LEVEL II SCOUR ANALYSIS FOR BRIDGE 108 (STJOUS00020108) on U.S. HIGHWAY 2, crossing MOOSE RIVER, ST. JOHNSBURY, VERMONT

U.S. Geological Survey
Open-File Report 97-107

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

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By MICHAEL A. IVANOFF

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Pembroke, New Hampshire

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

BF	bank full	LWW	left wingwall
cfs	cubic feet per second	MC	main channel
D_{50}	median diameter of bed material	RAB	right abutment
DS	downstream	RABUT	face of right abutment
elev.	elevation	RB	right bank
f/p	flood plain	ROB	right overbank
ft^2	square feet	RWW	right wingwall
ft/ft	feet per foot	TH	town highway
JCT	junction	UB	under bridge
LAB	left abutment	US	upstream
LABUT	face of left abutment	USGS	United States Geological Survey
LB	left bank	VTAOT	Vermont Agency of Transportation
LOB	left overbank	WSPRO	water-surface profile model

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 108 (STJOUS00020108) ON U.S. HIGHWAY 2, CROSSING MOOSE RIVER, ST. JOHNSBURY, VERMONT

By Michael A. Ivanoff

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure STJOUS00020108 on U.S. Highway 2 crossing the Moose River, St. Johnsbury, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). Results of a Level I scour investigation also are included in Appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in Appendix D.

The site is in the New England Upland/White Mountain sections of the New England physiographic province in north-east Vermont. The 117-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture on the upstream right bank, forest on the upstream left bank, shrub and brush on the downstream left bank, and forest on the downstream right bank.

In the study area, the Moose River has an incised, sinuous channel with a slope of approximately 0.008 ft/ft, an average channel top width of 96 ft and an average channel depth of 6 ft. The predominant channel bed material is cobble with a median grain size (D_{50}) of 94.1 mm (0.309 ft). The geomorphic assessment at the time of the Level I and Level II site visit on August 14, 1995, indicated that the reach was stable.

The U.S. Highway 2 crossing of the Moose River is a 103-ft-long, two-lane bridge consisting of three spans with a maximum 57-foot concrete T-beam span (Vermont Agency of Transportation, written communication, March 28, 1995). The bridge is supported by two piers, and vertical, concrete abutments with no wingwalls. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is 0 degrees.

The scour protection measures at the site were type-2 stone fill (less than 36 inches diameter) at the upstream and downstream channel banks. There is also type-3 stone fill (less than 48 inches diameter) at both the upstream and downstream ends of the left and right abutments. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995). Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 0.4 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 9.3 to 12.2 ft. The worst-case abutment scour occurred at the left abutment 500-year discharge. Pier scour ranged from 8.3 to 15.7 for both piers. The worst case pier scour occurred at the left pier, for the 100-year discharge analysis. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1995, p. 47). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

Concord, VT. Quadrangle, 1:24,000, 1967
Photorevised 1988

NORTH

Figure 1. Location of study area on USGS 1:24,000 scale map.

Figure 2. Location of study area on Vermont Agency of Transportation town highway map.

LEVEL II SUMMARY

Structure Number STJOUS00020108 ***Stream*** Moose River

County Caledonia ***Road*** US 2 ***District*** 7

Description of Bridge

Bridge length 103 ***ft*** ***Bridge width*** 34 ***ft*** ***Max span length*** 57 ***ft***

Alignment of bridge to road (on curve or straight) Straight

Abutment type Spill-through, stone fill ***Embankment type*** Sloping

Stone fill on abutment? Yes ***Date of inspection*** 08/14/95

Description of stone fill Type-2, at both upstream and downstream banks. Type-3, at both the upstream and downstream ends of the left and right abutments.

Vertical abutment walls and piers are concrete. Stone fill between abutment walls and piers forms spill-through abutment.

Is bridge skewed to flood flow according to No ***survey?*** Yes ***Angle*** 10

Debris accumulation on bridge at time of Level I or Level II site visit:

	Date of inspection	*Percent of channel blocked horizontally*	*Percent of channel blocked vertically*
Level I	08/14/95	0	0
Level II	08/14/95	0	0

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) A large pile of stone fill was noted between the upstream ends of the left abutment and left pier. 08/14/95.

Description of the Geomorphic Setting

General topography The channel is located in a moderate relief valley setting with a narrow flood plain and steep valley walls on both sides.

Geomorphic conditions at bridge site: downstream (DS), upstream (US)

Date of inspection 08/14/95

DS left: Moderately sloping channel bank to a narrow flood plain

DS right: Narrow flood plain

US left: Steep valley wall

US right: Flood plain

Description of the Channel

Average top width 96 ***ft*** ***Average depth*** 6 ***ft***

Predominant bed material Cobbles ***Bank material*** Cobbles

Sinuous but stable with non-alluvial channel boundaries and a narrow flood plain.

08/14/95

Vegetative co Trees and brush

DS left: Forest

DS right: Forest

US left: Pasture

US right: Yes

Do banks appear stable? ***If not, describe location and type of instability and date of observation.***

The assessment of 08/14/95 noted flow conditions up to bank-full level are influenced by a pile of stone fill on the left bank side of the channel. The obstruction is between the left abutment and left pier at the upstream bridge face.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 117 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province/section	*Percent of drainage area*
New England/ White Mountain	75
New England/ New England Upland	25

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: There is warehouse building on the upstream right flood plain.

Is there a USGS gage on the stream of interest? Yes

USGS gage description Moose River at Victory and St. Johnsbury

USGS gage numbers 01134500 and 01135000

Gage drainage areas 75.2 ***mi²*** 128 ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 6,890 ***ft³/s*** ***Q500*** 8,940 ***ft³/s***

The 100- and 500-year discharges are interpolated from the 100- and 500-year discharges determined for the upstream (01134500, Moose River at Victory) and downstream (01135000, Moose River at St. Johnsbury) gages. The 100- and 500- year discharges at the gages were developed using a log-Pearson type-III analysis of annual peak-flow data (Interagency Advisory Committee on Water Data, 1982).

Description of the Water-Surface Profile Model (WSPRO) Analysis

Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans) USGS survey

Datum tie between USGS survey and VTAOT plans Add 1.8 ft. to USGS survey to obtain VTAOT plans' datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled square on top of the downstream end of the right abutment (elev. 750.51 ft, arbitrary survey datum). RM2 is a chiseled square on top of the downstream end of the left abutment (elev. 750.17 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT1	-70	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT1)
BRIDG	0	1	Bridge section
RDWAY	18	1	Road Grade section
APPR1	129	1	Approach section as surveyed

[1] For location of cross-sections see plan-view sketch included with Level I field form, Appendix E.
For more detail on how cross-sections were developed see WSPRO input file.

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The analyses reported herein reflect conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. Results of the hydraulic model are presented in the Bridge Hydraulic Summary, Appendix B, and figure 7.

Channel roughness factors (Manning's "n") used in the hydraulic model were estimated using field inspections at each cross section following the general guidelines described by Arcement and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.050 to 0.055, and overbank "n" values ranged from 0.040 to 0.050.

Normal depth at the exit section (EXIT1) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was 0.0078 ft/ft which was measured from the 100-year water surface profile downstream of the bridge in the Flood Insurance Study for the Town of St. Johnsbury, Vermont (Federal Emergency Management Agency, July 3, 1986).

The approach section (APPR1) was surveyed one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

Bridge Hydraulics Summary

Average bridge embankment elevation 751.2 *ft*
Average low steel elevation 746.9 *ft*

100-year discharge 6,890 *ft³/s*
Water-surface elevation in bridge opening 747.0 *ft*
Road overtopping? No *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 735 *ft²*
Average velocity in bridge opening 9.4 *ft/s*
Maximum WSPRO tube velocity at bridge 12.0 *ft/s*

Water-surface elevation at Approach section with bridge 749.4
Water-surface elevation at Approach section without bridge 746.5
Amount of backwater caused by bridge 2.9 *ft*

500-year discharge 8,940 *ft³/s*
Water-surface elevation in bridge opening 749.2 *ft*
Road overtopping? No *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 808 *ft²*
Average velocity in bridge opening 11.2 *ft/s*
Maximum WSPRO tube velocity at bridge 11.6 *ft/s*

Water-surface elevation at Approach section with bridge 751.0
Water-surface elevation at Approach section without bridge 747.4
Amount of backwater caused by bridge 3.6

Incipient overtopping discharge -- *ft³/s*
Water-surface elevation in bridge opening -- *ft*
Area of flow in bridge opening -- *ft²*
Average velocity in bridge opening -- *ft/s*
Maximum WSPRO tube velocity at bridge -- *ft/s*

Water-surface elevation at Approach section with bridge --
Water-surface elevation at Approach section without bridge --
Amount of backwater caused by bridge -- *ft*

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

The 100-year and 500-year discharge resulted in orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for the 100-year and 500-year discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146) The results of Laursen’s clear-water contraction scour for these events were also computed and can be found in appendix F.

