LEVEL II SCOUR ANALYSIS FOR BRIDGE 9 (LOWETH00020009) on TOWN HIGHWAY 2, crossing the EAST BRANCH MISSISQUOI RIVER, LOWELL, VERMONT

U.S. Geological Survey
Open-File Report 98-291

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 9 (LOWETH00020009) on TOWN HIGHWAY 2, crossing the EAST BRANCH MISSISQUOI RIVER, LOWELL, VERMONT

By ERICK M. BOEHMLER

U.S. Geological Survey
Open-File Report 98-291

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

Pembroke, New Hampshire

1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information
write to:

District Chief
U.S. Geological Survey
361 Commerce Way
Pembroke, NH 03275-3718

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
Open-File Reports Unit
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

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

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 9 (LOWETH00020009) ON TOWN HIGHWAY 2, CROSSING THE EAST BRANCH MISSISQUOI RIVER, LOWELL, VERMONT

By **Erick M. Boehmler**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure LOWETH00020009 on Town Highway 2 crossing the East Branch Missisquoi River, Lowell, 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 (FHWA, 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 Green Mountain section of the New England physiographic province in north-central Vermont. The 13.5-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover consists of shrubs and brushland, pasture, and forest.

In the study area, the East Branch Missisquoi River has a sinuous channel with a slope of approximately 0.005 ft/ft, an average channel top width of 46 ft and an average bank height of 4 ft. The predominant channel bed material is gravel with a median grain size (D_{50}) of 33.2 mm (0.109 ft). The geomorphic assessment at the time of the site visits on June 13 and June 15, 1995, indicated that the reach was laterally unstable. Cut-banks with slip and block failure of bank material, heavy bank erosion, and coincident point bars were evident in the reach near this site.

The Town Highway 2 crossing of the East Branch Missisquoi River is a 33-foot-long, two-lane bridge consisting of one 30-foot concrete T-beam span (Vermont Agency of Transportation, written communication, March 7, 1995). The opening length of the structure parallel to the bridge face is 29.6 feet. The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is zero degrees.

A scour hole 1 ft deeper than the mean thalweg depth was observed along the left abutment during the Level I assessment. There were no scour protection measures evident at the site. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995) for the 100- and 500-year discharges. In addition, the incipient roadway-overtopping discharge was determined and analyzed as another potential worst-case scour scenario. 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 1.9 to 3.2 feet. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 5.3 to 11.3 feet at the left abutment and from 13.3 to 15.6 feet at the right abutment. The worst-case abutment scour occurred at the 100-year discharge for the left abutment and at the 500-year discharge for the right abutment. 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.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

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 LOWETH00020009 ***Stream*** East Branch Missisquoi River

County Orleans ***Road*** TH 2 ***District*** 9

Description of Bridge

Bridge length 33 ***ft*** ***Bridge width*** 23.1 ***ft*** ***Max span length*** 30 ***ft***

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

Abutment type Vertical, concrete ***Embankment type*** None, left; Sloping, right

Stone fill on abutment? No ***Date of inspection*** 6/13/95

Description of stone fill There was no stone fill noted at the site.

Abutments and wingwalls are concrete. There is a one foot deep scour hole along the entire length of the left abutment and it's wingwalls.

Is bridge skewed to flood flow according to Yes ***survey?*** Yes ***Angle*** 10

There is a moderate channel bend in the upstream reach. The scour hole has developed in the location where the flow impacts the left abutment and wingwalls

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	6/13/95	0	0
Level II	6/15/95	0	0

Potential for debris High. There is significant coverage of vegetation on the channel banks and the channel is laterally unstable.

Describe any features near or at the bridge that may affect flow (include observation date) A large debris jam (perhaps a remnant beaver dam) was noted approximately 140 feet upstream of the site across the entire channel on 6/13/1995.

Description of the Geomorphic Setting

General topography The channel is located in a moderate relief valley setting with a narrow, irregular flood plain and steep to moderately sloping valley walls.

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

Date of inspection 6/13/95

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

DS right: Moderately sloping channel bank to a flood plain.

US left: Steep channel bank to a flood plain.

US right: Moderately sloping channel bank to a flood plain.

Description of the Channel

Average top width 46 ft ***Average depth*** 4 ft

Predominant bed material Gravel ***Bank material*** Sand / Gravel

Sinuous with alluvial channel boundaries and narrow point bars.

6/15/95

Vegetative co Trees, shrubs, and brush with short grass on the flood plain.

DS left: Shrubs and brush with a few trees.

DS right: Trees with some shrubs

US left: Shrubs and brush with a few trees.

US right:

Do banks appear stable? No

date of observation. There are cut banks and point bars noted in the reach at the time of the assessment on 6/13/95. Slip and block failure of the bank material was noted at the cut banks. Most trees on the immediate banks in the vicinity of cut banks, particularly in the upstream reach, were leaning over the channel.

