TECHNICAL REPORT

BAKER BRIDGE (TH-1)
SAFETY AND FUNCTIONAL
ASSESSMENT STUDY
RIPTON, VERMONT

October 4, 2013

MMI #3928-04-4

Prepared for:

Addison County Regional Planning Commission
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1.0 INTRODUCTION

The purpose of this report is to summarize the findings of the Baker Bridge Safety and Functional Assessment Study. Baker Bridge is a concrete structure located on Lincoln Road (TH-1) at the intersection of North Branch Road and Pearl Lee Road (Figure 1.1). The structure crosses over the North Branch of the Middlebury River and has been designated as a one-lane bridge. Traffic safety is an increasing concern in the area given the offset road alignment of the intersection and the conditions at the bridge. The bridge has experienced flood damage several times over the past 25 years. For example, heavy rainfall in the late 1980s caused roadside erosion along Lincoln Road, North Branch Road, and Pearl Lee Road resulting in damage to both the eastern and western bridge abutments and wingwalls. Additionally, two beaver dams failed during a flood in the late 1990s causing the culvert located just upstream of the bridge to overtop, resulting in erosion damage of Lincoln and Pearl Lee Roads and to the eastern portion of the bridge structure.

Section 2.0 of this report discusses the existing conditions at the Baker Bridge project site – data collection, structural conditions of the bridge, roadway safety, and natural resources. The results of the hydrologic and hydraulic analyses are provided in Section 3.0 of the report, followed by a discussion of conceptual alternatives for roadway improvements in Section 4.0. Section 5.0 provides initial recommendations for planning a bridge replacement and potential roadway reconfiguration.

1.1 Goals and Objectives

The primary goal of the study is to assess the safety and functionality of the existing Baker Bridge crossing and roadway configuration in an effort to plan for future bridge replacement and roadway improvements.

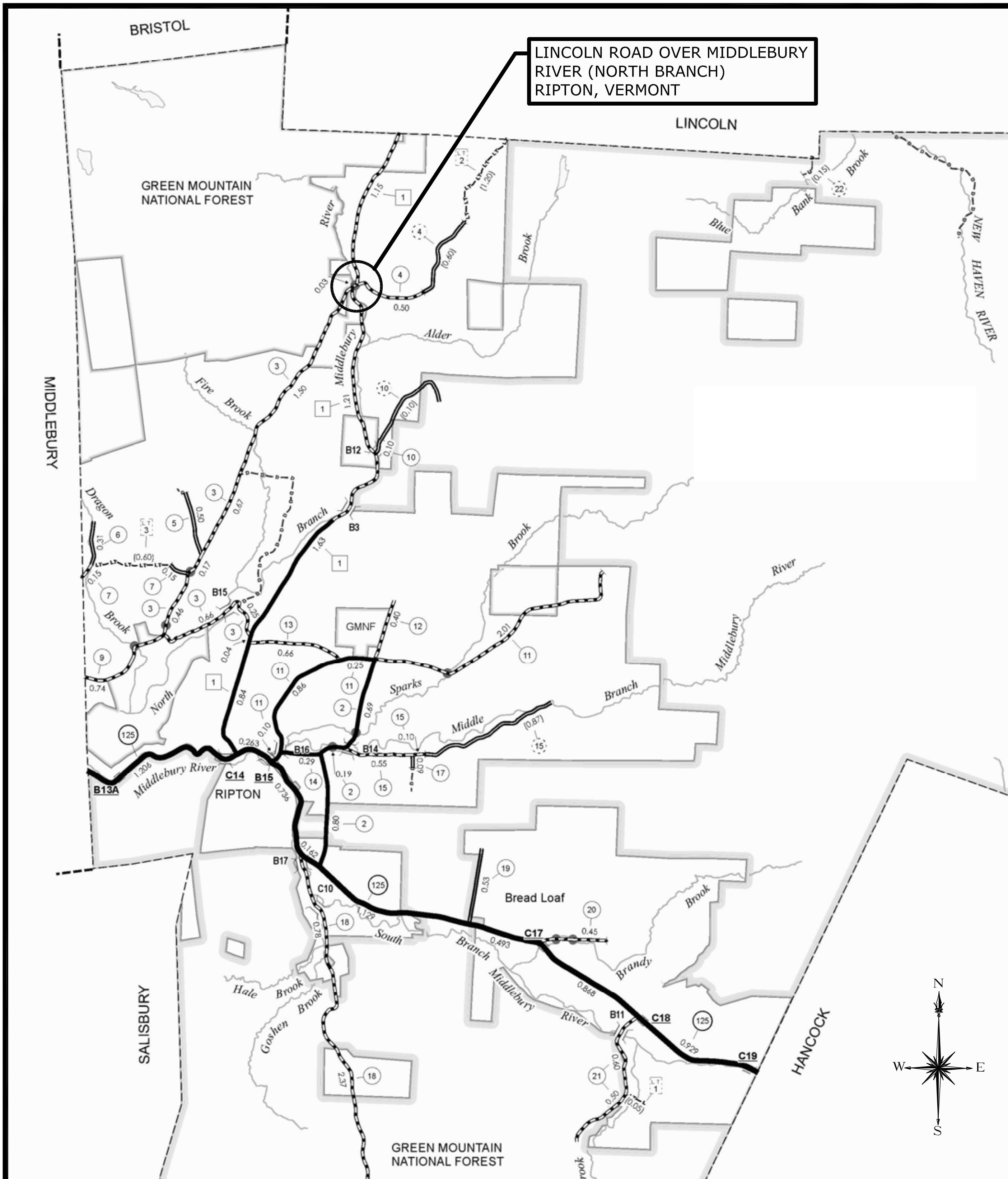
Project objectives include:

1. Gather existing information including structure inspection, roadway safety assessment, and natural resources to guide an alternatives analysis.

2. Conduct hydrologic and hydraulic analyses to assess the performance of the existing structure and provide guidance for planning future bridge reconstruction.

3. Provide conceptual alternative sketches for roadway safety and alignment improvements with conceptual-based opinions of probable construction costs.

4. Present findings to the public at a Town of Ripton Selectboard meeting and summarize findings and recommendations in a final project report.



LOCATION MAP

BAKER BRIDGE (TH-1) SAFETY & FUNCTIONAL ASSESSMENT STUDY

RIPTON, VERMONT

PROJECT PHASE: ---

REV: ---

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DATE	AUG. 1, 2013
SCALE	1"=5000'
PROJ. NO.	3928-04
DESIGNED	
DRAWN	FWW
CHECKED	
DRAWING NAME:	FIG 1.1

Drawing: P:\3928-04\DESIGN\CAD\NONPLANSET\LOCATIONMAP_RPT.DWG Layout Tab:FIG_1.1
Plotted by: BRIANC On this date: Thu, 2013 August 1 - 3:26pm
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2.0 EXISTING CONDITIONS

2.1 Data Collection

A project initiation meeting was conducted on May 9, 2013 where general information regarding the structure was gathered such as history of flood damage and past maintenance of the roadway and structure. The results from the September 2012 traffic count study were discussed, and information regarding adjacent landowners was collected. Bridge design plans, record drawings, or past bridge inspection reports are not available through the Town of Ripton, Addison County Regional Planning Commission (ACRPC), or District 5 of the Vermont Agency of Transportation (VTrans).

Past traffic safety issues were discussed, including a traffic collision that occurred on the bridge and required repair of the safety railing on the south side of the bridge. No hydrologic or hydraulic studies have been conducted at the project site. There is no history of the bridge being overtopped during a flooding event on the North Branch of the Middlebury River although damage to the bridge structure has occurred due to roadside erosion along Lincoln Road, North Branch Road, and Pearl Lee Road. Photos of past damage were reviewed and collected during the project initiation meeting.

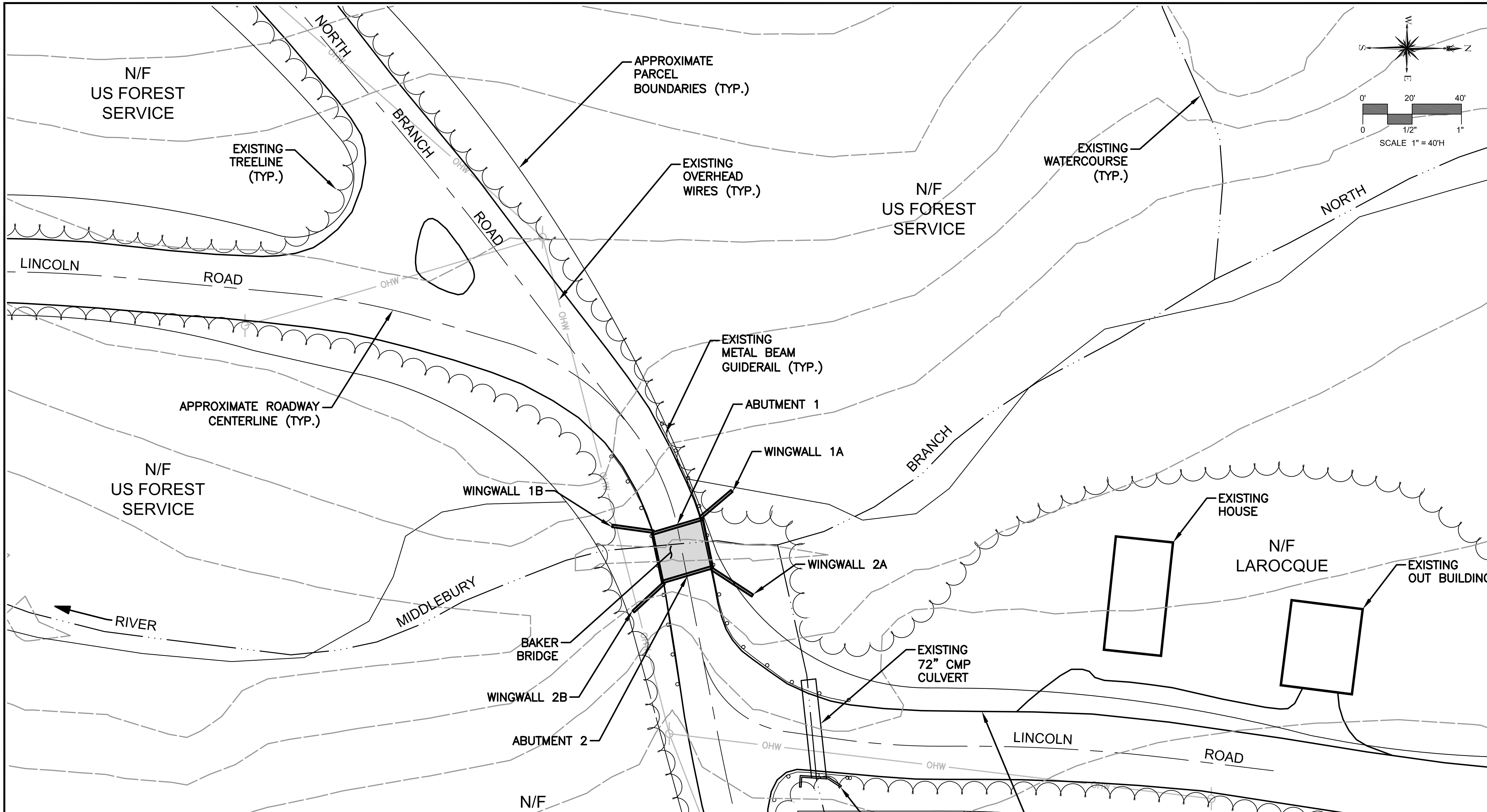
Geographic Information System (GIS) data were obtained through the Vermont Center for Geographic Information (VCGI) including aerial photography, coarse topographic information, roadway data, and parcel information. The Vermont Agency of Natural Resources (ANR) online *Natural Resources Atlas* was used to access information on the river channel and natural resources. The results of the traffic study conducted by the ACRPC were forwarded to the project team for use during the roadway assessment, alternatives analysis, and conceptual design. Stream gage data were obtained from regional United States Geological Survey (USGS) gage sites to be used in the hydrologic analysis.