Abutment scour for the left abutment was computed by use of the Froehlich equation (Richardson and others, 1995, p. 48, equation 28). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

Scour at the right abutment for the 100- and 500-year discharges was computed by use of the HIRE equation (Richardson and others, 1995, p. 49, equation 29) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

Pier scour was computed by use of the Colorado State University pier scour equation (Richardson and others, 1995, p. 36, equation 21). Variables for the Colorado State University pier scour equation include the Froude number of the flow approaching the pier, pier width ratio to the depth of flow, and correction factors for the pier nose shape, angle of attack of flow, bed condition, and armoring by bed material size.

Because the influence of scour processes on the spill-through embankment material is uncertain, the scour depth at the vertical concrete abutment walls is unknown. Therefore, the total scour depths were applied for the entire spill-through embankment below the elevation at the toe of each embankment, as shown in figure 8.

Scour Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.0	0.4	--
Depth to armoring	1.4	3.8	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour	10.4	12.2	--
Left abutment	9.3	11.8	--
Right abutment			
Pier scour	16.2	15.7	--
Pier 1	8.6	8.3	--
Pier 2	--	--	--
Pier 3			

Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:	2.4	3.2	--
Left abutment	2.4	3.2	--
Right abutment			
Piers:	1.1	1.5	--
Pier 1	1.1	1.5	--
Pier 2	--	--	--

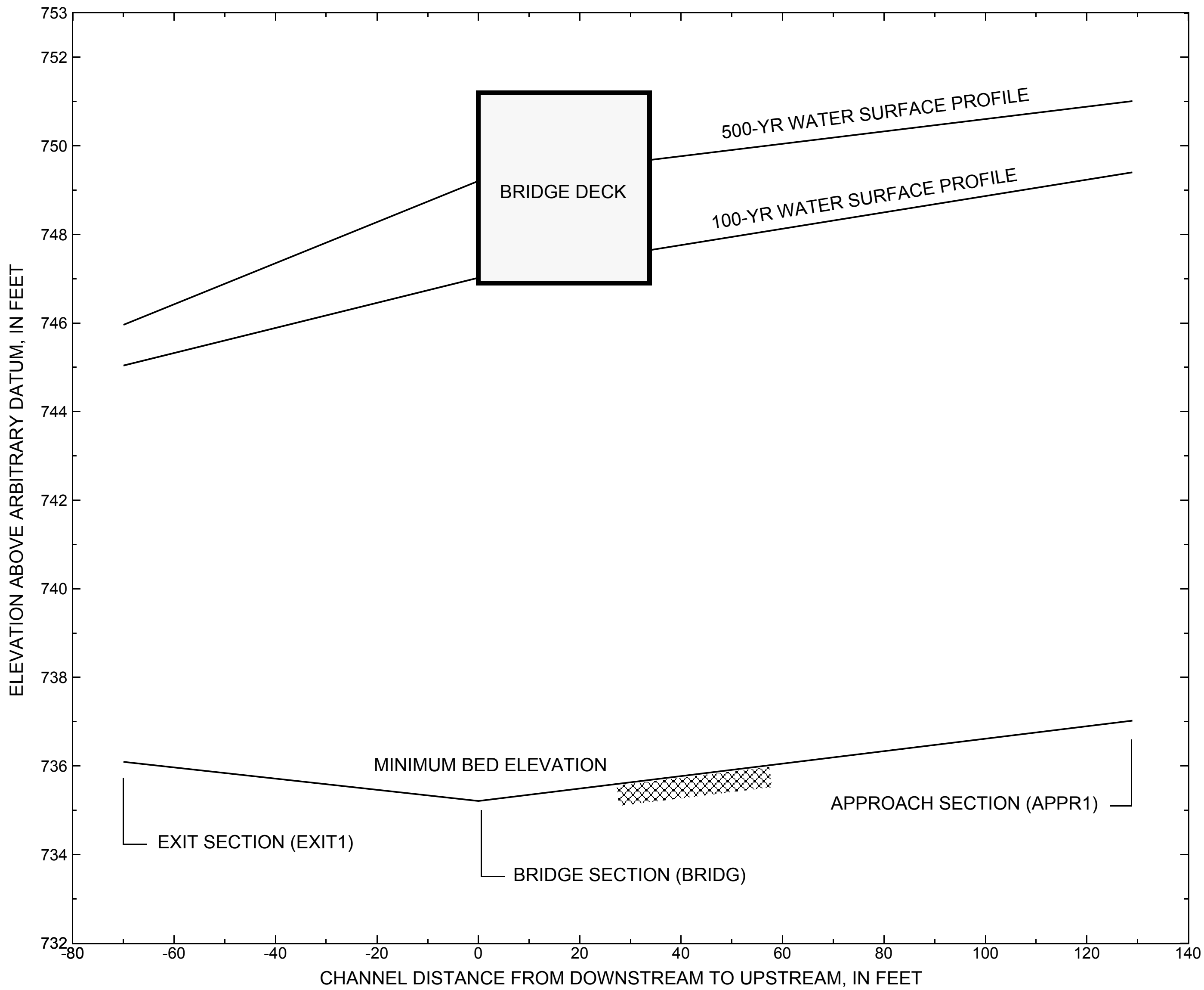

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure STJOUS00020108 on U.S. Highway 2, crossing Moose River, St. Johnsbury, Vermont.

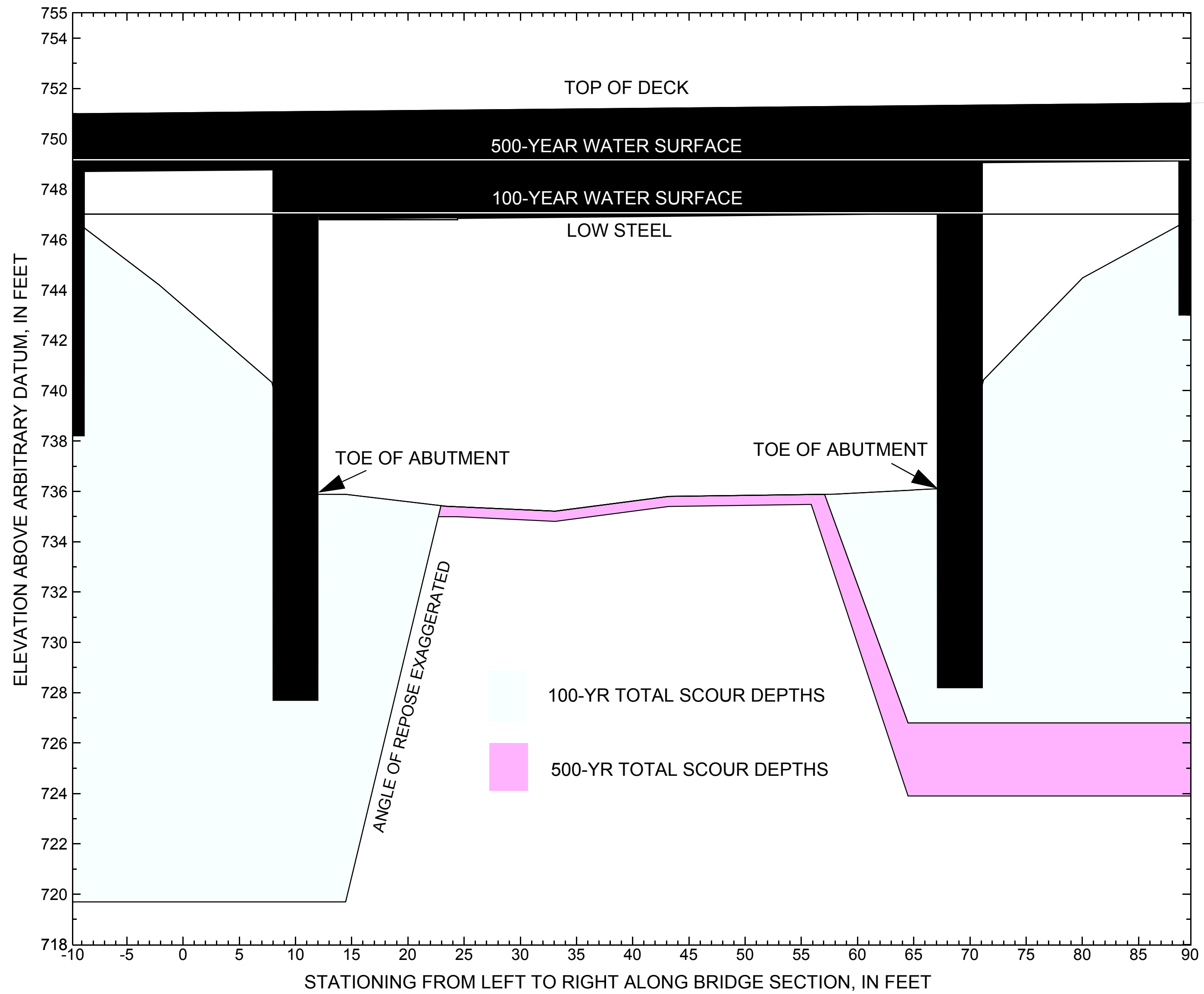

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure STJOUS00020108 on U.S. Highway 2, crossing Moose River, St. Johnsbury, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure STJOUS00020108 on U.S. Highway 2, crossing Moose River, St. Johnsbury, Vermont.