Describe any obstructions in channel and date of observation. The assessment of 6/15/95 noted flow conditions, which overtop the left bank upstream, may be obstructed by piles of wood chips, sand and gravel, or other material stockpiled by the town in this location.

Hydrology

Drainage area 13.5 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province/section	***Percent of drainage area***
New England / Green Mountain	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***:

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

USGS gage description Missisquoi River near North Troy, VT

USGS gage number 04293000

Gage drainage area 131 ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 2,000 ***ft³/s*** ***Q500*** 2,770 ***ft³/s***

The 100- and 500-year discharges are based on discharge frequency curves computed by use of several empirical methods and extrapolated to the 500-year event. The discharges selected were central in the range defined by several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887).

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 Subtract 298.0 feet from the USGS arbitrary survey datum to obtain the VTAOT plans' datum to the nearest 0.5 feet.

Description of reference marks used to determine USGS datum. RM1 is a chiseled "X" on top of the left end of the concrete curb on the downstream side of the bridge (elev. 500.43 feet, arbitrary survey datum). RM2 is a chiseled "X" on top of the right end of the concrete curb on the upstream side of the bridge. (elev. 500.49 feet, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
EXITX	-26	1	Exit section
FULLV	0	5	Downstream Full-valley section (EXITX overbank points with BRIDG channel points)
BRIDG	0	1	Bridge section
RDWAY	13	1	Road Grade section
APPRO	53	1	Approach section

[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 0.040 to 0.055, and overbank "n" values ranged from 0.040 to 0.085.

Normal depth at the exit section (EXITX) 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 0.0053 ft/ft, which was estimated from surveyed thalweg points in the channel downstream of the bridge.

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

Bridge Hydraulics Summary

Average bridge embankment elevation 499.9 ***ft***
Average low steel elevation 497.1 ***ft***

100-year discharge 2,000 ***ft^3/s***
Water-surface elevation in bridge opening 497.2 ***ft***
Road overtopping? Yes ***Discharge over road*** 30 ***ft^3/s***
Area of flow in bridge opening 209 ***ft^2***
Average velocity in bridge opening 9.4 ***ft/s***
Maximum WSPRO tube velocity at bridge 11.5 ***ft/s***

Water-surface elevation at Approach section with bridge 499.6
Water-surface elevation at Approach section without bridge 495.0
Amount of backwater caused by bridge 4.6 ***ft***

500-year discharge 2,770 ***ft^3/s***
Water-surface elevation in bridge opening 497.2 ***ft***
Road overtopping? Yes ***Discharge over road*** 663 ***ft^3/s***
Area of flow in bridge opening 209 ***ft^2***
Average velocity in bridge opening 10.1 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.4 ***/s***

Water-surface elevation at Approach section with bridge 500.2
Water-surface elevation at Approach section without bridge 495.3
Amount of backwater caused by bridge 4.9 ***ft***

Incipient overtopping discharge 1,880 ***ft^3/s***
Water-surface elevation in bridge opening 497.2 ***ft***
Area of flow in bridge opening 209 ***ft^2***
Average velocity in bridge opening 9.0 ***ft/s***
Maximum WSPRO tube velocity at bridge 11.0 ***ft/s***

Water-surface elevation at Approach section with bridge 499.2
Water-surface elevation at Approach section without bridge 494.9
Amount of backwater caused by bridge 4.3 ***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 analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the scour depths are shown graphically in figure 8.

At this site, each discharge resulted in unsubmerged 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 was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). Results of this analysis are presented in figure 8 and tables 1 and 2.

Additional estimates of contraction scour also were computed by use of Laursen's clear-water scour equation and the Umbrell pressure-flow equation (Richardson and others, 1995, p. 144). Results from these computations are presented in appendix F. Furthermore, contraction scour was computed by substituting alternative estimates for the depth of flow at the downstream bridge face in the contraction scour equations. Results with respect to these substitutions also are provided in appendix F.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1995, p. 48, equation 28) for the left abutment. 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 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.

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	2.4	3.2	1.9
Depth to armoring	N/A	N/A	N/A
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	11.3	5.3	8.5
Right abutment	14.0	15.6	13.3
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:			
Left abutment	2.0	2.2	2.0
Right abutment	2.0	2.2	2.0
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

