravel	32	**45**		6	4.9	38.2
very coarse gravel	45	**64**		10	8.1	46.3
small cobble	64	**90**		15	12.2	58.5
medium cobble	90	**128**		10	8.1	66.7
large cobble	128	**180**		12	9.8	76.4
very large cobble	180	**256**		14	11.4	87.8
small boulder	256	**362**		6	4.9	92.7
small boulder	362	**512**		9	7.3	100.0
medium boulder	512	**1024**			0.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	123	100.0	-

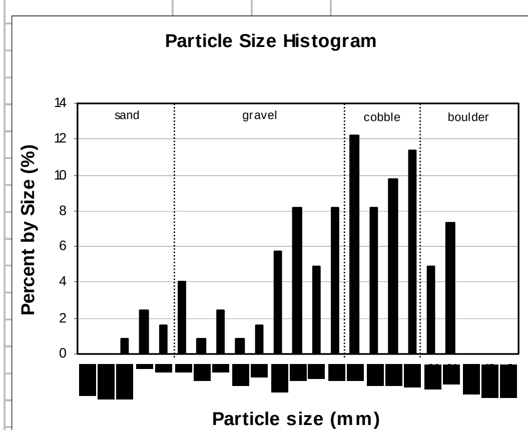
F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	7.3
D5	0.7
(Fuller and Thompson, 1907)	

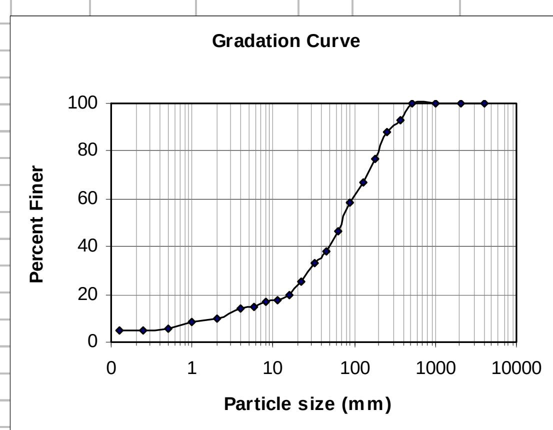
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Project/Sample Information			Particle Distribution (%)	
Project	Quinlan Bridge		silt/clay	2
Stream	Lewis Creek		sand	16
Location	Charlotte		gravel	37
Sample ID	XS10		cobble	32
Sample Date	Nov-09		boulder	13
Sampled By	KU		bedrock	0
Sample Method	Wolman pebble count			

Sample Site Descriptions by Observations		Particle Sizes (mm)	
Channel type	run	D16	1
D100 (mm)		D35	25
Colluvium		**D50**	**54**
Debris		D84	236
Other		D95	412
		(Bunte and Abt, 2001)	

	Size Limits (mm)				Percent	Cumulative
Particle Name	lower	upper	Tally	Count	Passing	% Finer
silt/clay	0	**0.063**		2	2.0	2.0
very fine sand	0.063	**0.125**			0.0	2.0
fine sand	0.125	**0.250**		2	2.0	4.0
medium sand	0.250	**0.500**		8	8.0	12.0
coarse sand	0.500	**1**		4	4.0	16.0
very coarse sand	1	**2**		2	2.0	18.0
very fine gravel	2	**4**		2	2.0	20.0
fine gravel	4	**5.7**		2	2.0	22.0
fine gravel	5.7	**8**		2	2.0	24.0
medium gravel	8	**11.3**		1	1.0	25.0
medium gravel	11.3	**16**		2	2.0	27.0
coarse gravel	16	**22.6**		7	7.0	34.0
coarse gravel	22.6	**32**		4	4.0	38.0
very coarse gravel	32	**45**		7	7.0	45.0
very coarse gravel	45	**64**		10	10.0	55.0
small cobble	64	**90**		4	4.0	59.0
medium cobble	90	**128**		8	8.0	67.0
large cobble	128	**180**		7	7.0	74.0
very large cobble	180	**256**		13	13.0	87.0
small boulder	256	**362**		5	5.0	92.0
small boulder	362	**512**		8	8.0	100.0
medium boulder	512	**1024**			0.0	100.0
large boulder	1024	**2048**			0.0	100.0
very large boulder	2048	**4096**			0.0	100.0
bedrock	4096	**-**			0.0	100.0
(Wenthworth, 1922)			Total	100	100.0	-

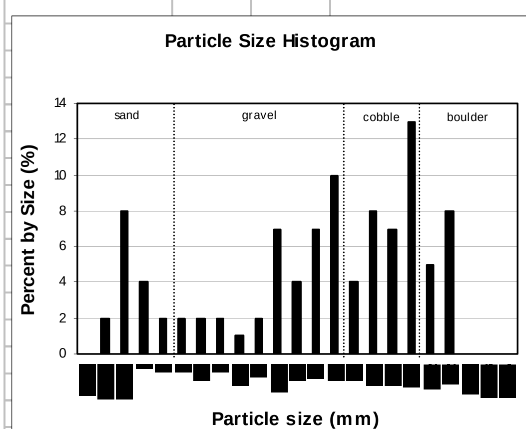
F-T Particle Sizes (mm)	
F-T n-value	0.5
D16	5.5
D5	0.5
(Fuller and Thompson, 1907)	