2.2 Field Survey

Field survey and site investigation were conducted by Milone & MacBroom, Inc. (MMI) on May 9, 2013. During the site visit, the dimensions of the bridge and wingwalls were measured. Elevations of the bridge, wingwalls, roadway profile, and channel geometry were measured relative to a temporary survey marker set to an assumed vertical datum. The surveyed points taken at the project site were tied into a known horizontal coordinate system (NAD 83 Vermont State Plane) using a handheld Global Positioning System (GPS) unit. The field survey data collected were used to create a base map of existing conditions (Figure 2.1).

The existing site distances (with a 3.5-foot eye height and a 2.0-foot object height) were measured from each intersection and from the bridge structure. The measurements recorded were used to determine the adequacy of the existing site distances for traffic safety. In addition, the channel dimensions were measured and surveyed, and survey points were recorded upstream of the bridge to estimate the existing channel profile.

Drawing: P:\3928-04\DESIGN\CAD\BB-EXCOND.DWG Layout Tab:FIG 2.1



NOTES:

1. ITEMS DEPICTED ON THIS MAP WERE CREATED USING AVAILABLE GIS DATA AND DIGITIZED FROM AERIAL PHOTOS, AND SHOULD BE CONSIDER APPROXIMATE.
2. FIVE (5) FOOT CONTOUR DATA DEVELOPED USING THE VERMONT HYDRO DIGITAL ELEVATION MODEL (DEM) AND IS SHOWN TO PROVIDE GENERAL TOPOGRAPHIC RELIEF.
3. HORIZONTAL DATUM IS NAD 83.

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REVISIONS

CONCEPTUAL

SKETCH PLAN - EXISTING CONDITIONS

BAKER BRIDGE (TH-1) SAFETY & FUNCTIONAL ASSESSMENT STUDY

LINCOLN ROAD
RIPTON, VERMONT

DESIGNED	DRAWN	CHECKED
--	BMC	--

SCALE: 1" = 40'

DATE: AUG. 1, 2013

PROJECT NO.: 3928-04-3

SHEET NO.: FIG 2.1

Plotted by: BRANC On this date: Thu, 2013 August 1 - 3:18pm

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2.3 Structural Conditions

The Baker Bridge carries Lincoln Road over the North Branch of the Middlebury River. The structure has a span of 19.7 feet (inside face of abutment to inside face of abutment) and width of 21.5 feet (out to out). The bridge was reportedly constructed in 1930. Evaluation of the structure at this time is based solely on the visual investigation performed by MMI on May 13, 2013. The following narrative summarizes the findings of the visual investigation; the full bridge inspection report has been provided in Appendix A of this report.

2.3.1 Superstructure: (Bridge Deck, Headwalls & Railings)

The structure was not built with a traditional bridge deck; the superstructure consists of a concrete slab and headwalls rising vertically from the top of the slab used to retain fill above the slab. Lincoln Road is a dirt road constructed within the roadway fill. Steel beam guardrail is present along the approaches and crossing the bridge; however, it was found that the guardrail height is inadequate. The existing top of rail was found to be between 20" and 22" above the roadway surface whereas the standard height should be 28". Additionally, standard bridge railing has not been provided across the bridge. Currently, the steel beam guardrail is attached directly to six 12" x 10" x 20"(H) concrete blocks (three per side) cast onto the headwalls. It is unknown whether or not this system meets National Highway System (NHS) crash test criteria. Collision damage to the guardrail was noted in eight separate locations, and repairs have been made to two of the south side guardrail concrete block attachments.

The cast-in-place concrete headwalls are 15"(W) x 16"(H) and appear to have been cast monolithically with the bridge slab. There is minor spalling and efflorescence but, overall, they are in good condition. The cast-in-place concrete bridge slab is 21'-6"(W) x 19'-8"(L) x 18"(T). It should be noted that the length of the slab was measured from the inside face of abutment to inside face of abutment; since bridge plans were not available, it is unknown how wide the bridge seat is. Currently, there are signs indicating that there has been 1.5" of movement of the concrete slab (see Field Notes – Sheet 5 of 21 provided in the Bridge Inspection Report).

Multiple areas of cracking, spalling, and heavy efflorescence were noted along the bottom of the slab. The spalled areas are generally located along the center of the slab, are between 2" and 2.5" deep, and vary in size. The largest area noted was 2'(W) x 7'(L). Rebar has been exposed, and rust is visible within the spalled locations as well as a 12"(L) length of exposed rebar at the face of Abutment No. 1. ***Although, as noted, this structure was not constructed with a traditional bridge deck, given the issues indicated a Condition Rating of 5 (Fair Condition) will be assigned to the "deck."***

2.3.2 Substructure: (Abutments & Wingwalls)

Abutment No. 1: (Western Abutment)
A crack with efflorescence runs longitudinally along the entire face of the abutment, and there is a 4"(D) spalled area at the north corner near Wingwall 1A. Heavy scale is present along the entire bottom of the abutment at the interface with the water as well as at each of the three weep holes. Water was actively flowing from the holes during the site visit; however, its source could not be determined. Additionally, a gap was noted between the seat and slab at the south side of the abutment, and moss and rust stains were noted along the entire face. A 1¼":36" rotation (overturning) was noted along the face of the abutment.

Wingwall 1A: (Northwest)
There are hairline cracks with efflorescence along most of the face of the wingwall with a larger crack ($^{1}/_{8}$" wide) noted at the approximate center of the wall. An 8"x30" hollow area was noted along with multiple spalled areas between ¾" and 1"(D). These ranged in sizes, with the largest being 10"x6". There is heavy scale along the entire bottom of the abutment and vegetation and moss growth along the top of wall. A 1¼":36" rotation (overturning) was noted along the face of the wingwall.

Wingwall 1B: (Southwest)
There are hairline cracks with efflorescence along most of the face of the wingwall with larger cracks ($^{1}/_{8}$" wide) and some honeycombing noted at the top and at the southern terminus of the wall. Heavy efflorescence is present along the lower portion and end of the wall. Hollow areas were noted along with multiple spalled areas of various sizes, the largest being 14"x23". There is heavy scale along the entire bottom of the abutment and vegetation and moss growth along the top of wall. It should be noted that the toe of the wall is visible within the watercourse. A 1½":36" rotation (overturning) was noted along the face of the wingwall.

Abutment No. 2: (Eastern Abutment)
Minor efflorescence and moss growth were noted along the face of Abutment No. 2 along with heavy scale along the entire bottom. Additionally, there is a 9"x48" spalled area located at the south side of the abutment. The southernmost weephole just below this spalled area is currently blocked while the other weepholes exhibit active water flow and additional scaling. A $^{7}/_{8}$":36" rotation (overturning) was noted along the face of the abutment.

Wingwall 2A: (Northeast)
Minor map cracking, efflorescence, and moss growth are characteristic along the face of the wingwall. There is heavy scale along the entire bottom of the abutment and heavy vegetation and moss growth along the top of wall. A $1^{1}/_{8}$":36" rotation (overturning) was noted along the face of the wingwall.

Wingwall 2B: (Southeast)
Hairline cracks with efflorescence and moss growth are characteristic along the top face of the wingwall. Additionally, there is medium scale along the entire bottom of the abutment and vegetation and moss growth along the top of wall. A 5"x5"x1" spall was noted at the top of the wingwall adjacent to Abutment No. 2. A $^{1}/_{4}$":36" rotation (overturning) was noted along the face of the wingwall.

2.4 Roadway Conditions

Baker Bridge is located at a four-legged offset intersection. Lincoln Road, which is the predominant route according to recent traffic study data, forms the north-south leg. North Branch Road and Pearl Lee Road form the western and eastern legs of the intersection.

Lincoln Road is a gravel road that is classified by VTrans as a Class 2 rural roadway. The Lincoln Road northbound approach is on an upslope and splits into channelized lanes at the intersection with North Branch Road. This approach is stop sign controlled. The Lincoln Road southbound approach is on a downslope and is also stop sign controlled. The posted speed limit on Lincoln Road is 35 miles per hour.

Pearl Lee Road and North Branch Road are also gravel roads and are both classified by VTrans as Class 3 rural roadways. The Pearl Lee Road approach is characterized by a downslope and a sharp horizontal curve approximately 300 feet east of the Baker Bridge. This approach is stop sign controlled. Similarly, North Branch Road is characterized by a downslope and a horizontal curve approaching the bridge. However, the North Branch Road approach is uncontrolled. The posted speed limit on Pearl Lee Road and North Branch Road is 35 miles per hour.