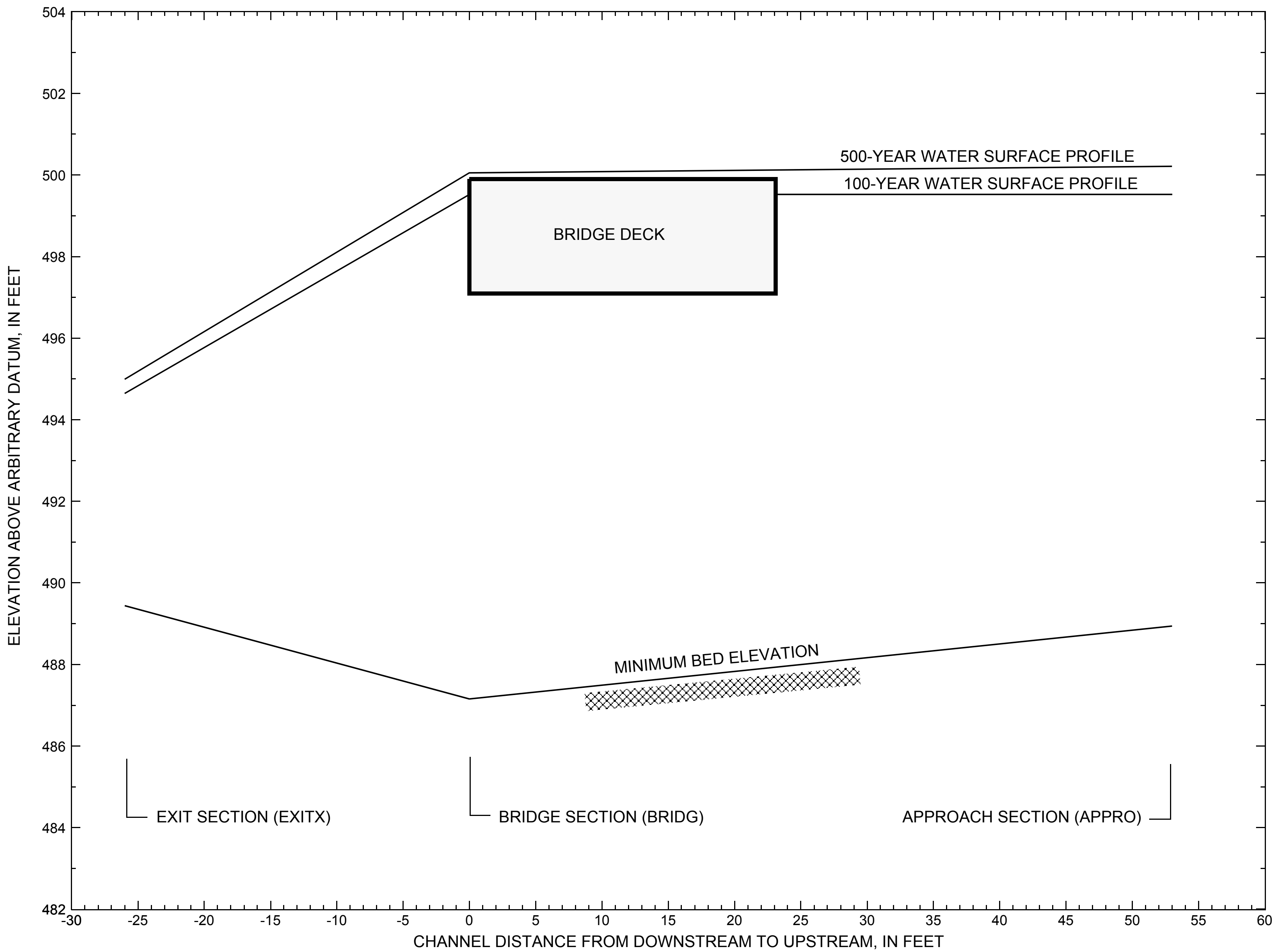


Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure LOWETH00020009 on Town Highway 2, crossing East Branch Missisquoi River, Lowell, Vermont.