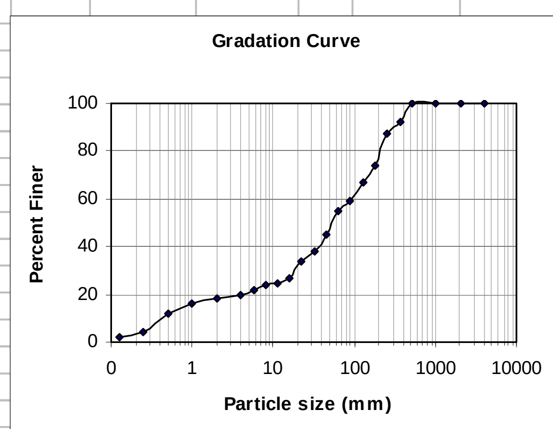
D (mm) of the largest mobile particles on bar	
Mean	

Riffle Stability Index (%)

(Kappesser, 2002)

Notes





Appendix C: Ballpark Cost Estimates for Preferred Alternatives

Description	Unit	Quantity	Unit Price ($)	Amount ($)	Opinion ($)
Site Preparation					
MOBILIZATION	LS	1	2,000	2,000	
EROSION CONTROL	LF	600	10	6,000	
CONSTRUCTION SIGNS	LS	1	500	500	
CONSTRUCTION STAKING/SURVEY	LS	1	5,000	5,000	
TRAFFIC CONTROL ON SPEAR STREET	LS	1	1,000	1,000	
				14,500	**15**
US Wetland					
EARTH EXCAVATION	CY	996	10	9,960	
RIPRAP	CY	10	40	400	
				10,360	**10**
Remove berm along Spear Street					
EARTH EXCAVATION	CY	10	284	**2,840**	**5**
Enlarge small bridge under Spear Street					
ENGINEERING/PEMITTING	LS	1	13,750	13,750	
CONCRETE REMOVAL	CY	31	350	10,850	
PRE-CAST CONCRETE	LS	1	27,500	27,500	
INSTALLATION	LS	1	27,500	27,500	
				79,600	**80**
Lower Spear Street 1.5 feet to the north					
ROAD MILLING	SY	833	10	8,333	
RIPRAP	CY	700	40	28,000	
PAVING	TON	192	75	14,375	
				50,708	**50**
Lower Spear Street to the west					
ROAD MILLING	SY	917	10	9,167	
RIPRAP	CY	50	40	2,000	
PAVING	TON	211	75	15,813	
				26,979	**30**

Appendix D: Preliminary Alternatives Analysis

#	ALTERNATIVES	OBJECTIVES=> Reduce risk of annual ice jam flooding and erosion	Reduce risk of non-ice, large storm flooding and erosion	Protect historic Quinlan Covered Bridge	Naturalize local sediment and debris transport	Improve floodplain-channel connection	Improve local habitat quality and stability	Ballpark cost opinion*	Notes
1	No action							0	Elevation of bridge and roadways relative to Lewis Creek provides some relief for ice jam and larger flooding. Overtopping of roadway approaching bridge currently takes place.
2	Reconnect U/S left bank wetland near Lewis Creek Road				√	√	√	10	Improve existing connection to wetland to provide more ice storage. Design needs to ensure that channel will not migrate/avulse to the left of the bedrock outcrop at the upstream end of split channel.
3	Remove 2-foot tall berm along Spear Street north of Quinlan Bridge	√	√	√	√	√	√	5	Improves wetland connection to provide small increase in ice shed and water storage area. Periodic road closures during peak flooding will take place, slightly more than existing conditions, while water recedes and ice is removed.
4	Remove berm along Spear Street north of Quinlan Bridge and enlarge small bridge under Spear Street west of Quinlan Bridge	√	√√	√	√	√	√	85	Larger structure would replace deteriorating small bridge and would improve drainage from floodplain with enhanced connection. The structure would be designed to improve passage of aquatic organisms and wildlife.
5	Remove berm along Spear Street and lower roadway 1.5 feet to the north of Quinlan Bridge	√√	√√	√√	√√	√√	√	50	Improves wetland connection to provide moderate increases in ice shed and water storage area. Roadway surface could be lowered during resurfacing by removing old asphalt. Roadway closures could increase while ice is removed and floods recede.
6	Remove berm along Spear Street, lower roadway north of Quinlan Bridge, and lower roadway 1.5 feet to the west of Quinlan Bridge	√√√	√√√	√√√	√√	√√	√	80	Improves storage and conveyance around bridge to provide greater pressure relief during flooding. Water velocity at the bridge would decrease substantially. Lowering both roads would require traffic detours during flood events.
7	Combination - reconnect wetland, lower berm, lower Spear north of Quinlan Bridge, and enlarge small bridge on tributary	√√	√√	√√	√√	√√	√	145	Combination alternatives to improve floodplain connection to provide increases in ice shed and water storage area. These alternatives can be implemented incrementally as normal maintenance work is required on the roadways and small bridge, and funding is available.

*The ballpark cost opinion is presented in thousands of dollars. Approximate costs do not consider mobilization, erosion control, traffic control, and other construction services that could be up to $15,000 for each item if pursued individually. Incorporating the proposed activities into scheduled maintenance can substantially reduce these costs, as will pursuing multiple alternatives at the same time.