The intersection configuration and roadway geometry restricts sightlines and presents some safety and traffic operation issues. Based on the VTrans design guidelines, a minimum corner sight distance of 385 feet is required for a design speed of 35 miles per hour. The sight distance looking west (left) from the Lincoln Road northbound approach was measured as 185 feet while the sight distance looking east (right) from the Lincoln Road northbound approach and looking east (left) from the Lincoln Road southbound approach were both found to be 95 feet. The sightlines at these locations currently do not meet the minimum requirements.

2.5 Traffic Volumes and Vehicular Speeds

A review of automatic traffic recorder (ATR) counts published by ACRPC and VTrans indicates an average daily traffic (ADT) of 210 vehicles per day on Lincoln Road and 80 vehicles per day on North Branch Road. Morning and afternoon peak-hour traffic volumes across the bridge were found to be approximately 20 vehicles per hour and 30 vehicles per hour. The 85th percentile speeds were found to be approximately 32 miles per hour.

2.6 Natural Resources

2.6.1 Channel Geomorphology

The North Branch of the Middlebury River flows from north to south through the Baker Bridge project site approximately 4.5 miles upstream of its confluence with the Middlebury River in the town of Ripton. Past geomorphic assessment indicates that the channel is a steep-gradient stream with steps and pools (SGA reach ID T3.09). The channel substrate primarily consists of boulder and cobble with some gravel and coarse sand. Occasional embedded logs exist that control the grade of the channel.

The bankfull width of the channel was found to be 28 feet during past assessment of reach T3.09. Based on survey and several local measurements at the Baker Bridge project site, the bankfull channel width is 30 feet.

Although limited floodplain typically exists high up in the watershed at the project site (area ~ 4.4 square miles), some flood benches are present adjacent to the channel. These riparian features are important for natural flood control during annual and larger flood events. The flood benches also play important habitat roles such as forming naturally vegetated buffers to filter runoff as it makes its way to the channel and forming travel corridors for birds and wildlife.

River channels evolve over time moving through phases of stability and instability as they cut down, widen, and form new floodplain. The project reach was found to be in stage one of channel evolution indicating that it is stable and connected to its floodplain.

The head of a riffle exists just at the upstream face of the bridge where a buildup of sediment is located. A small sediment bar and plunge pool exist in this location. The sediment bar was observed to direct flow along Abutment No. 1 (western abutment). Flow from an upstream tributary passes along the sediment buildup and has formed a small pool directly in front of Abutment No. 2 (eastern abutment). Trees and shrubs are found directly along the edge of the channel. Some minor bank erosion has taken place.

The channel is generally in good and stable condition. Some sediment and debris accumulations are present in the project area that could be problematic for the bridge if they continue to build up. Observations suggest that some material is able to move through the bridge at moderate or high flows.

2.6.2 Habitat

The channel has good cold-water instream habitat with a diversity of hydraulic features such as steps, riffles, runs, and pools. Large woody debris and organic matter exist in the channel, which are important habitat features. Overhanging vegetation exists on the riverbanks that shades the channel and provides shelter for fish and insects. The channel appears to be good cold-water habitat.

The river corridor and floodplain are mostly forested other than the roadways and the occasional house with lawn. The observed riparian corridor was naturally vegetated and protected the stream channel from runoff. The BioFinder database shows high contribution to biodiversity along the North Branch of the Middlebury River.

2.6.3 Roadside Runoff

Roadside erosion has taken place due to uncontrolled runoff from the road surfaces during storms and thaw cycles. Signs of erosion exist along the south side of Pearl Lee Road and both sides of North Branch Road as they approach the intersection with Lincoln Road. There appears to have been some roadside ditching completed recently along Pearl Lee Road. The outlet of the roadside swale is directed toward the end of the southeastern wingwall (2B). Similarly, the roadside swale along the north side of North Branch Road directs runoff toward the northwestern wingwall (1A). Clear signs of erosion exist around the end of the wingwall. Additional erosion was noted along the end of the southwestern wingwall (1B) and at the outfall of the upstream culvert. Roadside erosion is an important issue at the site and should be considered with changes to the bridge and road.

2.6.4 Upstream Tributary and Culvert

An unnamed tribuary joins the North Branch of the Middlebury River from the east located just upstream (north) of the bridge. A 72" corrugated metal pipe (CMP) culvert passes the tributary under Lincoln Road just to the northeast of Baker Bridge. The CMP was installed when the smaller-diamater culvert washed out during past flooding. The 72" culvert appears to be in good condition. Some minor scour was evident at the outlet of the culvert, and the culvert is currently perched above the channel bed.

The channel segment between the culvert outlet and the North Branch of the Middlebury River consists of steep banks. Some evidence of erosion exists at the culvert outlet where it appears that uncontrolled stormwater runoff from the roadway surface has eroded the area around the pipe.

2.6.5 Landforms and Soils

Glacial till is the primary landform in the vicinity of the project site, yet a pocket of mapped glacial outwash exists near the project site. The soils at the project site are poorly drained and have slow to very slow infiltration rates (Table 2.1 and Appendix B). The stony loam on steep slopes thus generates a lot of runoff during precipitation events. This condition is leading to the roadside erosion at the project site. The Cabot soils at the site are hydric, or linked to shallow groundwater and wetlands. Prime agricultural soils do not exist at the project site according to the ANR online *Natural Resources Atlas*.

TABLE 2.1
Soils

ID	Soil	Location	Hydrologic Soil Group
CbC	Cabot extremely stony loam, 0 to 15 percent slopes	Upstream of bridge in valley	D
BsE	Berkshire and Marlow extremely stony loams, 20 to 50 percent slopes	Downstream of bridge	C

2.6.6 Wetlands

Vermont Class 1 or 2 wetlands are not mapped at the project site, yet riparian wetlands were observed along the river channel approximately coincident with the mapped hydric soils. Bordering vegetated wetlands are present in the flood benches upstream and downstream of the project area.

The U.S Fish and Wildlife National Wetland Inventory was reviewed, and no mapped wetlands exist near the project site.

Wetland delineation will be required for understanding potential impacts caused by future changes at the bridge and road.

2.6.7 Threatened or Endangered Species

Two rare plant species are mapped in the Vermont Natural Heritage Database that are located approximately 1,200 feet downstream of Baker Bridge (ID 1221 and 8082). The plants were observed in 2012 and are designated as S2, meaning that the species are imperiled and of great conservation concern to the state.

A review with Vermont Fish and Wildlife will be needed with future changes to the bridge and road.

2.6.8 Water quality

The water quality in the North Branch of the Middlebury River is known to be good. No rivers in the area are on the list of impaired waters [Clean Water Act 303(d)]. Several residential drinking water wells exist near the project site.

2.6.9 Cultural Resources

A map of the project area has been submitted to the Vermont Division for Historic Preservation for an initial review. An initial discussion about the project site with a state archeologist did not raise immediate concerns or red flags. However, a more formal review will be needed with future changes to the bridge and roadway.

3.0 HYDROLOGY AND HYDRAULICS

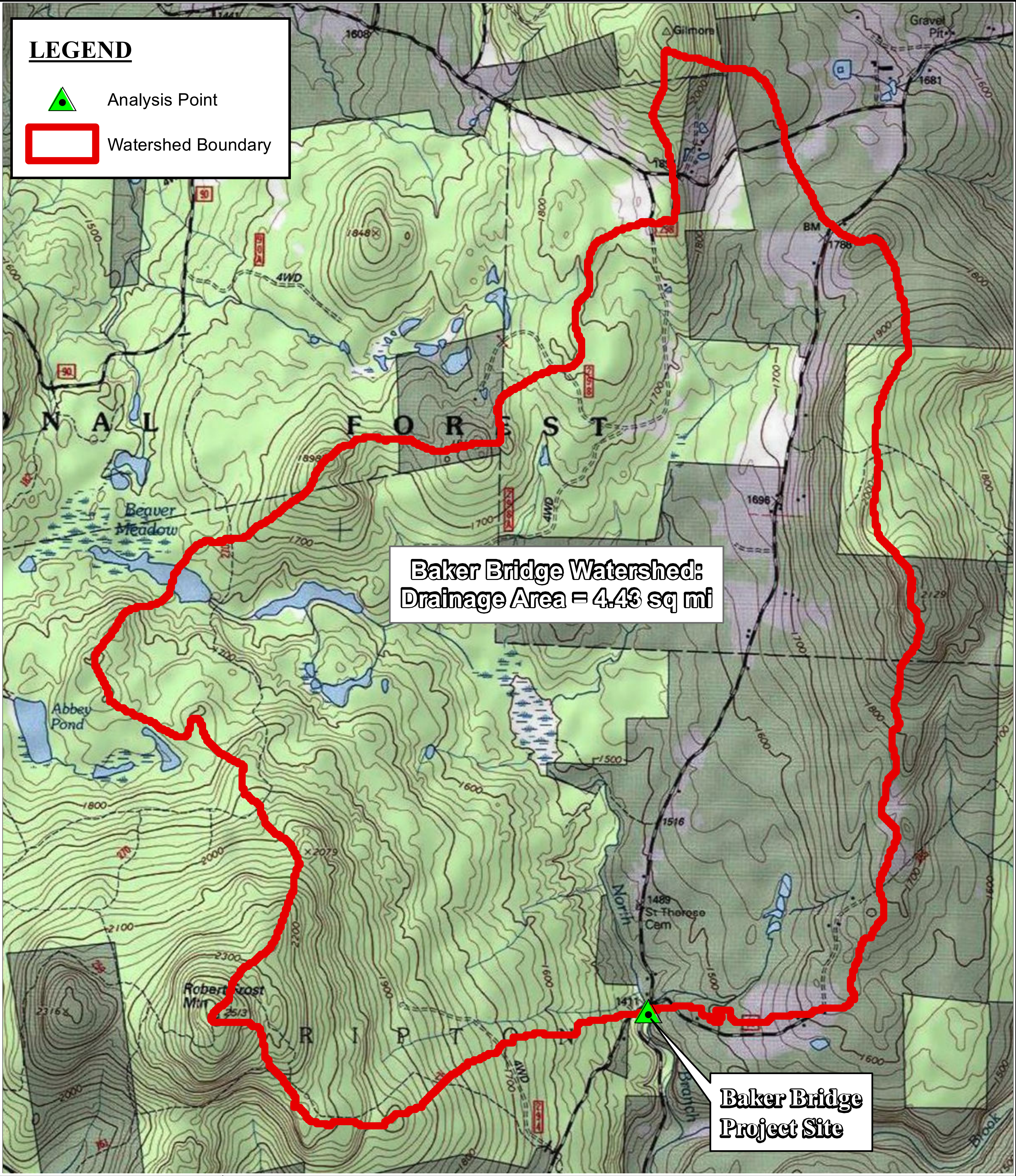
An initial hydrologic and hydraulic analysis of the Baker Bridge project site has been conducted. Peak flow rates were estimated for a range of flood events that were then used to calculate the capacity of the existing bridge structure, as well as provide guidance for sizing a future replacement structure.