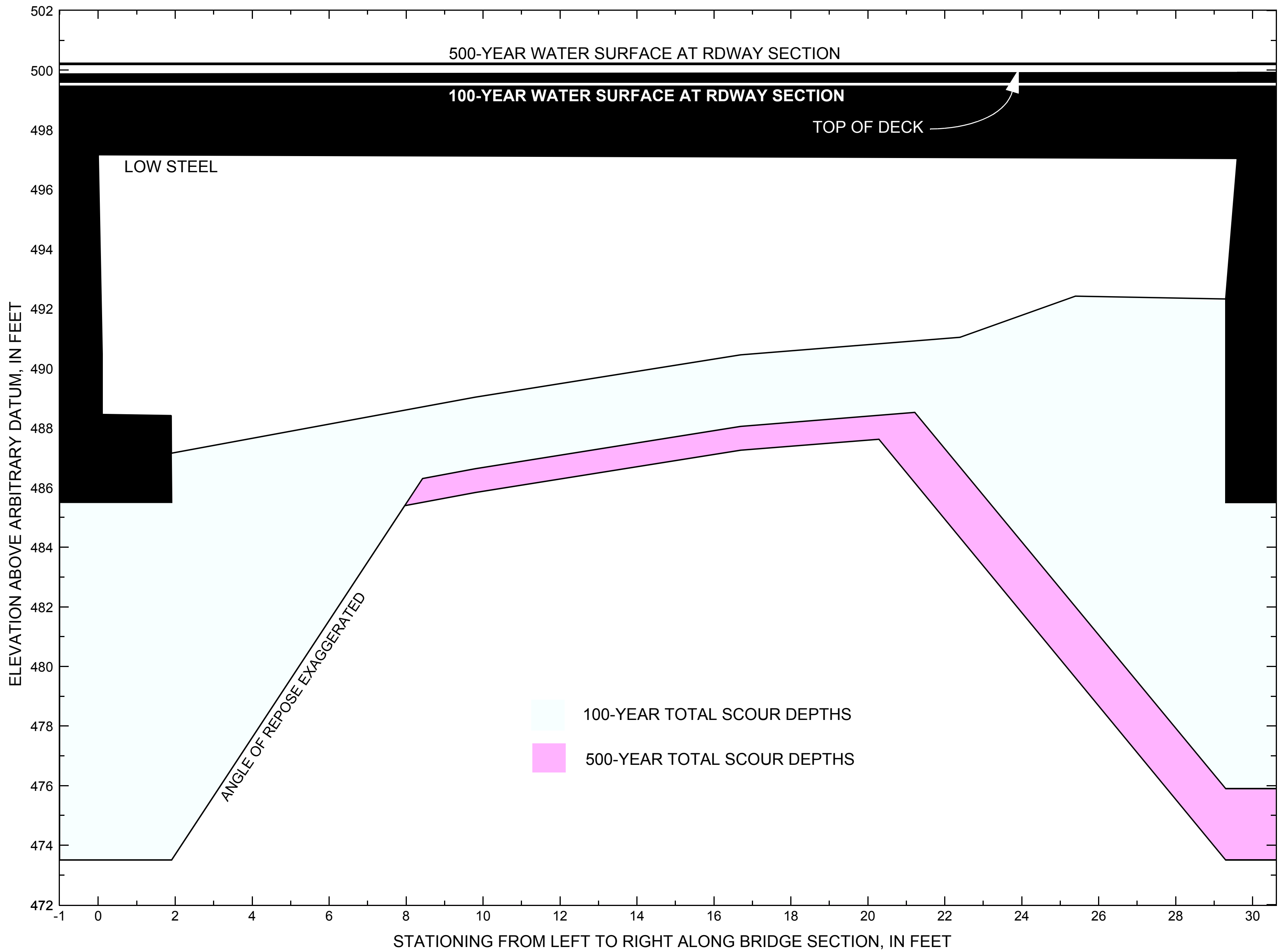


Figure 8. Scour elevations for the 100- and 500-year discharges at structure LOWETH00020009 on Town Highway 2, crossing East Branch Missisquoi River, Lowell, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure LOWETH00020009 on Town Highway 2, crossing East Branch Missisquoi River, Lowell, Vermont.
[VTAOT, Vermont Agency of Transportation; --,no data]

Description	Station[1]	VTAOT Bridge seat 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-year discharge is 2,000 cubic-feet per second											
Left abutment	0.0	198.8	497.2	485.5	487.2	2.4	11.3	--	13.7	473.5	-12.0
Right abutment	29.6	198.9	497.0	485.5	492.3	2.4	14.0	--	16.4	475.9	-9.6

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 LOWETH00020009 on Town Highway 2, crossing East Branch Missisquoi River, Lowell, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT Bridge seat 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-year discharge is 2,770 cubic-feet per second											
Left abutment	0.0	198.8	497.2	485.5	487.2	3.2	5.3	--	8.5	478.7	-6.8
Right abutment	29.6	198.9	497.0	485.5	492.3	3.2	15.6	--	18.8	473.5	-12.0

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

SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M. A., 1962, Factors Influencing the Occurrence of Floods in a Humid Region of Diverse Terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Brown, S.A. and Clyde, E.S., 1989, Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11, Publication FHWA-IP-89-016, 156 p.

Federal Highway Administration, 1983, Runoff estimates for small watersheds and development of sound design: Federal Highway Administration Report FHWA-RD-77-158.

Federal Highway Administration, 1993, Stream Stability and Scour at Highway Bridges: Participant Workbook: Federal Highway Administration Report FHWA-HI-91-011.

Froehlich, D.C., 1989, Local scour at bridge abutments *in* Ports, M.A., ed., Hydraulic Engineering--Proceedings of the 1989 National Conference on Hydraulic Engineering: New York, American Society of Civil Engineers, p. 13-18.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Johnson, C.G. and Tasker, G.D.,1974, Progress report on flood magnitude and frequency of Vermont streams: U.S. Geological Survey Open-File Report 74-130, 37 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream Stability at Highway Structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Laursen, E.M., 1960, Scour at bridge crossings: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 86, no. HY2, p. 39-53.