[VTAOT, Vermont Agency of Transportation; --,no data]

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 6,890 cubic-feet per second											
Left abutment	-9.8	--	748.6	738.2	746.6	0.0	--	--	--	--	-18.5
Toe of slope	12.0	--	--	--	735.9	0.0	10.4	--	10.4	725.5	--
Pier 1	12.0	748.6	746.8	727.7	735.9	0.0	--	16.2	16.2	719.7	-8.0
Pier 2	67.1	749.0	747.1	728.2	736.1	0.0	--	8.6	8.6	727.5	-0.7
Toe of slope	67.1	--	--	--	736.1	0.0	9.3	--	9.3	726.8	--
Right abutment	88.6	--	749.2	743.0	746.7	0.0	--	--	--	--	-16.2

1.Measured along the face of the most constricting side of the bridge.
2.Arbitrary datum for this study.

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure STJOUS00020108 on U.S. Highway 2, crossing Moose River, St. Johnsbury, Vermont.

[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 8,940 cubic-feet per second											
Left abutment	-9.8	--	748.6	738.2	746.6	0.4	--	--	0.4	--	-18.4
Toe of slope	12.0	--	--	--	735.9	0.4	12.2	--	12.6	723.3	--
Pier 1	12.0	748.6	746.8	727.7	735.9	0.4	--	15.7	16.1	719.8	-7.9
Pier 2	67.1	749.0	747.1	728.2	736.1	0.4	--	8.3	8.7	727.4	-0.8
Toe of slope	67.1	--	--	--	736.1	0.4	11.8	--	12.2	723.9	--
Right abutment	88.6	--	749.2	743.0	746.7	0.4	--	--	0.4	--	-19.1

1.Measured along the face of the most constricting side of the bridge.
2.Arbitrary datum for this study.

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U.S. Geological Survey, 1967, Concord, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Photorevised 1988, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File stjo108.wsp
T2        Hydraulic analysis for structure STJOUS00020108   Date: 20-SEP-96
T3        Bridge # 108 over the Moose River in St.Johnsbury, VT  by MAI
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
Q           6890.0   8940.0
SK          0.0078   0.0078
*
XS   EXIT1    -70
GR         -200.8, 765.71   -104.0, 751.05    -76.5, 749.93    -10.7, 749.34
GR           -3.2, 747.31      0.0, 744.95      4.0, 741.66     12.8, 738.08
GR           14.6, 737.09     26.9, 736.13     42.3, 736.09     52.7, 736.56
GR           67.4, 737.09     86.4, 738.07     91.1, 740.79    105.9, 742.14
GR          131.6, 743.74    185.6, 743.76    218.7, 744.77    289.5, 759.43
GR          298.1, 763.26
N           0.050        0.055        0.050
SA                  -10.7        91.1
*
XS   FULLV       0  * * *   0.0016
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0    746.9        0.0
GR           -9.8, 748.63     -9.8, 746.63     -2.1, 744.19      8.0, 740.33
GR           10.0, 737.50     12.0, 735.89     12.5, 735.89     16.2, 735.88
GR           23.3, 735.41     33.1, 735.21     43.2, 735.80     57.9, 735.89
GR           67.1, 736.10     69.1, 737.02     70.9, 740.42     80.0, 744.47
GR           88.6, 746.69     88.6, 749.21     71.2, 749.53     71.2, 747.12
GR           67.2, 747.10     12.1, 746.75      8.2, 746.75      8.0, 749.16
GR           -9.8, 748.63
*           PIER DATA - ELEV, WIDTH PAIRS
PW           736.10,4  740.33,4  740.33,8  746.75,8  746.75,4 747.10,4  747.10,0
*        BRTYPE  BRWDTH
CD           1       36.1
N            0.05
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     18       34.0     1
GR         -167.2, 765.71    -71.9, 751.05    -16.5, 750.91    -16.5, 753.05
GR          -14.7, 752.97     -8.3, 753.11      0.0, 753.24     44.8, 753.48
GR           97.3, 753.71     97.3, 751.51    154.0, 752.67    240.2, 755.06
GR          443.4, 764.61    567.6, 769.05
*
AS   APPR1    129
*           Approach section shifted 4.5 feet to the left bank
GR         -222.6, 765.71    -42.0, 756.67    -27.6, 746.65    -17.3, 745.48
GR          -15.8, 745.36     -4.5, 744.83      0.0, 743.90     11.6, 738.38
GR           20.3, 737.30     29.6, 737.02     39.6, 737.61     45.5, 737.23
GR           56.3, 737.34     64.6, 738.56     85.0, 744.08    144.8, 743.29
GR          179.1, 744.90    206.5, 746.99    320.2, 748.51    335.9, 750.38
GR          358.0, 750.87    379.3, 755.01    569.5, 759.54    582.3, 763.14
GR          613.9, 764.15
N           0.040     0.055        0.040
SA               -4.5         85.0
*
HP 1 BRIDG   747.02 1 747.02
HP 2 BRIDG   747.02 * * 6890
HP 1 APPR1   749.40 1 749.40
```

APPENDIX B:

WSPRO OUTPUT FILE

```
     U.S. Geological Survey WSPRO Input File stjo108.wsp
     Hydraulic analysis for structure STJOUS00020108   Date: 20-SEP-96
     Bridge # 108 over the Moose River in St.Johnsbury, VT  by MAI
        *** RUN DATE & TIME: 11-15-96  10:53
 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

  WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
          1      805     72729     52    152                         17969
747.02           805     72729     52    152  1.00     -9     89    17969

 VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL     LEW     REW    AREA        K        Q    VEL
    747.02    -9.8    88.6   804.7   72729.    6890.   8.56

X STA.       -9.8        7.7       13.2       17.1       20.8       24.3
 A(I)            58.7       51.0       41.7       41.9       39.8
 V(I)            5.86       6.76       8.26       8.22       8.66

X STA.       24.3       27.8       31.1       34.4       37.8       41.2
 A(I)            39.4       38.9       38.6       38.4       39.0
 V(I)            8.75       8.85       8.94       8.96       8.82

X STA.       41.2       44.7       48.2       51.7       55.1       57.7
 A(I)            39.0       38.9       39.4       37.5       28.6
 V(I)            8.83       8.85       8.75       9.20      12.04

X STA.       57.7       60.4       63.2       66.1       69.9       88.6
 A(I)            29.9       31.3       32.0       39.3       61.5
 V(I)           11.53      11.02      10.77       8.76       5.60


 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR1;  SRD =     129.

  WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
          1       94      7907     27     28                          1001
          2      915    114860     90     92                         16605
          3      809     67261    243    243                          8387
 749.40          1819    190027    359    363  1.12    -31    328    21915

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR1;  SRD =     129.

      WSEL     LEW     REW    AREA        K        Q    VEL
    749.40   -31.6   327.7  1818.8  190027.    6890.   3.79

X STA.      -31.6       -0.2       11.5       18.0       23.9       29.4
 A(I)           115.8       96.1       73.9       70.9       67.9
 V(I)            2.97       3.59       4.66       4.86       5.07

X STA.       29.4       34.9       40.6       46.3       51.9       57.6
 A(I)            67.3       67.5       68.7       68.5       68.1
 V(I)            5.12       5.10       5.01       5.03       5.06

X STA.       57.6       63.8       71.9       86.2      102.8      118.5
 A(I)            71.5       80.2       99.5       90.5       88.9
 V(I)            4.82       4.30       3.46       3.81       3.87

X STA.      118.5      134.1      149.9      170.2      203.2      327.7
 A(I)            91.2       95.6      109.2      128.2      199.4
 V(I)            3.78       3.60       3.16       2.69       1.73
```

```
       U.S. Geological Survey WSPRO Input File stjo108.wsp
       Hydraulic analysis for structure STJOUS00020108   Date: 20-SEP-96
       Bridge # 108 over the Moose River in St.Johnsbury, VT  by MAI
          *** RUN DATE & TIME: 11-15-96  10:53
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      877     71291     17    195                          35345
  749.21           877     71291     17    195  1.00     -9     89    35345

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

        WSEL     LEW     REW    AREA        K        Q    VEL
      749.21    -9.8    88.6   877.2   71291.    8940.  10.19

X STA.        -9.8        5.5       12.2       16.5       20.3       24.1
  A(I)            73.2       58.8       46.7       42.6       42.3
  V(I)            6.11       7.60       9.57      10.50      10.56

X STA.        24.1       27.5       31.0       34.4       37.7       41.1
  A(I)            39.8       40.5       38.5       39.0       38.4
  V(I)           11.24      11.03      11.60      11.45      11.63

X STA.        41.1       44.6       48.1       51.6       55.1       58.5
  A(I)            38.8       38.7       39.2       38.9       38.7
  V(I)           11.51      11.55      11.41      11.50      11.56

X STA.        58.5       62.1       65.7       69.7       76.0       88.6
  A(I)            39.1       40.3       42.4       47.5       53.8
  V(I)           11.44      11.09      10.54       9.41       8.31


   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR1;  SRD =     129.

    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      140     14274     29     31                           1731
            2     1059    146558     90     92                          20677
            3     1218    122631    274    274                          14576
  751.01          2417    283463    393    397  1.08    -33    359    32794

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR1;  SRD =     129.