The drainage area contributing to the Baker Bridge project site is approximately 4.4 square miles. The watershed is primarily forested and mountainous, with some ponds and wetland areas located through the middle one-third of the watershed. The Green Mountain National Forest is found along the eastern portion of the overall watershed (Figure 3.1).

The headwaters of the North Branch of the Middlebury River originate approximately three miles away from the Baker Bridge project site. The highest point in the watershed is at approximately 2,500 feet NGVD88 at the peak of Robert Frost Mountain while the elevation at the project site is approximately 1,400 feet. The average channel slope upstream of the Baker Bridge project site was measured as 1.3%, or approximately 70 feet per mile.

3.1 Hydrology

Several methods were used to estimate peak flow rates for the contributing watershed. Statistical analysis of annual peak flow gage data obtained from regional USGS stream flow gage stations was used to estimate peak flow rates (USGS, 1982). The estimates were then scaled to the Baker Bridge project site via the ratio of watershed areas raised to the 0.75 exponent (ANC, 1976). Gages were selected based on proximity to the Baker Bridge project site and similarities in watershed characteristics (Table 3.1).



SOURCE(S):		LOCATION:
USGS StreamSTATs US Topo Maps	Figure 3.1: Overall Watershed Map	Ripton, VT

N Baker Bridge (TH-1) Safety and Functional Assessment Study MXD: P:\3928-04\Design\GIS\Maps\BB-WatershedMap.mxd	Map By: BMC MMI#: 3928-04-2 Original: 08/01/2013 Revision: --- Scale: 1 inch = 2,000 feet	MILONE & MACBROOM 1 South Main Street - 2nd Floor Waterbury, Vermont 05676 (802) 882-8335 Fax: (802) 882-8346 www.miloneandmacbroom.com

TABLE 3.1
USGS Stream Flow Gage Sites

USGS Stream Flow Gage Site	River	Location	Drainage Area (square miles)	Years of Record
01150900	Ottauquechee River	West Bridgewater, VT	23.4	28
01142500	Ayers Brook	Randolph, VT	30.5	76
04276842	Putnam Creek	Crown Point, NY	51.6	23
04287000	Dog River	Northfield, VT	76.1	78
04282525	New Haven River	Brooksville, VT	115	22

The results of the gage analysis were used as the basis of the hydrology analysis. The estimated peak flow rates as well as the unit peak flow in cubic feet per second per square mile of watershed (csm) were compared to estimates using other methods. The unit peak discharge is a useful way of comparing how much runoff is produced by watersheds of different sizes (Table 3.2).

TABLE 3.2
Estimated Peak Discharge (cfs) and Unit Peak Flow (csm) Based on Gage Analysis

Storm Event	**2-year**	**5-year**	**10-year**	**50-year**	**100-year**	**500-year**
Return Frequency	**50%**	**20%**	**10%**	**2%**	**1%**	**0.2%**
Scaled from the Ottauquechee River	268 cfs	367 cfs	437 cfs	605 cfs	683 cfs	879 cfs
	39.9 csm	54.7 csm	65.1 csm	90.1 csm	101.6 csm	130.9 csm
Scaled from Ayers Brook	170 cfs	266 cfs	352 cfs	615 cfs	767 cfs	1,244 cfs
	23.6 csm	37.1 csm	49.0 csm	85.8 csm	106.9 csm	173.4 csm
Scaled from Putnam Creek	195 cfs	327 cfs	429 cfs	692 cfs	820 cfs	1,156 cfs
	23.9 csm	40.0 csm	52.5 csm	84.6 csm	100.2 csm	141.3 csm
Scaled from the Dog River	370 cfs	614 cfs	813 cfs	1,364 cfs	1,651 cfs	2,461 cfs
	41.0 csm	68.1 csm	90.2 csm	151.3 csm	183.1 csm	272.8 csm
Scaled from the New Haven River	386 cfs	680 cfs	956 cfs	1,878 cfs	2,442 cfs	4,330 cfs
	38.6 csm	68.0 csm	95.6 csm	187.8 csm	244.3 csm	433.0 csm

The results of the gage analysis are similar for the Ottauquechee River, Ayers Brook, and Putnam Creek locations; however, similarities begin to diverge when looking at the values obtained using the Dog River and New Haven River gage sites. Therefore, the estimated peak discharge rates obtained from these two gage sites were considered inappropriate for this analysis.

As a check, estimated peak discharge rates were also obtained from the *StreamStats* interactive website based on regional regression equations for the State of Vermont published by the USGS (Olson, 2002). The peak flow estimates (Table 3.3) obtained using the regional regression equations generally agree with the gage analysis results.

TABLE 3.3
Estimated Peak Discharge (cfs) and Unit Peak Flow (csm) Based on Regression Equations

Storm Event	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**500-year**
Return Frequency	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**
Discharge Rate (cfs)	164	250	314	416	501	594	842
Unit Peak Flow (csm)	37.0	56.4	70.9	93.9	113.1	134.1	190.1

The third method utilized for estimating peak discharge rates is based on the analysis outlined in a report published by the New England Transportation Consortium under the Federal Highway Administration (Jacobs, 2010). The report is titled *Estimating the Magnitude of Peak Flows for Steep Gradient Streams in New England* and uses regression equations to estimate peak flows for streams with a channel slope greater than 50 feet per mile (or approximately 1%). Estimated peak discharge rates were calculated using the steep streams regression equations, which are based on drainage area and the mean annual precipitation. The mean annual precipitation of 46.6 inches was obtained from the recorded rainfall data for the South Lincoln weather station (COOP:437612) available through the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center. In general, the resulting peak flows obtained using the steep streams regression analysis (Table 3.4) are higher than the peak flow estimates from the regional regression equations but are still in general agreement with the estimated peak flows obtained in the gage analysis.

TABLE 3.4
Estimated Peak Discharge (cfs) and Unit Peak Flow (csm) for Steep Streams

Storm Event	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**500-year**
Return Frequency	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.2%**
Discharge Rate (cfs)	207	332	445	599	718	847	1,257
Unit Peak Flow (csm)	46.7	75.1	100.5	135.2	162.1	191.1	283.7

VTrans has not completed a hydraulic study at the Baker Bridge site. Several studies have been performed at sites along Lincoln Road in Ripton, yet these studies had very small drainage areas and are not applicable to the North Branch of the Middlebury River at Baker Bridge.

Peak discharge rates used for the hydraulic analysis and conceptual design were taken as the average value of appropriate methods described above (Table 3.5). The design storm for local roads in Vermont is the 25-year storm (VTrans, 2001). The 100-year storm was used as a check for hydraulic capacity during large floods and roadway overtopping. All hydrologic computations used to develop the estimated peak discharge rates for design are provided in Appendix C of this report.

TABLE 3.5
Estimated Peak Discharge (cfs) for Design

Storm Event	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
Return Frequency	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**
Design Peak Discharge Rate (cfs)	205	310	400	510	630	745

3.2 Existing Hydraulics

The hydraulic capacity of the existing Baker Bridge structure was approximated using the Federal Highway Administration's (FHWA) software package known as *HY-8* (FHWA, 2012). The *HY-8* software is based on the methodologies outlined in Hydraulic Engineering Circular No. 5 (FHWA, 1965, 1985). Although this software is typically used for analysis and design of culverts, it is appropriate to provide an initial understanding and conceptual design guidance for bridges. Additional study will be required during subsequent design phases.

Data entry for the *HY-8* model of existing conditions was obtained from field survey of the project site conducted on May 9, 2013. Data required to develop the model includes the dimensions of the bridge opening, the shape and dimensions of the tailwater control cross section downstream of the bridge, and the roadway profile.

The dimensions of the bridge used in the hydraulic analysis include an opening width of 19.0 feet and an overall length (parallel to the stream flow) of 21.6 feet. The bridge opening height varies from 9.2 feet at the upstream opening to 10.6 feet at the downstream opening. As a conservative approach, an opening height of 9.2 feet was used. Elevations used in the hydraulic analysis are based on an assumed datum relative to a temporary survey marker set at the project site while collecting field survey data. Additional data regarding the physical makeup and dimensions of the bridge can be found in the Bridge Inspection Report provided in the Appendix of this report and Existing Conditions sketch plan provided in Section 2.0.

The results of the existing hydraulic analysis (Appendix D) indicate that the peak flood water surface elevation drops approximately 3.1 feet through the structure during the 25-year storm event (Figure 3.2). Approximately half of the bridge height is filled during the 25-year flood with 5.2 feet of freeboard at the upstream face of the bridge. Exit velocities are estimated to be 13.3 feet per second during a 25-year storm event. During the 100-year storm, the estimated freeboard is 4.0 feet. The hydraulic drop through the bridge increases to approximately 3.8 feet, and the exit velocity increases to approximately 14.8 feet per second.