Potter, W. D., 1957a, Peak rates of runoff in the Adirondack, White Mountains, and Maine woods area, Bureau of Public Roads

Potter, W. D., 1957b, Peak rates of runoff in the New England Hill and Lowland area, Bureau of Public Roads

Richardson, E.V. and Davis, S.R., 1995, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process Geomorphology: W.C. Brown Co., Debuque, Iowa, 603 p.

Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

Talbot, A.N., 1887, The determination of water-way for bridges and culverts.

U.S. Geological Survey, 1986, Lowell, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photographs, 1981; Contour interval, 6 meters; Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File lowe009.wsp
T2        Hydraulic analysis for structure LOWETH00020009   Date: 14-APR-97
T3        Town Highway 2 over the East Branch Missisquoi River, Lowell, VT   EMB
*
J1         * * 0.005
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           2000.0   2770.0   1800.0
SK          0.0053   0.0053   0.0053
*
XS   EXITX    -26
GR         -218.9, 506.70   -213.9, 498.01   -191.4, 492.53   -165.2, 492.13
GR          -94.8, 493.46    -45.8, 494.16     -8.7, 494.64      0.0, 491.52
GR            4.8, 490.76      7.2, 490.47     15.2, 489.73     25.3, 489.44
GR           29.0, 490.43     29.7, 490.92     36.8, 494.34     48.1, 494.18
GR           67.1, 494.37     92.4, 493.67    338.8, 493.67    338.8, 499.29
*
N           0.040        0.045        0.085
SA                  -8.7         36.8
*
XS   FULLV      0
GR         -218.9, 506.70   -213.9, 498.01   -191.4, 492.53   -165.2, 492.13
GR          -94.8, 493.46    -45.8, 494.16     -8.7, 494.64      1.9, 487.15
GR            9.8, 489.03     16.7, 490.45     22.4, 491.04     25.4, 492.42
GR           29.3, 492.32     36.8, 494.34     48.1, 494.18     67.1, 494.37
GR           92.4, 493.67    338.8, 493.67    338.8, 499.29
*
N           0.040        0.045        0.080
SA                  -8.7         36.8
*
*             SRD     LSEL
BR   BRIDG     0    497.10
GR            0.0, 497.16      0.1, 490.48      0.1, 488.45      1.9, 488.41
GR            1.9, 487.15      9.8, 489.03     16.7, 490.45     22.4, 491.04
GR           25.4, 492.42     29.3, 492.32     29.6, 497.04      0.0, 497.16
*
*         BRTYPE  BRWDTH    EMBSS   EMBELV   WWANGL
CD          4      25.4      1.7     499.9     49.7
N           0.040
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     13      23.1     1
GR         -209.6, 508.00   -204.6, 499.20      0.0, 499.87      0.4, 501.29
GR           29.3, 501.29     29.7, 499.92     65.2, 499.80    121.3, 499.70
GR          321.3, 499.70    322.0, 508.00
*
*           For the incipient overtopping discharge model a vertical wall was
*           inserted at station -12.3 to prevent WSPRO from modeling flow on
*           the left overbank. The left bank point at station -12.3 is higher
*           and is assumed to block flow access to the left overbank.
*
AS   APPRO     53
GR         -133.7, 507.90   -128.7, 499.21    -27.6, 498.85    -12.3, 499.70
GR           -3.2, 493.91     -0.2, 491.70      0.0, 489.95      3.4, 488.94
GR           15.3, 489.55     18.8, 490.53     21.9, 491.08     28.6, 490.57
GR           33.6, 493.61     60.9, 495.01     67.0, 493.38     78.8, 494.35
GR           95.7, 493.60    111.5, 494.25    118.1, 493.30    124.4, 493.60
GR          324.4, 493.60    325.0, 499.25    325.0, 508.00
*
N           0.040        0.055        0.080
SA                 -12.3         33.6
*
HP 1 BRIDG 497.16 1 497.16
HP 2 BRIDG 497.16 * * 1964
HP 2 BRIDG 494.83 * * 1964
HP 2 RDWAY 499.52 * * 30
HP 1 APPRO 499.57 1 499.57
HP 2 APPRO 499.57 * * 2000
*
HP 1 BRIDG 497.16 1 497.16
HP 2 BRIDG 497.16 * * 2109
HP 2 BRIDG 495.16 * * 2109
HP 2 RDWAY 500.05 * * 663
HP 1 APPRO 500.21 1 500.21
HP 2 APPRO 500.21 * * 2770
*
```