        WSEL     LEW     REW    AREA        K        Q    VEL
      751.01   -33.9   358.7  2416.8  283463.    8940.   3.70

X STA.       -33.9       -4.7       10.5       18.2       25.3       31.8
  A(I)           138.8      131.6      100.3       97.1       91.1
  V(I)            3.22       3.40       4.46       4.61       4.91

X STA.        31.8       38.7       45.6       52.4       59.3       67.2
  A(I)            94.2       93.4       92.5       94.3       99.1
  V(I)            4.75       4.79       4.83       4.74       4.51

X STA.        67.2       78.6       95.3      110.6      125.7      140.6
  A(I)           116.8      122.1      109.4      111.1      112.8
  V(I)            3.83       3.66       4.09       4.02       3.96

X STA.       140.6      156.2      175.7      204.1      251.7      358.7
  A(I)           117.7      131.2      149.7      177.8      235.9
  V(I)            3.80       3.41       2.99       2.51       1.90
```

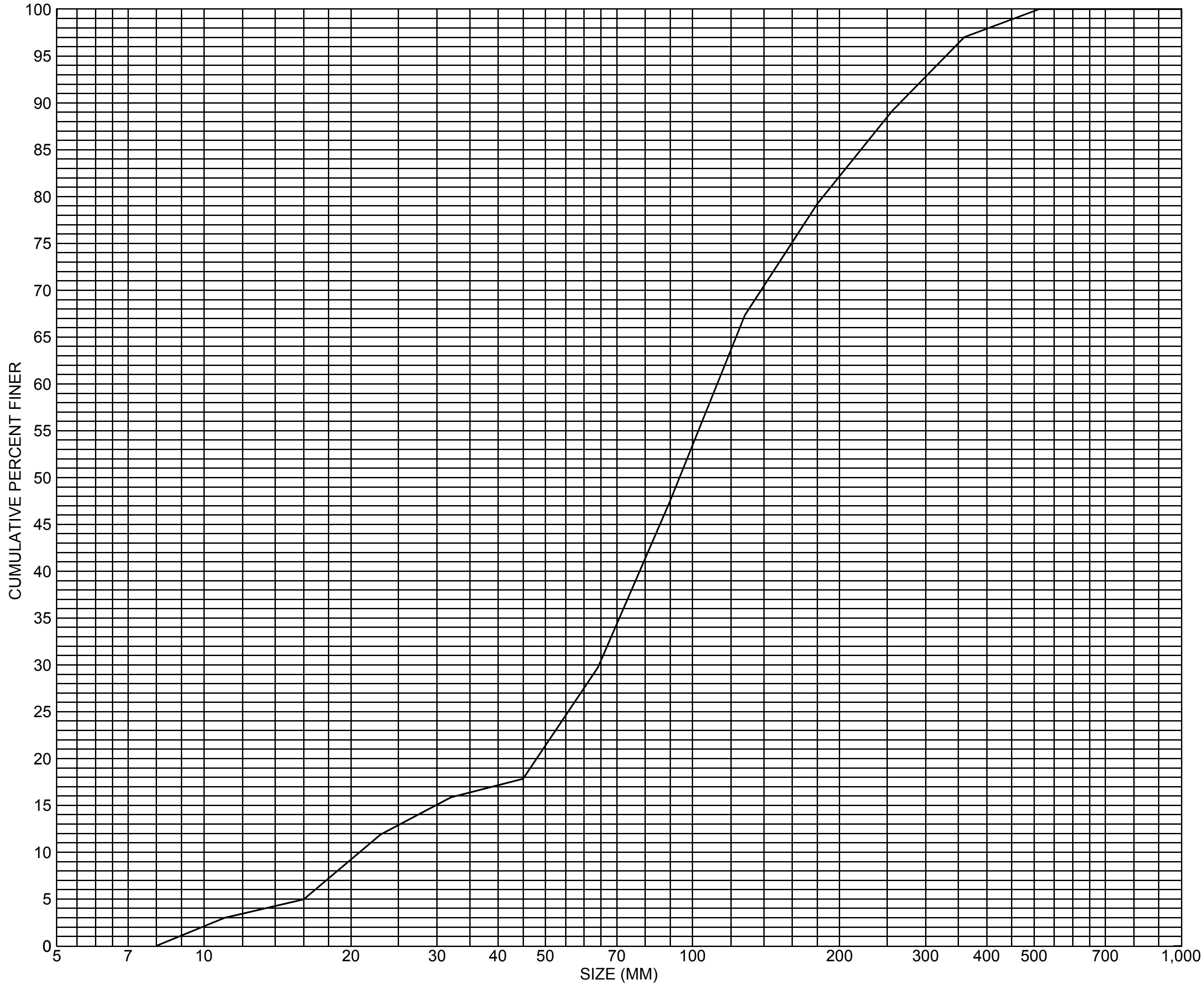
```
        U.S. Geological Survey WSPRO Input File stjo108.wsp
        Hydraulic analysis for structure STJOUS00020108   Date: 20-SEP-96
        Bridge # 108 over the Moose River in St.Johnsbury, VT  by MAI
           *** RUN DATE & TIME: 11-15-96  10:53

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXIT1:XS   ******      0      888  1.15 *****  746.18  743.25    6890  745.04
       -69 ******    220    77978  1.23 ***** *******    0.75    7.76

FULLV:FV       70      0     1028  0.85  0.46  746.63 *******    6890  745.78
         0     70    223    93408  1.21  0.00   -0.02    0.61    6.70
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR1:AS      129    -25      950  0.91  0.77  747.43 *******    6890  746.52
       129    129    200    84767  1.11  0.03    0.00    0.66    7.25
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   744.75     747.02     747.66     746.90

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

BRIDG:BR       70     -9      735  1.37 *****  748.39  743.72    6902  747.02
         0 ******     89    72941  1.00 ***** *******    0.61    9.39

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1.   0.   2.  0.472  0.086  746.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

APPR1:AS       93    -31     1818  0.25  0.34  749.65  745.33    6890  749.40
       129     99    328   189928  1.12  0.43    0.00    0.31    3.79

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q         K      AREA     VEL    WSEL
   EXIT1:XS     -70.     0.   220.   6890.   77978.     888.    7.76  745.04
   FULLV:FV       0.    -1.   223.   6890.   93408.    1028.    6.70  745.78
   BRIDG:BR       0.   -10.    89.   6902.   72941.     735.    9.39  747.02
   RDWAY:RG      18.**************       0.******************    1.00********
   APPR1:AS     129.   -32.   328.   6890.  189928.    1818.    3.79  749.40