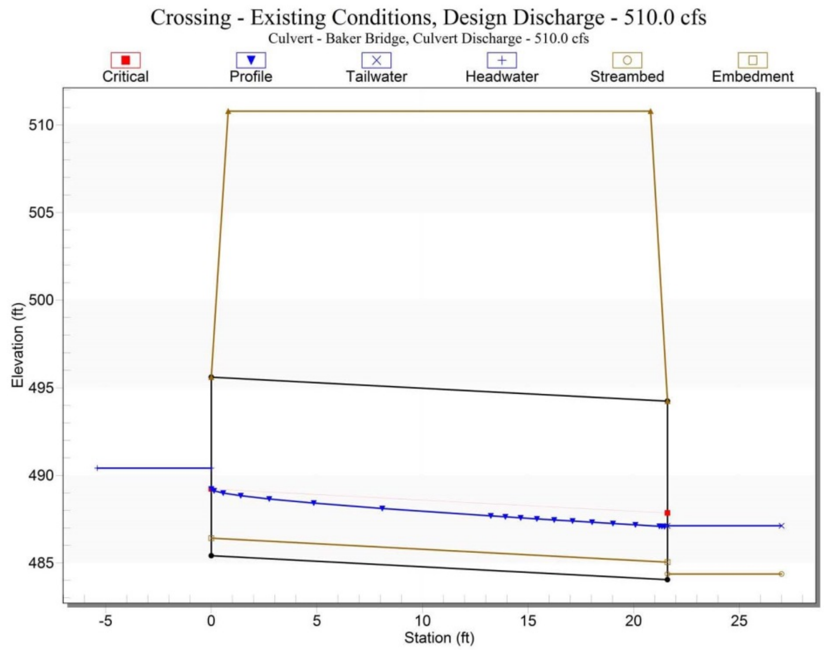


FIGURE 3.2: Hydraulic Drop Through Bridge Structure – Existing Conditions

The Vermont bridge design standard is that the peak flood water surface for the design flow does not touch the lowest beam of the bridge deck. The hydraulic study indicates that the existing Baker Bridge does provide adequate conveyance and freeboard during the 25-year storm event (Table 3.6).

TABLE 3.6
Hydraulic Analysis Results – Existing Conditions

Hydraulic Results	25-Year Storm (4% Annual Chance)	100-Year Storm (1% Annual Chance)
Upstream Water Surface Elevation (feet)	490.4	491.6
Tailwater Elevation (feet)	487.3	487.7
Hydraulic Drop (feet)	3.1	3.8
Available Freeboard (feet)	5.2	4.0
Exit Velocity (feet/second)	13.3	14.8
Tailwater Velocity (feet/second)	8.0	9.0

3.3 Conceptual Alternatives

Conceptual design alternatives were developed to provide guidance for future bridge design efforts. Given that the existing bridge opening generally performs adequately during the 25-year design storm, the focus of the conceptual alternatives was to meet likely future state standard design criteria based on fluvial geomorphic conditions to match structure openings to the natural width of the channel. The proposed standard is 1.2 times the channel bankfull width, with an option for 1.0 bankfull width sizing in low risk settings. Bankfull sizing is important to improve the transport of sediment, debris, and ice; reduce scour during large floods; limit channel impacts due to crossing structures; and improve aquatic organism passage. Each of these conceptual alternatives was analyzed.

As previously mentioned, the bankfull width at the Baker Bridge project site was determined to be 28 feet. Therefore, the bridge opening width (perpendicular to the stream flow) was set to 28.0 feet and 33.6 feet for the conceptual alternative analyses, representing 1x bankfull width and 1.2x bankfull width, respectively. All other dimensions and input data for the hydraulic analysis remain unchanged from existing conditions since the bridge appears to have adequate height, and the existing channel dimensions appear to be adequate.

The results of the alternative hydraulic analysis indicate that the hydraulic drop through the bridge structure would decrease from 3.1 feet under existing conditions to 2.4 feet during the 25-year storm event with a 1x bankfull width structure (Figure 3.3). The increase in bridge width would increase freeboard to 6.1 feet and reduce exit velocities to 11.7 feet per second (Table 3.7). The results indicate similar improvements during the 100-year storm event.

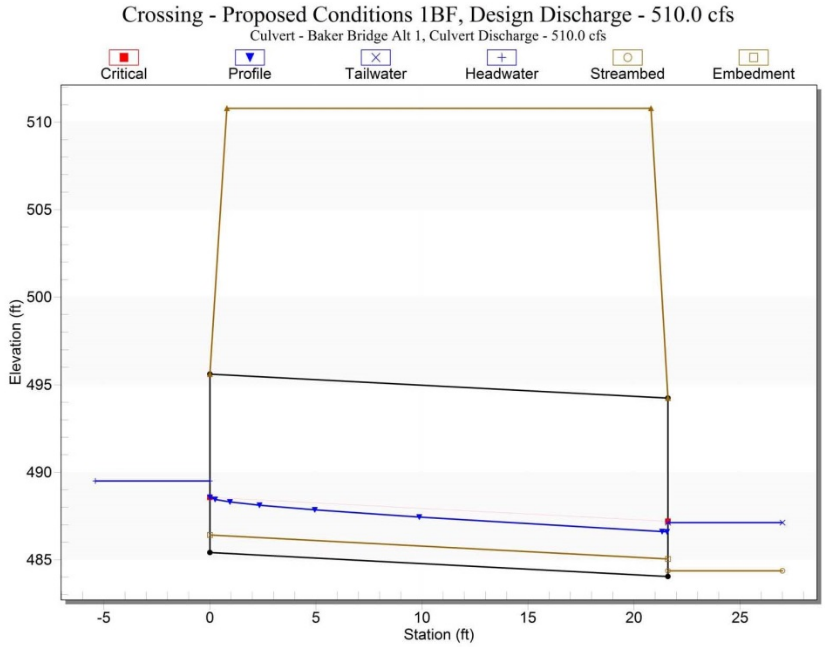


FIGURE 3.3: Hydraulic Drop Through Bridge Structure – Alternative 1

TABLE 3.7
Hydraulic Analysis Results – Conceptual Alternative 1 – 1x Bankfull

Hydraulic Results	25-Year Storm (4% Annual Chance)		100-Year Storm (1% Annual Chance)	
	Value	Change from Existing	Value	Change from Existing
Upstream Water Surface Elevation (feet)	489.5	-0.9	490.4	-1.2
Tailwater Elevation (feet)	487.1	-0.2	487.7	0.0
Hydraulic Drop (feet)	2.4	-0.7	2.6	-1.2
Available Freeboard (feet)	6.1	+0.9	5.2	+1.2
Exit Velocity (feet/second)	11.7	-1.6	13.2	-1.6
Tailwater Velocity (feet/second)	8.0	0.0	9.0	0.0

The results of the alternative hydraulic analysis indicate that the hydraulic drop through the bridge structure would decrease further from existing conditions to approximately 2.0 feet during a 25-year storm event and approximately 2.2 feet during the 100-year storm event for the 1.2x bankfull width structure (Figure 3.4). Similarly, the exit velocity would also decrease during both the 25-year and 100-year storm events while additional freeboard would be provided (Table 3.8). Results of the hydraulic analysis exploring the conceptual alternatives are provided in Appendix D of this report.

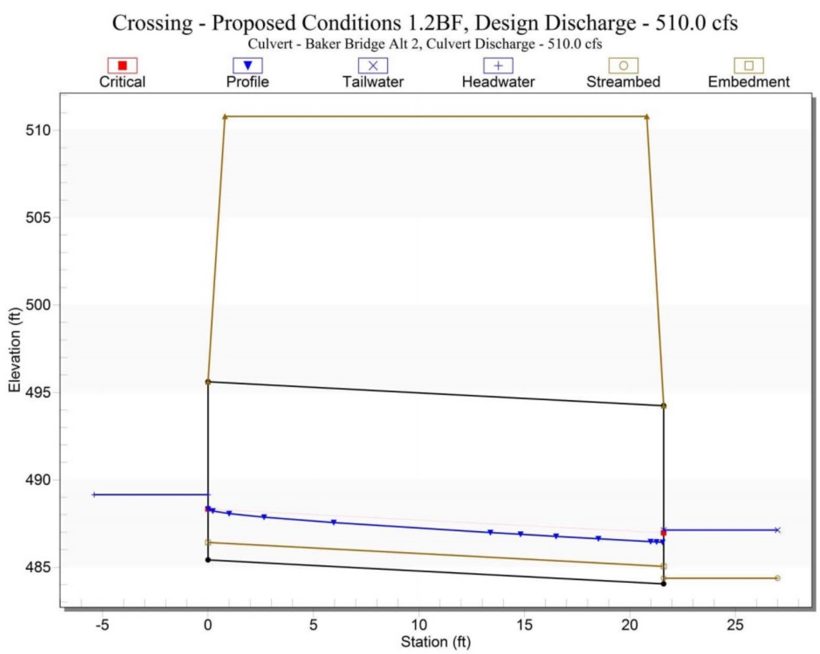


FIGURE 3.4: Hydraulic Drop Through Bridge Structure – Alternative 2

TABLE 3.8
Hydraulic Analysis Results – Conceptual Alternative 2 – 1.2x Bankfull

Hydraulic Results	25-Year Storm (4% Annual Chance)		100-Year Storm (1% Annual Chance)	
	Value	Change from Existing	Value	Change from Existing
Upstream Water Surface Elevation (feet)	489.2	-1.2	489.9	-1.7
Tailwater Elevation (feet)	487.1	-0.2	487.7	0.0
Hydraulic Drop (feet)	2.0	-1.1	2.2	-1.6
Available Freeboard (feet)	6.5	+1.3	5.7	+1.7
Exit Velocity (feet/second)	11.0	-2.3	12.5	-2.3
Tailwater Velocity (feet/second)	8.0	0.0	9.0	0.0

4.0 ROADWAY IMPROVEMENT ALTERNATIVES

4.1 Preliminary Improvement Alternatives

Three schematic improvement alternatives are proposed to address roadway geometry and safety issues at the Baker Bridge project site. These alternatives have been developed under the premise that a new two-lane bridge will be constructed to replace the existing one-lane bridge. The intention is that these alternatives would be reviewed and screened by the Town of Ripton, the ACRPC, and other project stakeholders to eventually develop a preferred improvement concept for the bridge. A description of the proposed improvement alternatives is presented below.