```
HP 1 BRIDG 497.16 1 497.16
HP 2 BRIDG 497.16 * * 1880
HP 2 BRIDG 494.76 * * 1880
HP 1 APPRO 499.23 1 499.23
HP 2 APPRO 499.23 * * 1880
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

```
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

       WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
               1      209     15577     0     74                            0
     497.16           209     15577     0     74  1.00      0     30        0

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

          WSEL     LEW     REW    AREA        K        Q    VEL
        497.16     0.0    29.6   209.4   15577.    1964.   9.38

 X STA.        0.0        2.1        3.2        4.2        5.2        6.2
  A(I)            18.3       10.6        9.7        9.1        8.7
  V(I)            5.36       9.25      10.08      10.81      11.24

 X STA.        6.2        7.1        8.1        9.2       10.2       11.4
  A(I)             8.6        8.5        8.7        8.6        8.9
  V(I)           11.39      11.53      11.34      11.37      11.00

 X STA.       11.4       12.5       13.8       15.1       16.5       18.1
  A(I)             8.9        9.2        9.6        9.7       10.0
  V(I)           10.99      10.68      10.20      10.15       9.83

 X STA.       18.1       19.7       21.4       23.3       25.8       29.6
  A(I)            10.2       10.7       11.4       12.8       17.0
  V(I)            9.65       9.16       8.62       7.65       5.78

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

          WSEL     LEW     REW    AREA        K        Q    VEL
        494.83     0.0    29.5   142.4   12357.    1964.  13.79

 X STA.        0.0        2.2        3.2        4.2        5.0        5.9
  A(I)            13.9        7.7        6.8        6.1        5.9
  V(I)            7.07      12.70      14.53      16.20      16.51

 X STA.        5.9        6.7        7.6        8.5        9.5       10.5
  A(I)             5.7        5.6        5.7        5.6        5.7
  V(I)           17.31      17.59      17.38      17.53      17.10

 X STA.       10.5       11.5       12.6       13.8       15.1       16.6
  A(I)             5.8        5.9        6.2        6.4        6.5
  V(I)           16.94      16.57      15.94      15.43      15.05

 X STA.       16.6       18.2       19.9       21.8       24.4       29.5
  A(I)             7.0        7.0        7.7        8.8       12.4
  V(I)           13.95      14.00      12.70      11.16       7.92

     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      13.

          WSEL     LEW     REW    AREA        K        Q    VEL
        499.52  -204.8  -106.9    15.7     172.      30.   1.92

 X STA.     -204.8     -203.0     -201.3     -199.6     -197.8     -195.9
  A(I)             0.5        0.5        0.5        0.5        0.6
  V(I)            2.74       2.91       2.88       2.74       2.66

 X STA.     -195.9     -193.9     -191.8     -189.5     -187.1     -184.6
  A(I)             0.6        0.6        0.6        0.6        0.7
  V(I)            2.62       2.52       2.43       2.34       2.27

 X STA.     -184.6     -181.8     -178.7     -175.4     -171.7     -167.6
  A(I)             0.7        0.7        0.8        0.8        0.8
  V(I)            2.16       2.04       1.99       1.85       1.78

 X STA.     -167.6     -162.9     -157.3     -150.3     -140.3     -106.9
  A(I)             0.9        1.0        1.1        1.3        1.8
  V(I)            1.66       1.52       1.40       1.19       0.82

     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

       WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
               1       59      1425   114    114                          242
               2      361     36131    46     51                         5758
               3     1700    101284   291    297                        23303
     499.57          2120    138840   451    463  1.21   -128    325    23677

     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

          WSEL     LEW     REW    AREA        K        Q    VEL
        499.57  -128.9   325.0  2120.5  138840.    2000.   0.94

 X STA.     -128.9        3.2        9.5       15.4       22.2       29.2
  A(I)           139.1       65.5       60.5       61.9       61.6
  V(I)            0.72       1.53       1.65       1.61       1.62

 X STA.       29.2       46.0       70.0       91.5      112.3      131.3
  A(I)           101.6      124.6      119.3      118.2      113.4
  V(I)            0.98       0.80       0.84       0.85       0.88

 X STA.      131.3      150.2      169.1      188.3      207.3      226.1
  A(I)           112.9      112.9      114.3      113.4      112.8
  V(I)            0.89       0.89       0.88       0.88       0.89

 X STA.      226.1      245.3      264.6      283.6      302.3      325.0
  A(I)           114.3      115.0      113.7      111.7      133.8
  V(I)            0.87       0.87       0.88       0.90       0.75
```