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXIT1:XS    743.25    0.75  736.09  765.71************  1.15  746.18  745.04
   FULLV:FV  ********    0.61  736.20  765.82  0.46  0.00  0.85  746.63  745.78
   BRIDG:BR    743.72    0.61  735.21  749.53************  1.37  748.39  747.02
   RDWAY:RG  ****************  750.91  769.05************  0.11  751.67********
   APPR1:AS    745.33    0.31  737.02  765.71  0.34  0.43  0.25  749.65  749.40
```

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File stjo108.wsp
        Hydraulic analysis for structure STJOUS00020108   Date: 20-SEP-96
        Bridge # 108 over the Moose River in St.Johnsbury, VT  by MAI
           *** RUN DATE & TIME: 11-15-96  10:53

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXIT1:XS   ******      0     1093  1.25 *****  747.21  744.98    8940  745.96
       -69 ******    224   101177  1.20 ***** *******    0.72    8.18

FULLV:FV       70     -1     1237  0.96  0.46  747.66 *******    8940  746.70
         0     70    227   119279  1.18  0.00   -0.01    0.60    7.23
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR1:AS      129    -28     1176  1.02  0.79  748.48 *******    8940  747.45
       129    129    241   109982  1.14  0.03    0.00    0.68    7.61
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   745.20     749.21     749.77     746.90

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

           <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

BRIDG:BR       70     -9      808  1.96 *****  751.17  745.27    9055  749.21
         0 ******     89    71289  1.00 ***** *******    0.69   11.21

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1.   0.   2.  0.493  0.079  746.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

APPR1:AS       93    -33     2419  0.23  0.39  751.24  746.09    8940  751.01
       129    100    359   283790  1.08  0.62    0.01    0.27    3.70

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q         K     AREA     VEL    WSEL
   EXIT1:XS     -70.    -1.   224.   8940.  101177.    1093.    8.18  745.96
   FULLV:FV       0.    -2.   227.   8940.  119279.    1237.    7.23  746.70
   BRIDG:BR       0.   -10.    89.   9055.   71289.     808.   11.21  749.21
   RDWAY:RG      18.**************      0.        0.       0.    1.00********
   APPR1:AS     129.   -34.   359.   8940.  283790.    2419.    3.70  751.01

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF     HO   VHD     EGL    WSEL
   EXIT1:XS    744.98    0.72  736.09  765.71************  1.25  747.21  745.96
   FULLV:FV  ********    0.60  736.20  765.82  0.46  0.00  0.96  747.66  746.70
   BRIDG:BR    745.27    0.69  735.21  749.53************  1.96  751.17  749.21
   RDWAY:RG  ****************  750.91  769.05************  0.23  751.15********
   APPR1:AS    746.09    0.27  737.02  765.71  0.39  0.62  0.23  751.24  751.01
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure STJOUS00020108, in St. Johnsbury, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number STJOUS00020108

General Location Descriptive

Data collected by *(First Initial, Full last name)* E. BOEHMLER

Date *(MM/DD/YY)* 03 / 28 / 95

Highway District Number *(I - 2; nn)* 07

County *(FIPS county code; I - 3; nnn)* 005

Town *(FIPS place code; I - 4; nnnnn)* 62125

Mile marker *(I - 11; nnn.nnn)* 007240

Waterway *(I - 6)* MOOSE RIVER

Road Name *(I - 7):* -

Route Number US002

Vicinity *(I - 9)* 0.6 MI E JCT VT.18

Topographic Map Concord

Hydrologic Unit Code: 01080102

Latitude *(I - 16; nnnn.n)* 44260

Longitude *(i - 17; nnnnn.n)* 71571

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 20002801080311

Maintenance responsibility *(I - 21; nn)* 01

Maximum span length *(I - 48; nnnn)* 0057

Year built *(I - 27; YYYY)* 1929

Structure length *(I - 49; nnnnnn)* 000103

Average daily traffic, ADT *(I - 29; nnnnnn)* 004205

Deck Width *(I - 52; nn.n)* 340

Year of ADT *(I - 30; YY)* 92

Channel & Protection *(I - 61; n)* 8

Opening skew to Roadway *(I - 34; nn)* 00

Waterway adequacy *(I - 71; n)* 6

Operational status *(I - 41; X)* A

Underwater Inspection Frequency *(I - 92B; XYY)* N

Structure type *(I - 43; nnn)* 104

Year Reconstructed *(I - 106)* 1950

Approach span structure type *(I - 44; nnn)* 101

Clear span (*nnn.n ft*) 091.2

Number of spans *(I - 45; nnn)* 001

Vertical clearance from streambed (*nnn.n ft*) 013.0

Number of approach spans *(I - 46; nnnn)* 0002

Waterway of full opening (*nnn.n* ft^2) 870.0

Comments:

The structural inspection report of 9/7/93 indicates the structure is a three span concrete T-beam type bridge. The abutment walls and piers are concrete. The abutment walls only have minor stains reported. The tops of the pier walls have quite a few cracks noted with rust stains. Below the centerline of the roadway some spalling is noted on pier 1 (left). The footings of the abutments and piers are not exposed. There is granite block stone fill noted along the banks. The waterway is noted as making a slight bend into the crossing. The streambed consists of sand and gravel with some randomly distributed stones and boulders. The report indicates there has been no channel scour or streambank erosion. **(Continued, page 31)**

Bridge Hydrologic Data

Is there hydrologic data available? Y *if No, type ctrl-n h* VTAOT Drainage area *(mi^2)*: 117.6

Terrain character: -

Stream character & type: -

Streambed material: -

Discharge Data *(cfs)*: $Q_{2.33}$ 2500 Q_{10} 4500 Q_{25} 5550

Q_{50} 6650 Q_{100} 7600 Q_{500} -

Record flood date *(MM / DD / YY)*: - / / Water surface elevation *(ft)*: -

Estimated Discharge *(cfs)*: - Velocity at Q - *(ft/s)*: -

Ice conditions *(Heavy, Moderate, Light)* : - Debris *(Heavy, Moderate, Light)*: -

The stage increases to maximum highwater elevation (*Rapidly, Not rapidly*): -

The stream response is (*Flashy, Not flashy*): -

Describe any significant site conditions upstream or downstream that may influence the stream's stage: -

Watershed storage area (*in percent*): 1 %

The watershed storage area is: - (*1-mainly at the headwaters; 2- uniformly distributed; 3-immediatly upstream oi the site*)

Water Surface Elevation Estimates for Existing Structure:

Peak discharge frequency	$Q_{2.33}$	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Water surface elevation (*ft*)	-	747.3	-	749.2	750.0
Velocity (*ft / sec*)	-	-	-	-	-

Long term stream bed changes: -

Is the roadway overtopped below the Q_{100}? (*Yes, No, Unknown*): U Frequency: -

Relief Elevation (*ft*): - Discharge over roadway at Q_{100} (*ft^3/ sec*): -

Are there other structures nearby? (*Yes, No, Unknown*): Y *If No or Unknown, type ctrl-n os*

Upstream distance (*miles*): 0.6 Town: E. St. Johnsbury Year Built: 1926

Highway No. : TH40 Structure No. : 31 Structure Type: Concrete T-beam

Clear span (*ft*): 82.0 Clear Height (*ft*): 15.0 Full Waterway (*ft^2*): 1230.

Downstream distance (*miles*): 0.7 Town: St. Johnsbury Year Built: 1978

Highway No. : US2 Structure No. : 107 Structure Type: Steel stringer

Clear span (*ft*): 62.0 Clear Height (*ft*): 12.0 Full Waterway (ft^2): 744.0

Comments:

Point bar and debris accumulation problems are noted as minor.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* 116.693 mi^2

Lake and pond area 3.22 mi^2

Watershed storage *(ST)* 2.76 %

Bridge site elevation 741 ft

Headwater elevation 3174 ft

Main channel length 32.065 mi

10% channel length elevation 795 ft

85% channel length elevation 1850 ft

Main channel slope *(S)* 43.87 ft / mi

Watershed Precipitation Data

Average site precipitation ____ in

Average headwater precipitation ____ in

Maximum 2yr-24hr precipitation event *(I24,2)* ____ in

Average seasonal snowfall *(Sn)* ____ ft

Bridge Plan Data