Improvement Alternative A would maintain the existing intersection offset configuration; however, the channelized lanes on the Lincoln Road northbound approach will be consolidated into a more traditional "T" intersection with North Branch Road. The existing bridge would be widened to accommodate two lanes of traffic, and the roadway across the bridge would be widened to 28 feet (12-foot lanes with two-foot shoulders). "All Way Stop" sign control is proposed at both intersections to calm traffic and improve safety. It should be noted that this alternative proposes two "All Way Stop" controlled intersections, one on either side of the bridge. In addition, "Stop Ahead" signs would be installed on North Branch Road and Pearl Lee Road in advance of the offset intersection. Given that the majority of this alternative occurs within the existing roadway alignment, potential impacts to natural resources will be limited. Figure 4.1 presents a layout of *Improvement Alternative A.*

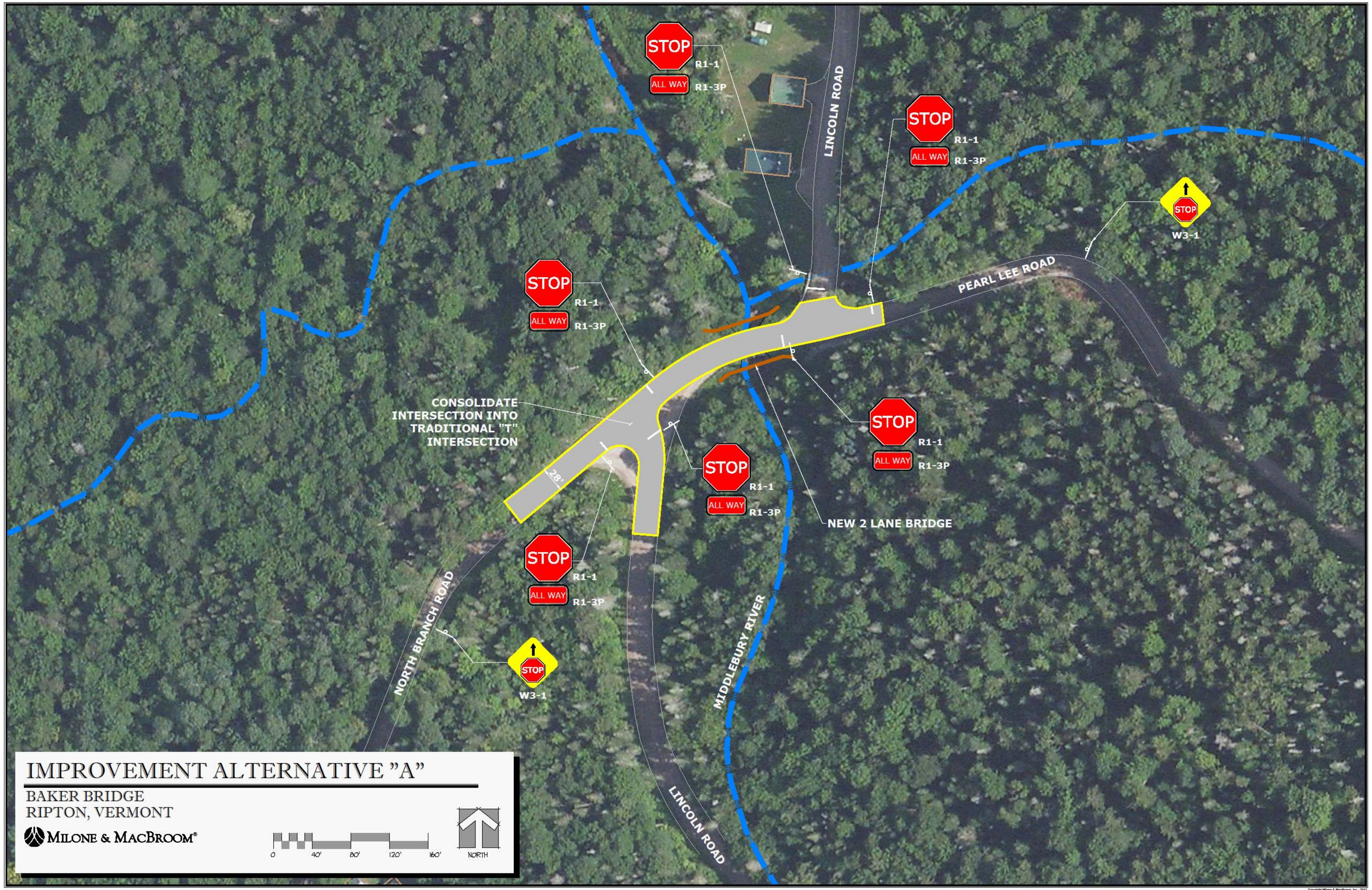


Figure 4.1- Improvement Alternative A

Improvement Alternative B would involve the realignment of the offset intersection such that Lincoln Road would serve as the predominant route, which is consistent with measured traffic volumes, while North Branch Road and Pearl Lee Road would serve as side roads. This reconfiguration would improve sightlines and traffic operations. The North Branch Road and Pearl Lee Road approaches would be stop sign controlled. In addition, "Stop Ahead" signs would be installed on North Branch Road and Pearl Lee Road in advance of the offset intersection. A new two-lane bridge would be constructed on Lincoln Road, just south of the existing Baker Bridge. The roadway width across the bridge would be increased to 28 feet (12-foot lanes with two-foot shoulders). This alternative would produce the largest amount of potential impacts to natural resources. Figure 4.2 presents a schematic layout of *Improvement Alternative B.*

Improvement Alternative C would be similar to Improvement Alternative B but less drastic in terms of roadway realignment. Lincoln Road would serve as the predominant route while North Branch Road and Pearl Lee Road would serve as side roads. The North Branch Road and Pearl Lee Road approaches would be stop sign controlled. In addition, "Stop Ahead" signs would be installed on North Branch Road and Pearl Lee Road in advance of the offset intersection. This realignment alternative would improve sightlines and traffic operations. Given that the majority of this alternative occurs within the existing roadway alignment, potential impacts to natural resources will be limited. Figure 4.3 presents a schematic layout of *Improvement Alternative C.*

Ballpark opinions of probable construction costs were developed for each of the alternatives based on the conceptual designs (Table 4.1). The cost opinions would be refined during more detailed design phases. Some uncertainty has been built into the cost opinions by providing values for minor items not yet considered in design, inflation, construction contingency, and incidentals to construction not specifically quantified. Additionally, an estimated 10% of the construction costs have been added to represent final design engineering and permitting needs. It should be noted that because the new bridge will generally be located in the same position as the existing bridge under Alternatives A and C the use of a temporary bridge may be required unless a road closure is acceptable.