WSPRO OUTPUT FILE (continued)

```
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      209     15577      0     74                            0
   497.16           209     15577      0     74  1.00      0     30        0

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

         WSEL     LEW     REW    AREA         K        Q    VEL
       497.16     0.0    29.6   209.4   15577.    2109.  10.07

 X STA.        0.0         2.1         3.2         4.2         5.2         6.2
  A(I)             18.3        10.6         9.7         9.1         8.7
  V(I)             5.75        9.93       10.83       11.61       12.07

 X STA.        6.2         7.1         8.1         9.2        10.2        11.4
  A(I)              8.6         8.5         8.7         8.6         8.9
  V(I)            12.23       12.38       12.18       12.21       11.82

 X STA.       11.4        12.5        13.8        15.1        16.5        18.1
  A(I)              8.9         9.2         9.6         9.7        10.0
  V(I)            11.81       11.47       10.95       10.90       10.55

 X STA.       18.1        19.7        21.4        23.3        25.8        29.6
  A(I)             10.2        10.7        11.4        12.8        17.0
  V(I)            10.37        9.83        9.26        8.22        6.21

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

         WSEL     LEW     REW    AREA         K        Q    VEL
       495.16     0.0    29.5   152.1   13644.    2109.  13.86

 X STA.        0.0         2.2         3.3         4.3         5.2         6.0
  A(I)             15.1         8.3         7.2         6.7         6.2
  V(I)             7.01       12.73       14.56       15.78       17.02

 X STA.        6.0         6.9         7.8         8.8         9.7        10.7
  A(I)              6.1         6.1         6.0         6.0         6.2
  V(I)            17.31       17.30       17.47       17.60       17.14

 X STA.       10.7        11.8        12.9        14.2        15.5        17.0
  A(I)              6.2         6.3         6.6         6.8         7.0
  V(I)            17.07       16.68       16.03       15.48       15.07

 X STA.       17.0        18.5        20.2        22.2        24.7        29.5
  A(I)              7.3         7.6         8.1         9.3        13.1
  V(I)            14.48       13.94       12.96       11.29        8.05

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      13.

         WSEL     LEW     REW    AREA         K        Q    VEL
       500.05  -205.1   321.3   199.2    3369.     663.   3.33

 X STA.     -205.1      -198.3      -192.0      -185.2      -178.1      -170.5
  A(I)              5.5         5.2         5.4         5.5         5.7
  V(I)             6.05        6.36        6.14        6.03        5.82

 X STA.     -170.5      -162.4      -153.7      -144.5      -134.0      -122.6
  A(I)              5.8         6.1         6.2         6.6         6.9
  V(I)             5.68        5.45        5.36        4.99        4.82

 X STA.     -122.6      -109.8       -94.8       -76.4       -52.3        -8.6
  A(I)              7.2         7.7         8.5         9.4        12.2
  V(I)             4.62        4.30        3.92        3.51        2.72

 X STA.       -8.6       112.6       164.2       217.3       269.3       321.3
  A(I)             22.3        18.0        18.6        18.2        18.2
  V(I)             1.49        1.85        1.78        1.82        1.82

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      134      5439    117    118                          813
             2      390     41030     46     51                         6461
             3     1887    120298    291    298                        27240
   500.21          2411    166766    454    467  1.19   -128    325    28865

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

         WSEL     LEW     REW    AREA         K        Q    VEL
       500.21  -129.3   325.0  2410.9  166766.    2770.   1.15

 X STA.     -129.3        -0.9         7.1        13.5        20.2        27.8
  A(I)            181.3        85.1        69.9        68.7        71.1
  V(I)             0.76        1.63        1.98        2.02        1.95

 X STA.       27.8        42.4        66.6        88.3       108.4       128.5
  A(I)            104.0       139.1       135.6       128.1       130.6
  V(I)             1.33        1.00        1.02        1.08        1.06

 X STA.      128.5       147.6       166.7       186.0       205.2       224.7
  A(I)            126.3       126.3       127.7       126.7       129.2
  V(I)             1.10        1.10        1.08        1.09        1.07

 X STA.      224.7       244.2       263.1       282.3       302.0       325.0
  A(I)            128.4       125.1       127.1       129.9       150.5
  V(I)             1.08        1.11        1.09        1.07        0.92
```

```
        U.S. Geological Survey WSPRO Input File lowe009.io.wsp
        Hydraulic analysis for structure LOWETH00020009   Date: 14-APR-97
        Town Highway 2 over the East Branch Missisquoi River, Lowell, VT   EMB
           *** RUN DATE & TIME: 06-20-97  10:50

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      209     15577      0     74                            0
   497.16           209     15577      0     74  1.00      0     30        0

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.16     0.0    29.6   209.4   15577.    1880.   8.98

X STA.        0.0        2.1        3.2        4.2        5.2        6.2
 A(I)            18.3       10.6        9.7        9.1        8.7