Are plans available? **Y** *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: **04** / **1929**

Project Number **F 118(13)** Minimum channel bed elevation: **735.0**

Low superstructure elevation: USLAB _______ DSLAB ________ USRAB _______ DSRAB _______

Benchmark location description:

BM#18, paint spot on the upstream right end of the bridge rail, elevation 755.85

Reference Point (*MSL, Arbitrary, Other*): **Arbitrary** Datum (*NAD27, NAD83, Other*): **Arbitrary**

Foundation Type: **1** (*1-Spreadfooting; 2-Pile; 3- Gravity; 4-Unknown*)

If 1: Footing Thickness **2.0** Footing bottom elevation: **729.5***

If 2: Pile Type: ____ (*1-Wood; 2-Steel or metal; 3-Concrete*) Approximate pile driven length: _______

If 3: Footing bottom elevation: _______

Is boring information available? **Y** *If no, type ctrl-n bi* Number of borings taken: **1**

Foundation Material Type: **1** (*1-regolith, 2-bedrock, 3-unknown*)

Briefly describe material at foundation bottom elevation or around piles:

The abutment footings probably are set in a clay gravel shale.

Comments:

These plans are for the bridge widening construction performed in 1949, about 20 years after the original structure was installed.

The low chords for the piers are: pier 1(left) left 750.74 and right 748.56; pier 2(right) left 749.03 and right 751.21. The bottom of the pier footings are: pier 1 (left) 729.49 and pier 2 (right) 729.96. The footing thickness of both piers is 2.0 feet.

***The value is for the lowest pier footing. The footing bottom elevation for the left abutment is 739.96 and for the right abutment is 744.79.**

Cross-sectional Data

Is cross-sectional data available? N *If no, type ctrl-n xs*

Source (*FEMA, VTAOT, Other*)? -

Comments: **NO CROSS SECTION INFORMATION**

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Source (*FEMA, VTAOT, Other*)? -

Comments: **NO CROSS SECTION INFORMATION**

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

U. S. Geological Survey
Bridge Field Data Collection and Processing Form

Qa/Qc Check by: EW Date: 03/21/96
Computerized by: EW Date: 03/22/96
Reviewd by: MAI Date: 12/13/96

Structure Number STJOUS00020108

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* M. IVANOFF Date *(MM/DD/YY)* 08 / 14 / 1995

2. Highway District Number 07

County CALENDONIA (005)

Waterway *(I - 6)* MOOSE RIVER

Route Number US 2

Mile marker 007240

Town ST. JOHNSBURY (62125)

Road Name US 2

Hydrologic Unit Code: 01080102

3. Descriptive comments:

Located 0.6 miles east of the junction with VT 18

B. Bridge Deck Observations

4. Surface cover... LBUS 6 RBUS 4 LBDS 5 RBDS 6 Overall 6
*(2b us,ds,lb,rb: **1**- Urban; **2**- Suburban; **3**- Row crops; **4**- Pasture; **5**- Shrub- and brushland; **6**- Forest; **7**- Wetland)*

5. Ambient water surface... US 2 UB 1 DS 2 *(**1**- pool; **2**- riffle)*

6. Bridge structure type 2 *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*

7. Bridge length 103 *(feet)* Span length 57 *(feet)* Bridge width 34 *(feet)*

Road approach to bridge:

8. LB 1 RB 2 *(**0** even, **1**- lower, **2**- higher)*

9. LB 1 RB 1 *(**1**- Paved, **2**- Not paved)*

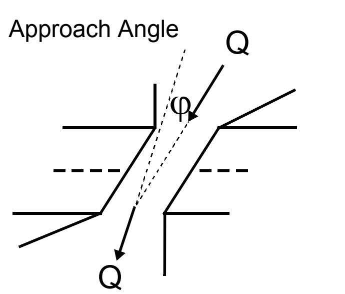
10. Embankment slope (*run / rise in feet / foot*):
US left 0.0:1 US right 0.0:1

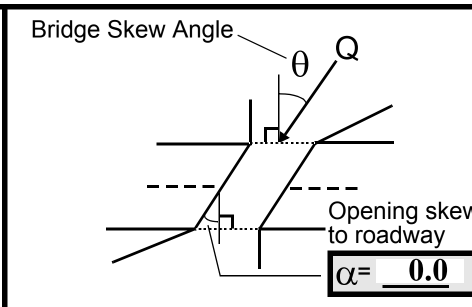
	Protection			
	11.Type	12.Cond.	13.Erosion	14.Severity
LBUS	0	-	0	0
RBUS	0	-	0	0
RBDS	0	-	0	0
LBDS	3	1	0	0

*Bank protection types: **0**- none; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*
*Erosion: **0** - none; **1**- channel erosion; **2**- road wash; **3**- both; **4**- other*
*Erosion Severity: **0** - none; **1**- slight; **2**- moderate; **3**- severe*

Channel approach to bridge (BF):

15. Angle of approach: 0 16. Bridge skew: 10





17. Channel impact zone 1: Exist? Y *(Y or N)*
Where? LB *(LB, RB)* Severity 1
Range? 0 feet US *(US, UB, DS)* to 0 feet DS

Channel impact zone 2: Exist? N *(Y or N)*
Where? ____ *(LB, RB)* Severity ____
Range? ____ feet ____ *(US, UB, DS)* to ____ feet ____

*Impact Severity: **0**- none to very slight; **1**- Slight; **2**- Moderate; **3**- Severe*

18. Bridge Type: **1b**

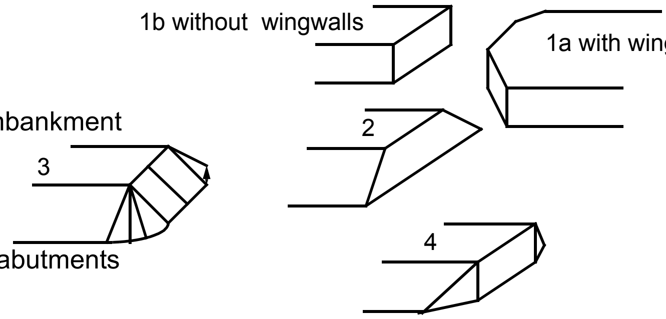
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls perpendicular to abut. face

3- Spill through abutments

4- Sloping embankment, vertical wingwalls and abutments
Wingwall angle less than 90°.



19. Bridge Deck Comments (surface cover variations, measured bridge and span lengths, bridge type variations, approach overflow width, etc.)

#7: Values are from VTAOT. The measured values are bridge length 101 feet, span 55 feet, and width 34 feet.

#19: The approach overflow width is 34 feet at left road approach to the bridge.

C. Upstream Channel Assessment

20. SRD	21. Bank height (BF) LB	21. Bank height (BF) RB	22. Bank angle (BF) LB	22. Bank angle (BF) RB	26. % Veg. cover (BF) LB	26. % Veg. cover (BF) RB	27. Bank material (BF) LB	27. Bank material (BF) RB	28. Bank erosion (BF) LB	28. Bank erosion (BF) RB
95.0	**6.5**			**5.5**	**4**	**1**	**453**	**453**	**0**	**0**

23. Bank width **20.0** 24. Channel width **15.0** 25. Thalweg depth **89.5** 29. Bed Material **453**

30 .Bank protection type: LB **2** RB **2** 31. Bank protection condition: LB **1** RB **1**

SRD - Section ref. dist. to US face *% Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

32. Comments (bank material variation, minor inflows, protection extent, etc.):

The banks are covered with exposed cobble, boulder and some gravel.

#30: LB protection extends beyond 300 feet from the bridge

RB protection extends 20 feet US of the bridge as a spill through abutment embankment

33. Point/Side bar present? N (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: - 35. Mid-bar width: -

36. Point bar extent: - feet - (US, UB) to - feet - (US, UB, DS) positioned - %LB to - %RB

37. Material: -

38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):

NO POINT BARS

39. Is a cut-bank present? N (Y or if N type ctrl-n cb) 40. Where? - (LB or RB)

41. Mid-bank distance: - 42. Cut bank extent: - feet - (US, UB) to - feet - (US, UB, DS)

43. Bank damage: - (1- eroded and/or creep; 2- slip failure; 3- block failure)

44. Cut bank comments (eg. additional cut banks, protection condition, etc.):

NO CUT BANKS

45. Is channel scour present? N (Y or if N type ctrl-n cs) 46. Mid-scour distance: -

47. Scour dimensions: Length - Width - Depth : - Position - %LB to - %RB

48. Scour comments (eg. additional scour areas, local scouring process, etc.):

NO CHANNEL SCOUR

49. Are there major confluences? N (Y or if N type ctrl-n mc) 50. How many? -

51. Confluence 1: Distance - 52. Enters on - (LB or RB) 53. Type - (1- perennial; 2- ephemeral)

Confluence 2: Distance - Enters on - (LB or RB) Type - (1- perennial; 2- ephemeral)

54. Confluence comments (eg. confluence name):

NO MAJOR CONFLUENCES

D. Under Bridge Channel Assessment

55. Channel restraint (BF)? LB 1 RB ___ (1- natural bank; 2- abutment; 3- artificial levee)

56. Height (BF) LB	56. Height (BF) RB	57 Angle (BF) LB	57 Angle (BF) RB	61. Material (BF) LB	61. Material (BF) RB	62. Erosion (BF) LB	62. Erosion (BF) RB
53.0		1.0		1	5	5	1

58. Bank width (BF) - 59. Channel width (Amb) - 60. Thalweg depth (Amb) 90.0 63. Bed Material 0

*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*

*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*

64. Comments (bank material variation, minor inflows, protection extent, etc.):

453

There is a large pile of stone fill at the upstream bridge face between the left pier and left abutment.

65. **Debris and Ice** Is there debris accumulation? ____ *(Y or N)* 66. Where? N____ *(**1**- Upstream; **2**- At bridge; **3**- Both)*