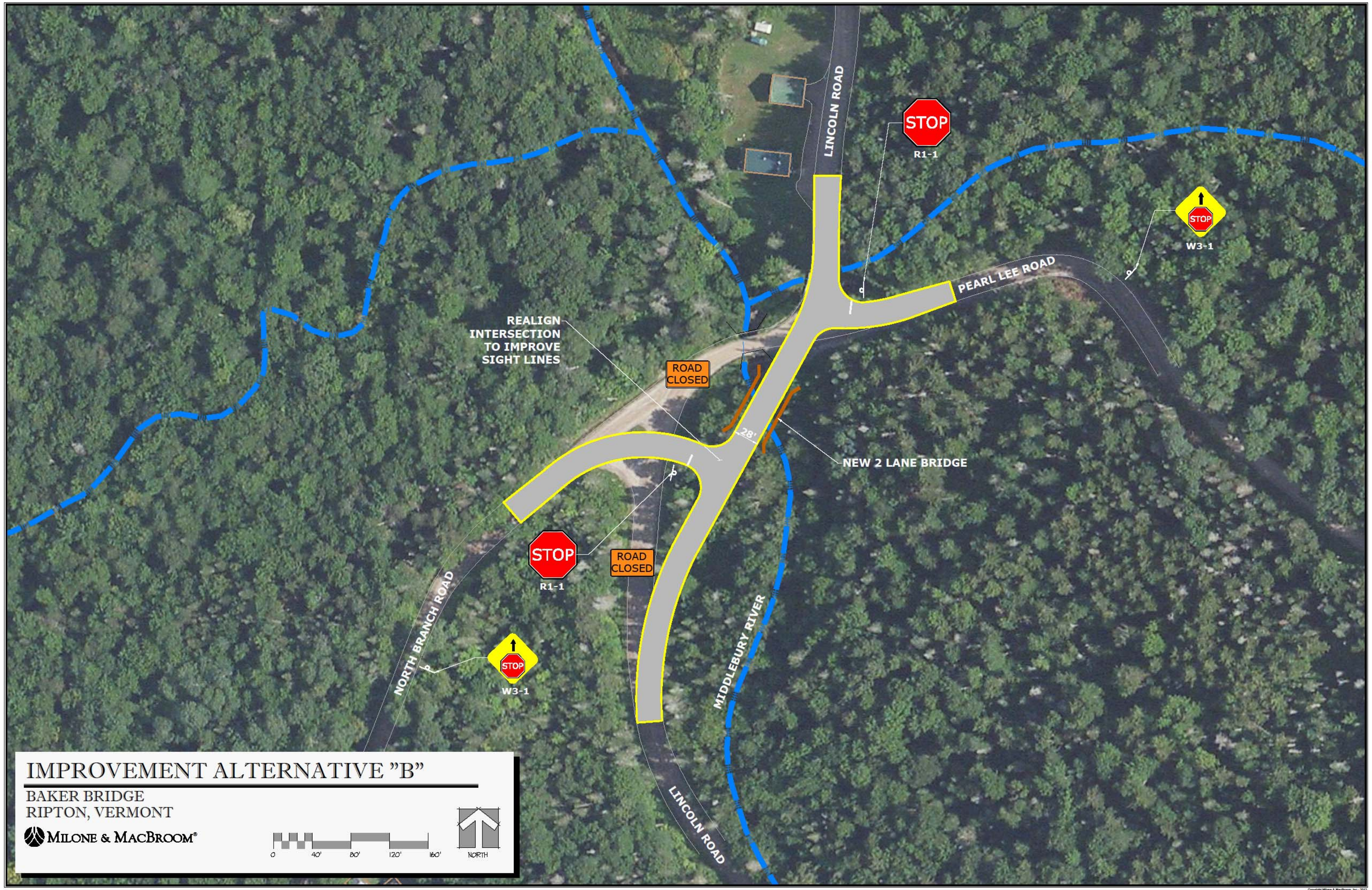


Figure 4.2 - Improvement Alternative B

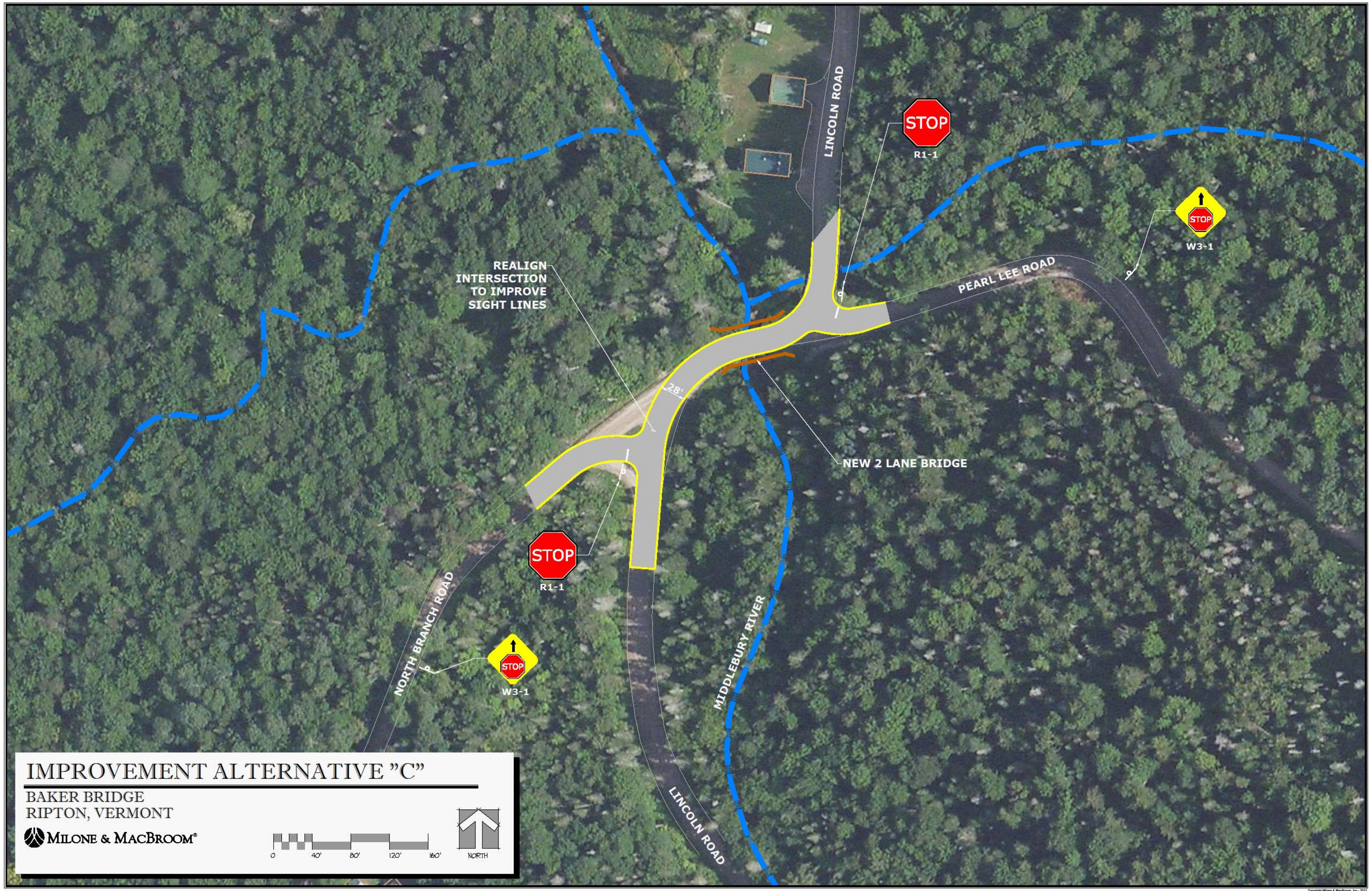


Figure 4.3 – Improvement Alternative C

TABLE 4.1

ENGINEER'S BALLPARK OPINION OF PROBABLE CONSTRUCTION COSTS

BAKER BRIDGE - RIPTON, VERMONT

Construction Item	Alternative A	Alternative B	Alternative C
Project Mobilization / Sedimentation Control	$18,000	$34,000	$21,000
Earthwork	$10,000	$100,000	$10,000
Roadway Construction	$26,000	$44,000	$30,000
Site Restoration	$7,000	$25,000	$9,000
Traffic Control	$15,000	$18,000	$15,000
Bridge Replacement	$535,000	$685,000	$535,000
Minor Items (±10%, Rounded)	$61,000	$91,000	$62,000
Project Subtotal	$672,000	$997,000	$682,000
Inflation (5%, Rounded)	$34,000	$50,000	$35,000
Project Subtotal	$706,000	$1,047,000	$717,000
Design and Permitting (10%, Rounded)	$71,000	$105,000	$72,000
Contingency (10%, Rounded)	$71,000	$105,000	$72,000
Incidentals to Construction (15%, Rounded)	$106,000	$158,000	$108,000
Total	*$954,000*	*$1,415,000*	*$969,000*
Temporary Bypass Bridge	$100,000	$0	$100,000
Total with Temporary Bypass Bridge	*$1,054,000*	*$1,415,000*	*$1,069,000*

5.0 RECOMMENDATIONS

5.1 Structural Recommendations

The damaged concrete on the underside of the bridge slab should be repaired to halt any further degradation of the slab and reinforcement. Due to indications of rotation within the superstructure, the slab should be monitored for further movement. Additional movement may necessitate a weight restriction or closing of the bridge.

While our observations did not identify the need for immediate action on the abutments and wingwalls, the damaged concrete should be monitored to identify any further degradation. Additionally, the overturning measured during the bridge assessment should be monitored for further movement.

The sediment deposition at the upstream opening of the bridge and the erosion along both abutments through the bridge should be monitored twice a year after large floods and ice-out to identify problems. Large woody debris deposited at the bridge should be removed to maintain a clear opening. The debris can simply be passed through the structure or placed in the channel downstream. The material will distribute, get buried, or break down before the next bridge.

If the conditions of the bridge worsen, it is recommended that additional inspection take place to determine if the condition rating should be adjusted and to re-examine the urgency of replacement. Since the bridge is showing signs of wear and it is near the end of its engineering life, the town should move forward with gathering required field data as well as design of a new bridge and roadway improvements in order to prepare for replacement.

5.2 Hydraulic Recommendations

The results of the hydrologic and hydraulic analyses indicate that a larger structure would help decrease scour and improve conveyance of water, sediment, debris, and ice. The site is low risk as overtopping is rare and, thus, a 1.0x bankfull width structure is appropriate. The recommended bridge width is 28 feet, and the height is to remain the same as the current opening height (9.5 feet average). The preliminary hydraulic analysis performed here will be refined as design advances and state design guidance is finalized to identify the final design width, height, and amount of freeboard for the selected design flood.

5.3 Recommended Roadway Improvement Alternative

On August 12, 2013, the results of the alternatives analysis were discussed during a site walk and Ripton Selectboard meeting. Present at the meeting were Town of Ripton Selectboard members, Ripton town staff, the Ripton Road Foreman, as well as local residents. The existing conditions of the site, structural assessment of the bridge, roadway conditions, hydrology and hydraulics, natural resources, results of the alternatives analysis, and cost opinions were discussed. Discussion and input from the meeting appeared to reach consensus on a modification of Alternative A as the preferred alternative (Figure 5.1).

The preferred alternative would maintain the existing intersection offset configuration; however, the channelized lanes on the Lincoln Road northbound approach would be consolidated into a more traditional "T" intersection with North Branch Road. The existing bridge would be widened to accommodate two lanes of traffic, and the roadway across the bridge would be widened to 28 feet (12-foot lanes with two-foot shoulders). Stop sign control would be used on the Lincoln Road northbound and southbound approaches. Additionally, stop signs would be used at the Pearl Lee Road westbound approach at its intersection with the northern leg of Lincoln Road, as well as the North Branch Road eastbound approach at its intersection with the southern leg of Lincoln Road. "Stop Ahead" signs would be installed on North Branch Road and Pearl Lee Road in advance of the offset intersection. The stop signs on North Branch Road and Pearl Lee Road would include additional signage noting that oncoming traffic does not stop. Vehicles travelling across and away from the bridge would not need to stop when turning left onto Lincoln Road northbound or southbound at the proposed "T" intersections.

5.4 Environmental Recommendations

Roadside drainage should be improved as part of future work on the roadway alignment and bridge. Proper drainage is essential to the service life of an unpaved road, and it is recommended that the roadway be reshaped and that roadside ditches be improved to adequately drain the roadway. Drainage improvements will reduce erosion along the edge of the road embankment and bridge. The erosion prevention will protect water quality as less material will be carried in runoff that passes over poorly drained soils and into the river channel. Less erosion will also prevent sedimentation of the healthy instream habitat near the bridge.

Sheet flow over the sides of the bridge should be eliminated. Drainage improvements could take place before bridge replacement to try and extend the service life of the bridge structure and help prevent repetitive damage along the roadway due to erosion.

Future road and bridge projects should at minimum preserve the bankfull channel width and adjacent flood benches to protect instream habitat and allow for good flood conveyance. As a headwater stream, accommodation must be made for the expected sediment, woody debris, and ice load that will move with floodwaters. The Vermont River Management Program should be consulted for guidance on preserving a natural river channel setting during a future project.