67. Debris Potential -____ *(**1**- Low; **2**- Moderate; **3**- High)* 68. Capture Efficiency 1____ *(**1**- Low; **2**- Moderate; **3**- High)*

69. Is there evidence of ice build-up? 2___ *(Y or N)* Ice Blockage Potential N____ *(**1**- Low; **2**- Moderate; **3**- High)*

70. Debris and Ice Comments:

1

The capture efficiency is moderate due to the piers under the bridge.

Abutments	71. Attack ∠(BF)	72. Slope ∠ (Qmax)	73. Toe loc. (BF)	74. Scour Condition	75. Scour depth	76. Exposure depth	77. Material	78. Length
LABUT		10	90	1	1	0	0	90.0
RABUT	1	0	90			1	0	98.5

Pushed: LB or RB *Toe Location (Loc.): **0**- even, **1**- set back, **2**- protrudes*
*Scour cond.: **0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**-undermined footing; **4**- piling exposed; **5**- settled; **6**- failed*
Materials: ***1***- Concrete; ***2***- Stone masonry or drywall; ***3***- steel or metal; ***4***- wood

79. Abutment comments (eg. undermined penetration, unusual scour processes, debris, etc.):

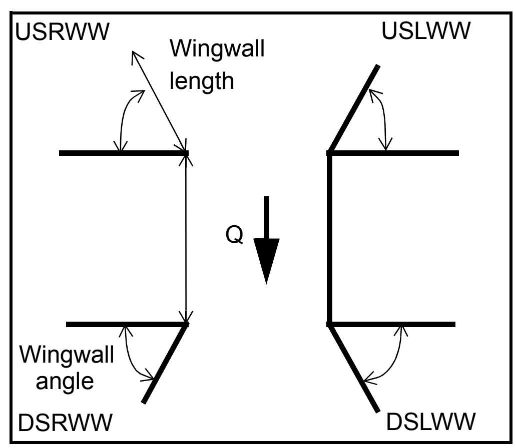
0
0
1
#71: The left abutment attack angle was measured below the bridge.
#74: The left abutment bank has been scoured under the left span DS of a large pile of stones between pier 1 and left abutment. The stones of spill through abutment are only on the DS end of the left abutment.

The concrete wall of each abutment reveals the previous skeleton abutment footing.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						98.5	
USRWW:	N		-		-	2.5	
DSLWW:	-		-		N	36.0	
DSRWW:	-		-		-	36.0	

*Wingwall materials: **1**- Concrete; **2**- Stone masonry or drywall; **3**- steel or metal; **4**- wood*



82. **Bank / Bridge Protection**:

Location	USLWW	USRWW	LABUT	RABUT	LB	RB	DSLWW	DSRWW
Type	-	-	N	-	-	-	-	-
Condition	N	-	-	-	-	-	-	-
Extent	-	-	-	0	0	0	0	3

*Bank / Bridge protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank / Bridge protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*
*Protection extent: **1**- entire base length; **2**- US end; **3**- DS end; **4**- other*

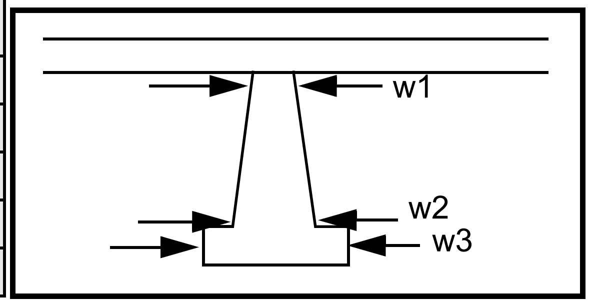
83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):

1
4
3
1
4
0
-
-
0
-
-

Piers:

84. Are there piers? **#82** *(Y or if N type ctrl-n pr)*

85. Pier no.	width (w) feet			elevation (e) feet		
	w1	w2	w3	e@w1	e@w2	e@w3
Pier 1	-	-	-	-	-	-
Pier 2	-	4	4	-	746.8	740.3
Pier 3	4	4	4	735.9	747.1	740.4
Pier 4	4	-	-	736.1	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	: The	nstre	ugh”	bank	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	bank	am	abut	betw	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	pro-	ends	ment	een	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	tec-	of	type	the	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	tion	the	with	piers	*Y- yes; N- no*
91. Attack ∠ (BF)	exist	right	large	and	
92. Pushed	s at	abut	flat	the	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	the	ment	stone	abut	
95. Cross-members	upst	as a	s	ment	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	ream	“spil	cov-	s.	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	and	l	ering	The	
98. Exposure depth	dow	thro	the	left	

99. Pier comments (eg. undermined penetration, protection and protection extent, unusual scour processes, etc.):
abutment stone fill has been piled at the US end and placed like a "spill through" type at the DS end

Y

E. Downstream Channel Assessment

100.

SRD	Bank height (BF) LB	Bank height (BF) RB	Bank angle (BF) LB	Bank angle (BF) RB	% Veg. cover (BF) LB	% Veg. cover (BF) RB	Bank material (BF) LB	Bank material (BF) RB	Bank erosion (BF) LB	Bank erosion (BF) RB
-	**-**			**-**	**LB**	**1**	**2**	**3**	**Y**	**10**

Bank width (BF) **-** Channel width (Amb) **38** Thalweg depth (Amb) **38** Bed Material **-**

Bank protection type (Qmax): LB **UN** RB **K** Bank protection condition: LB **0** RB **0**

SRD - Section ref. dist. to US face *% Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

Comments (eg. bank material variation, minor inflows, protection extent, etc.):
0
0
RB
1
2
3
Y
0
-
UNK
0
0
0
0

101. Is a drop structure present? ____ *(Y or N, if N type ctrl-n ds)* 102. Distance: - feet

103. Drop: - feet 104. Structure material: ____ *(**1**- steel sheet pile; **2**- wood pile; **3**- concrete; **4**- other)*

105. Drop structure comments (eg. downstream scour depth):

106. Point/Side bar present? _____ *(Y or N. if N type ctrl-n pb)* Mid-bar distance: ______ Mid-bar width: ______

Point bar extent: ______ feet ____ *(US, UB, DS)* to ______ feet ____ *(US, UB, DS)* positioned ____ %LB to _____ %RB

Material: _____

Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

Is a cut-bank present? _____ *(Y or if N type ctrl-n cb)* Where? **The** *(LB or RB)* Mid-bank distance: **left**

Cut bank extent: **pier** feet **att** *(US, UB, DS)* to **ack** feet **ang** *(US, UB, DS)*

Bank damage: **le** *(**1**- eroded and/or creep; **2**- slip failure; **3**- block failure)*

Cut bank comments (eg. additional cut banks, protection condition, etc.):

was measured from under the bridge. The channel was deeper along the left pier.

Is channel scour present? _____ *(Y or if N type ctrl-n cs)* Mid-scour distance: _______

Scour dimensions: Length ______ Width ______ Depth: _____ Positioned ____ %LB to **3** %RB

Scour comments (eg. additional scour areas, local scouring process, etc.):

2
453
453
0

Are there major confluences? **0** *(Y or if N type ctrl-n mc)* How many? **453**

Confluence 1: Distance **2** Enters on **2** *(LB or RB)* Type **1** *(**1**- perennial; **2**- ephemeral)*

Confluence 2: Distance **1** Enters on **LB** *(LB or RB)* Type **pro-** *(**1**- perennial; **2**- ephemeral)*

Confluence comments (eg. confluence name):

tection extends from the flow through embankment protection at the DS left end of the bridge face to 150 feet DS.

F. Geomorphic Channel Assessment

107. Stage of reach evolution **RB**

1- *Constructed*
2- *Stable*
3- *Aggraded*
4- *Degraded*
5- *Laterally unstable*
6- *Vertically and laterally unstable*

108. Evolution comments *(Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors)*:

protection extends DS 20 feet from the bridge as flow-through abutment embankment protection.

109. G. Plan View Sketch

N

point bar (pb)	debris	flow (Q)	stone wall
cut-bank (cb)	rip rap or stone fill	cross-section	other wall
scour hole		ambient channel	

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: STJOUS00020108 Town: St. Johnsbury
Road Number: US 2 County: Calendonia
Stream: Moose River

Initials MAI Date: 11/08/96 Checked: SAO

Analysis of contraction scour, live-bed or clear water?

Critical Velocity of Bed Material (converted to English units)
Vc=11.21*y1^0.1667*D50^0.33 with Ss=2.65
(Richardson and others, 1995, p. 28, eq. 16)

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	6890	8940	0
Main Channel Area, ft2	915	1059	0
Left overbank area, ft2	94	140	0
Right overbank area, ft2	809	1218	0
Top width main channel, ft	90	90	0
Top width L overbank, ft	27	29	0
Top width R overbank, ft	243	274	0
D50 of channel, ft	0.3086	0.3086	0
D50 left overbank, ft	--	--	0
D50 right overbank, ft	--	--	0
y1, average depth, MC, ft	10.2	11.8	ERR
y1, average depth, LOB, ft	3.5	4.8	ERR
y1, average depth, ROB, ft	3.3	4.4	ERR
Total conveyance, approach	190027	283463	0
Conveyance, main channel	114860	146558	0
Conveyance, LOB	7907	14274	0
Conveyance, ROB	67261	122631	0
Percent discrepancy, conveyance	-0.0005	0.0000	ERR
Qm, discharge, MC, cfs	4164.6	4622.2	ERR
Ql, discharge, LOB, cfs	286.7	450.2	ERR
Qr, discharge, ROB, cfs	2438.7	3867.6	ERR
Vm, mean velocity MC, ft/s	4.6	4.4	ERR
Vl, mean velocity, LOB, ft/s	3.0	3.2	ERR
Vr, mean velocity, ROB, ft/s	3.0	3.2	ERR
Vc-m, crit. velocity, MC, ft/s	11.1	11.4	N/A
Vc-l, crit. velocity, LOB, ft/s	ERR	ERR	N/A
Vc-r, crit. velocity, ROB, ft/s	ERR	ERR	N/A

Results

Live-bed(1) or Clear-Water(0) Contraction Scour?

Main Channel	0	0	N/A

ARMORING

D90	0.873	0.873	
D95	1.082	1.082	
Critical grain size,Dc, ft	0.353	0.485	ERR
Decimal-percent coarser than Dc	0.424	0.276	
Depth to armoring,ft	1.44	3.82	ERR

Clear Water Contraction Scour in MAIN CHANNEL

y2 = (Q2^2/(131*Dm^(2/3)*W2^2))^(3/7)   Converted to English Units
ys=y2-y_bridge
(Richardson and others, 1995, p. 32, eq. 20, 20a)

Approach Section	Q100	Q500	Qother
Main channel Area, ft2	915	1059	0
Main channel width, ft	90	90	0
y1, main channel depth, ft	10.17	11.77	ERR

Bridge Section			
(Q) total discharge, cfs	6890	8940	0
(Q) discharge thru bridge, cfs	6890	8940	
Main channel conveyance	72941	71289	
Total conveyance	72941	71289	
Q2, bridge MC discharge,cfs	6890	8940	ERR
Main channel area, ft2	735	808	0
Main channel width (skewed), ft	68.5	72.9	0.0
Cum. width of piers in MC, ft	8.0	8.0	0.0
W, adjusted width, ft	60.5	64.9	0
y_bridge (avg. depth at br.), ft	12.15	12.45	ERR
Dm, median (1.25*D50), ft	0.38575	0.38575	0
y2, depth in contraction,ft	9.41	11.07	ERR
ys, scour depth (y2-ybridge), ft	-2.74	-1.38	N/A

Pressure Flow Scour (contraction scour for orifice flow conditions)

Hb+Ys=Cq*qbr/Vc   Cq=1/Cf*Cc   Cf=1.5*Fr^0.43 (<=1)
Chang Equation   Cc=SQRT[0.10(Hb/(ya-w)-0.56)]+0.79 (<=1)
(Richarson and others, 1995, p. 145-146)

	Q100	Q500	OtherQ
Q, total, cfs	6890	8940	0
Q, thru bridge, cfs	6890	8940	0
Total Conveyance, bridge	72941	71289	0
Main channel(MC) conveyance, bridge	72941	71289	0
Q, thru bridge MC, cfs	6890	8940	ERR
Vc, critical velocity, ft/s	11.15	11.42	N/A
Vc, critical velocity, m/s	3.40	3.48	N/A
Main channel width (skewed), ft	68.5	72.9	0.0
Cum. width of piers in MC, ft	8	8	0
W, adjusted width, ft	60.5	64.9	0.0
qbr, unit discharge, ft2/s	113.9	137.8	ERR
qbr, unit discharge, m2/s	10.6	12.8	N/A
Area of full opening, ft2	735	808	0
Hb, depth of full opening, ft	12.15	12.45	ERR
Hb, depth of full opening, m	3.70	3.79	N/A
Fr, Froude number, bridge MC	0.61	0.69	1

Cf, Fr correction factor (<=1.0)	1.00	1.00	1.50
Elevation of Low Steel, ft	746.9	746.9	0
Elevation of Bed, ft	734.75	734.45	N/A
Elevation of Approach, ft	749.4	751.01	0
Friction loss, approach, ft	0.34	0.39	0
Elevation of WS immediately US, ft	749.06	750.62	0.00
ya, depth immediately US, ft	14.31	16.17	N/A
ya, depth immediately US, m	4.36	4.93	N/A
Mean elevation of deck, ft	751.2	751.2	0
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	0.96	0.93	ERR
Ys, depth of scour, ft	-1.51	0.45	N/A

Comparison of Chang and Laursen results (for unsubmerged orifice flow)

y2, from Laurse's equation, ft	9.41	11.07	0
Full valley WSEL, ft	745.78	746.7	0
Full valley depth, ft	11.03	12.25	N/A
Ys, depth of scour (y2-yfullv), ft	-1.619	-1.180	N/A

Abutment Scour

Froehlich's Abutment Scour
Ys/Y1 = 2.27*K1*K2*(a'/Y1)^0.43*Fr1^0.61+1
(Richardson and others, 1995, p. 48, eq. 28)

	Left Abutment			Right Abutment		
Characteristic	100 yr Q	500 yr Q	Other Q	100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	6890	8940	0	6890	8940	0
a', abut.length blocking flow, ft	36.6	36.9	0	254.2	282.8	0
Ae, area of blocked flow ft2	158.5	205.5	0	891.4	1295.4	0
Qe, discharge blocked abut.,cfs	497.6	673.4	0	2717.4	4128.9	0
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	3.14	3.28	ERR	3.05	3.19	ERR
ya, depth of f/p flow, ft	4.33	5.57	ERR	3.51	4.58	ERR
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)						
K1	0.55	0.55	0	0.55	0.55	0
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	90	90	0	90	90	0
K2	1.00	1.00	0.00	1.00	1.00	0.00
Fr, froude number f/p flow	0.266	0.245	ERR	0.287	0.262	ERR
ys, scour depth, ft	10.36	12.21	N/A	16.40	19.47	N/A

HIRE equation (a'/ya > 25)
ys = 4*Fr^0.33*y1*K/0.55
(Richardson and others, 1995, p. 49, eq. 29)

a'(abut length blocked, ft)	36.6	36.9	0	254.2	282.8	0
y1 (depth f/p flow, ft)	4.33	5.57	ERR	3.51	4.58	ERR
a'/y1	8.45	6.63	ERR	72.49	61.74	ERR
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.27	0.24	N/A	0.29	0.26	N/A
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	16.89	21.42	ERR
vertical w/ ww's	ERR	ERR	ERR	13.85	17.57	ERR
spill-through	ERR	ERR	ERR	9.29	11.78	ERR

Abutment riprap Sizing

Isbash Relationship
D50=y*K*Fr^2/(Ss-1) and D50=y*K*(Fr^2)^0.14/(Ss-1)
(Richardson and others, 1995, p112, eq. 81,82)

Characteristic	Q100	Q500	Qother			
Fr, Froude Number	0.61	0.69		0.61	0.69	
(Fr from the characteristic V and y in contracted section--mc, bridge section)						
y, depth of flow in bridge, ft	12.2	12.4		12.2	12.4	
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	2.81	3.65	0.00	2.81	3.65	0.00
Fr>0.8 (vertical abut.)	ERR	ERR	ERR	ERR	ERR	ERR
Fr<=0.8 (spillthrough abut.)	2.45	3.18	0.00	2.45	3.18	0.00
Fr>0.8 (spillthrough abut.)	ERR	ERR	ERR	ERR	ERR	ERR

Pier Scour (both live-bed and clear water scour)

ys/y1=2.0*K1*K2*K3*K4*(a/y1)^0.65*Fr1^0.43
(Richardson and others, 1995, p. 36, eq. 21)

K1, corr. factor for pier nose shape
Sharp nose, 0.9; round nose, cylinder, or cylinder grp., 1.0; square nose, 1.1

K2, corr. factor attack angle (see Table 3, p 37)
K2=[cos(attackangle)+L/a*sin(attackangle)]^0.65

K3, corr. factor for bed condition
Clear-water, plane bed, antidune, 1.1; med. dunes, 1.1-1.2 (see Tab.4,p37)

K4, corr. factor for armoring (the following equations are in Si units)
K4=[1-0.89*(1-Vr)^2]^0.5
Vr=(V1-Vi)/(Vc90-Vi)
V1=0.645*((D50/a)^0.053)*Vc50
Vc=6.19*(y^1/6)*(Dc^1/3)

Note for round nose piers:
ys<=2.4 times the pier width (a) for Fr<=0.8
ys<=3.0 times the pier width (a) for Fr>0.8

Pier 1	Q100	Q500	Qother
Pier stationing, ft	10	10	0
Area of WSPRO flow tube, ft2	28.6	38.4	0
Skewed width of flow tube, ft	2.6	3.4	0
y1, pier approach depth, ft	11.00	11.29	ERR
y1 in meters	3.353	3.442	N/A
V1, pier approach velocity, ft/s	12.04	11.63	0
a, pier width, ft	4	4	0

L, pier length, ft	38.4	38.4	0
Fr1, Froude number at pier	0.640	0.610	ERR
Pier attack angle, degrees	10	10	0
K1, shape factor	0.9	0.9	0
K2, attack factor	1.88	1.88	ERR
K3, bed condition factor	1.1	1.1	0
D50, ft	0.3085	0.3085	0
D50, m	0.0940	0.0940	0
D90, ft	0.873	0.873	0
D90, m	0.266	0.266	0
Vc50,critical velocity(D50),m/s	3.444	3.459	N/A
Vc90,critical velocity(D90),m/s	4.870	4.892	N/A
Vi,incipient velocity,m/s	1.939	1.948	ERR
Vr, velocity ratio	0.590	0.542	ERR
K4, armor factor	0.92	0.90	N/A
ys, scour depth (K4 applicable) ft	16.19	15.66	ERR

Pier 2	Q100	Q500	Qother
Pier stationing, ft	69.1	69.1	0
Area of WSPRO flow tube, ft2	28.6	38.4	0
Skewed width of flow tube, ft	2.6	3.4	0
y1, pier approach depth, ft	11.00	11.29	ERR
y1 in meters	3.353	3.442	N/A
V1, pier approach velocity, ft/s	12.04	11.63	0
a, pier width, ft	4	4	0
L, pier length, ft	38.4	38.4	0
Fr1, Froude number at pier	0.640	0.610	ERR
Pier attack angle, degrees	0	0	0
K1, shape factor	0.9	0.9	0
K2, attack factor	1.00	1.00	ERR
K3, bed condition factor	1.1	1.1	0
D50, ft	0.3085	0.3085	0
D50, m	0.0940	0.0940	0
D90, ft	0.873	0.873	0
D90, m	0.266	0.266	0
Vc50,critical velocity(D50),m/s	3.444	3.459	N/A
Vc90,critical velocity(D90),m/s	4.870	4.892	N/A
Vi,incipient velocity,m/s	1.939	1.948	ERR
Vr, velocity ratio	0.590	0.542	ERR
K4, armor factor	0.92	0.90	N/A

ys, scour depth, (K4 applicable) ft 8.59 8.31 ERR

D50=0.692(K*V)^2/(Ss-1)*2*g
(Richardson and others, 1995, p.115, eq. 83)

Pier-shape coefficient (K), round nose, 1.5; square nose, 1.7
Characteristic avg. channel velocity, V, (Q/A):
(Mult. by 0.9 for bankward piers in a straight, uniform reach,
up to 1.7 for a pier in main current of flow around a bend)

Pier 1	Q100	Q500	Qother
K, pier shape coeff.	1.5	1.5	0
V, char. aver. velocity, ft/s	8.5	10.1	0
D50, median stone diameter, ft	1.06	1.49	0.00

Pier 2			
K, pier shape coeff.	1.5	1.5	0
V, char. aver. velocity, ft/s	8.5	10.1	0
D50, median stone diameter, ft	1.06	1.49	0.00