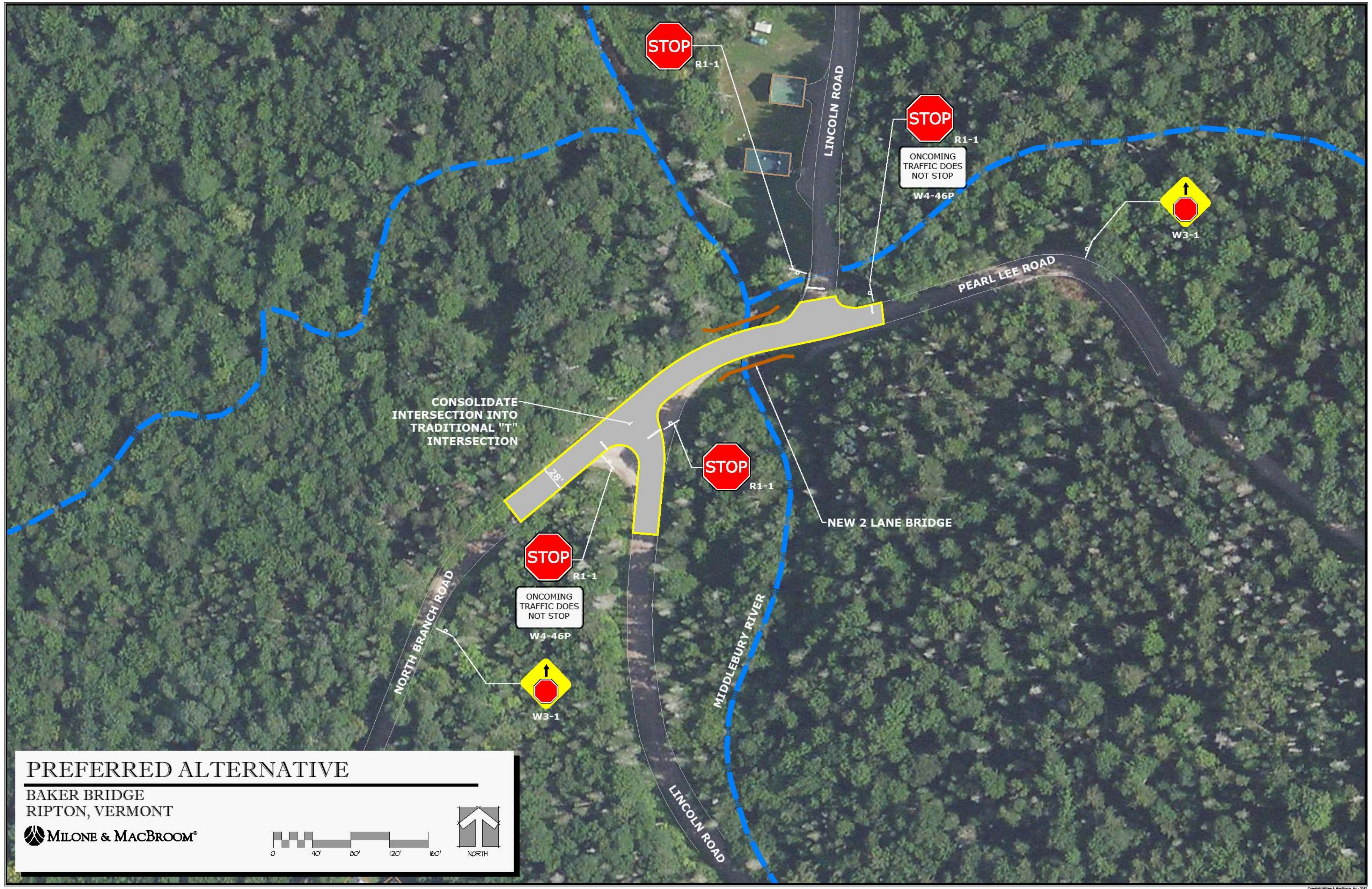


Figure 5.1 – Recommended Roadway Improvement Alternative

Several environmental considerations will have to be further addressed during design and permitting of a future bridge and roadway project. Wetland delineation will be required for understanding impacts with future changes at the bridge and road. The design should reduce wetland impacts as much as possible to protect the channel and reduce future flood vulnerability in the project area.

A review of the mapped threatened plant species will need to be conducted by Vermont Fish and Wildlife prior to any work at the bridge and road. The project will need to avoid impacts to these species of concern if they are found to exist at the project site.

Future design and implementation must protect the high water quality in the North Branch of the Middlebury River. Vegetation removal should be limited, especially along the banks of the river. Sediment and erosion controls should be used during construction.

5.5 Summary of Recommended Project Development Tasks

The following list of project development tasks is provided for the town to begin the necessary data collection and reviews that will be needed to advance design and implement the preferred alternative. These tasks can be worked on over the coming years to track the conditions at the bridge and to initiate project development.

- Monitor the bridge two times annually and after large floods for movement of the slab and additional deterioration of the slab, abutments, and wingwalls. If conditions worsen, contact a structural engineer for consideration of weight restrictions or the need to close the structure.
- Monitor sediment and woody debris buildup at the upstream face of the bridge. If a large deposit forms that impedes flow into the structure, clear the debris by passing it through the structure or removing it and placing it in the downstream channel for natural distribution.
- Monitor the existing erosion at the edge of the road embankment. If conditions worsen, some work to clean and line the ditches with stone should take place. The future bridge and road project must include improved runoff management to protect the road embankment and minimize future maintenance at the intersection and bridge.
- Conduct field survey at the site to locate property boundaries; formally survey the bridge, river channel, utilities, and roadways; and create topography at the project site. The survey will need to be performed by a Vermont Licensed Surveyor for property line work.
- Conduct land record research and in combination with boundary survey create a right-of-way plan. The plan should be reviewed with Green Mountain National Forest personnel and other abutting landowners. Conduct meetings with abutting landowners to review the preferred alternative and seek written agreements for work that takes place outside of the town road right-of-way. Having these agreements in place will support future funding applications for the project.

- Hire a boring contractor to get six borings drilled at the project site – two in each proposed abutment location and one in the road embankment on each side of the bridge. This information will be required for final design. One option for a boring contractor is Mike's Borings and Corings of Barre, Vermont (802-479-4154).
- Delineate the ordinary high water line and bordering vegetated wetlands at the project site that will be required to identify project impacts for a proposed project. This work is typically performed by a consulting wetland scientist. One professional contact is April Moulaert of West, Inc. out of Waterbury, Vermont (802-244-1755).
- Submit a request for a review with the Wildlife Diversity Program of Vermont Fish and Wildlife to build on the initial review completed in this report on species of concern in the vicinity of the project site. Contact Steve Parren, Project Coordinator (802-241-3700).
- Follow up on the initial submission made during this project to Vermont Division for Historical Resources for a cultural resources review. Contact either Giovanna Peebles, State Archeologist (802-828-3050), or Scott Dillon, Survey Archeologist (802-828-3048).
- Once survey and borings are complete, hire a design engineer to refine the initial hydraulics study performed here and complete preliminary and final design of the bridge and roadway. We recommend that the town complete the permit applications with the support of the Project Engineer.

6.0 FEMA BENEFIT-COST ANALYSIS

The damages that have occurred at Baker Bridge have been inexpensive to fix in comparison with the large cost of the preferred alternative. A Federal Emergency Management Agency (FEMA) Benefit-Cost Analysis was performed for the bridge using the Damage-Frequency Module of FEMA's Beneft-Cost Analysis Tool (Version 4.8) and resulted in a Benefit-Cost Ratio of 0.02. This Benefit-Cost Ratio is below the threshold for FEMA funding of 1.0.

The types of damages at the bridge are inherent to a bridge near the end of its anticipated life. Historic damages at the bridge were provided by the Ripton Selectboard including the cost of repairs and the loss of function of the bridge (days of road closure) (Table 6.1). Damages have typically included gravel washed off the road at the bridge approaches and damage to guiderails but have also included damage to the wingwalls and abutments. The bridge has poor drainage and requires annual maintenance to clear ice and water off the bridge and replace gravel. These annual costs are not considered by the FEMA analysis. Recurrence intervals for storm events were estimated based on USGS stream gage data or precipitation data.

The North Branch of the Middlebury River corridor where Baker Bridge is located is steep and narrow. Flood data suggest that intense thunderstorms lead to flash flooding that creates unique site conditions relative to available stream gage data and road drainage design approaches. Damages are associated with both erosion from the river and poor roadway drainage. A crest-stage gage located near the Breadloaf Mountain Campus of Middlebury College has a short period of record that has recorded a limited number of storms.

TABLE 6.1
Benefit-Cost Analysis Input

Storm Occurrence			Estimated Repair Cost	Estimated Recurrence Interval	Road Closures (days)	Sources
Year	Approximate Date	Description				
1927	November 3-7	Tropical storms	Bridge replaced	500-year		1927 Flood Book; Otter Creek @ Middlebury
1967	August 28		$24	1.8-year		Brandy Brook @ Breadloaf
1973	December 21		$182	2.2-year		Brandy Brook @ Breadloaf
1979	March 25		$700	1.2-year		Ayers Brook @ Randolph
1987	June 23	Summer flood	$9,020	1-year	3	Ayers Brook @ Randolph
1989	August 4-5	unknown	$11,806	100-year	3	VT Agency of Transportation, 2010; Ripton Town Report, 1989
1996	January 19-20	Winter thaw flood	$2,336	10- to 25-year	2	VT DEC 1999, App. 8
1996	June 10	Flash flooding	$1,520	100-year	1	Ripton Town Report, 1996
1998	Late June, Early July	Flash flooding	$12,694	100-year	5	VT Agency of Transportation, 2010; Ripton Town Report, 1998
1999	April 1		$200	1.1-year		Ayers Brook @ Randolph
2010	March 23		$1,485	1.8-year		Brandy Brook @ Breadloaf
2013	Annual Maintenance		$500	1-year		Road Commissioner and Selectboard Clerk

1930 was selected as the year Baker Bridge was built; the Selectboard reported that the bridge was constructed following its washout during the statewide 1927 flood. The project useful life was set at 50 years, the standard FEMA-accepted value for a bridge replacement. The cost opinion for Alternative A of $1,054,000 was used for the mitigation project cost.

Project benefits (i.e., past costs to be mitigated) include an estimation of economic loss for road closure. There is an average of 210 traffic trips per day on Lincoln Road and 80 vehicles per day on North Branch Road (assumed that half of vehicles on North Branch

Road would turn north and travel over the bridge). Vehicles traveling between Ripton and Lincoln would detour via Route 125 and Route 116 requiring an additional 11 miles, or 10 minutes. The estimated economic loss per day of road closure is $2,788.

Project benefits also include the loss of service of critical facilities including fire stations and EMS services. When the bridge is closed, the fire station is cut off from the 21 homes (assumed three residents per home = 63 residents) north of the bridge. The Lincoln Fire Department would need to respond to those residents. The EMS services would be provided by Bristol Rescue. The estimated economic loss per day of these services is $96.66.

Expected annual damages before mitigation (potential project benefits determined from previous damages, see Table 6.1) have been quantified as $1,506 with a total present value of $20,784.

The Benefit-Cost Analysis assumes that even after the mitigation project has been implemented there will still be some damages during large storms. Damages after mitigation were estimated to be $200 beyond the 100-year design level of the project and $1,000 at the 500-year recurrence interval storm event. These damages have an annual cost of $15 and a total present value of $207.

The expected annual damages after mitigation, considered to be the total benefits of the project, were found to be $1,491 annually and a total present value of $20,577. Thus, project benefits indicate that a corridor mitigation project of $1,054,000 would have a Benefit-Cost Ratio of 0.02.

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