 V(I)            5.13       8.85       9.65      10.35      10.76

X STA.        6.2        7.1        8.1        9.2       10.2       11.4
 A(I)             8.6        8.5        8.7        8.6        8.9
 V(I)           10.91      11.03      10.85      10.89      10.53

X STA.       11.4       12.5       13.8       15.1       16.5       18.1
 A(I)             8.9        9.2        9.6        9.7       10.0
 V(I)           10.52      10.23       9.76       9.72       9.41

X STA.       18.1       19.7       21.4       23.3       25.8       29.6
 A(I)            10.2       10.7       11.4       12.8       17.0
 V(I)            9.24       8.76       8.25       7.32       5.53

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       494.76     0.0    29.5   140.3   12089.    1880.  13.40

X STA.        0.0        2.2        3.2        4.1        5.0        5.8
 A(I)            13.6        7.6        6.7        6.0        5.9
 V(I)            6.90      12.35      14.13      15.76      16.06

X STA.        5.8        6.7        7.6        8.5        9.4       10.4
 A(I)             5.6        5.5        5.6        5.5        5.6
 V(I)           16.84      17.11      16.91      17.06      16.65

X STA.       10.4       11.4       12.5       13.7       15.0       16.5
 A(I)             5.7        5.9        6.1        6.3        6.4
 V(I)           16.39      16.04      15.44      14.95      14.60

X STA.       16.5       18.1       19.8       21.8       24.4       29.5
 A(I)             6.9        6.9        7.6        8.9       12.1
 V(I)           13.56      13.61      12.36      10.58       7.76

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      346     33874     45     50                         5425
             2     1601     91710    291    297                        21296
   499.23          1947    125583    337    347  1.20    -11    325    24268

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      53.

         WSEL     LEW     REW    AREA        K        Q    VEL
       499.23   -11.6   325.0  1946.7  125583.    1880.   0.97

X STA.      -11.6        4.4       10.4       16.0       22.6       29.4
 A(I)            87.0       60.3       54.6       57.1       57.7
 V(I)            1.08       1.56       1.72       1.65       1.63

X STA.       29.4       46.3       70.7       92.3      113.1      132.1
 A(I)            95.9      119.2      112.0      111.0      107.4
 V(I)            0.98       0.79       0.84       0.85       0.88

X STA.      132.1      150.9      169.7      188.8      207.7      226.5
 A(I)           106.1      106.1      107.3      106.5      106.0
 V(I)            0.89       0.89       0.88       0.88       0.89

X STA.      226.5      245.6      264.8      283.8      303.1      325.0
 A(I)           107.4      108.0      106.8      109.1      121.4
 V(I)            0.88       0.87       0.88       0.86       0.77
```

```
        U.S. Geological Survey WSPRO Input File lowe009.wsp
        Hydraulic analysis for structure LOWETH00020009   Date: 14-APR-97
        Town Highway 2 over the East Branch Missisquoi River, Lowell, VT   EMB
           *** RUN DATE & TIME: 06-20-97  10:50

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

EXITX:XS   ******   -199      676  0.28 ***** 494.91  494.25    2000  494.64
       -25 ******    339    27450  2.02 ***** *******    0.66    2.96

FULLV:FV       26   -200      792  0.19  0.11  495.02 *******    2000  494.83
         0     26    339    34814  1.92  0.00    0.00    0.51    2.52
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  0.56

APPRO:AS       53     -4      535  0.48  0.31  495.47 *******    2000  494.99
        53     53    325    19407  2.22  0.15   -0.01    0.77    3.74
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.24      498.75      498.88      497.10

 ===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       26      0      209  1.37 ***** 498.53  495.16    1964  497.16
         0 ******     30    15577  1.00 ***** *******    0.62    9.38

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   5.  0.480  0.000  497.10 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG       13.    30.  0.01  0.02  499.58    0.00     30.  499.52

           Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    30.    97.  -205.  -108.   0.3   0.2   2.1   2.0   0.2   3.0
   RT:     0.   216.   105.   321.   0.0   0.0   1.6   5.2   0.1   2.9

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

APPRO:AS       28   -128     2120  0.02  0.10  499.59  494.82    2000  499.57
        53     53    325   138820  1.21  0.56    0.00    0.08    0.94

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.

    XSID:CODE     SRD    LEW    REW      Q        K      AREA     VEL    WSEL
   EXITX:XS      -26.  -200.   339.   2000.   27450.     676.    2.96  494.64
   FULLV:FV        0.  -201.   339.   2000.   34814.     792.    2.52  494.83
   BRIDG:BR        0.     0.    30.   1964.   15577.     209.    9.38  497.16
   RDWAY:RG       13.*******    30.     30.*********       0.    1.00  499.52
   APPRO:AS       53.  -129.   325.   2000.  138820.    2120.    0.94  499.57

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS   ***********************

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXITX:XS    494.25    0.66  489.44  506.70************  0.28  494.91  494.64
   FULLV:FV   ********   0.51  487.15  506.70  0.11  0.00  0.19  495.02  494.83
   BRIDG:BR    495.16    0.62  487.15  497.16************  1.37  498.53  497.16
   RDWAY:RG   ****************  499.20  508.00  0.01******  0.02  499.58  499.52
   APPRO:AS    494.82    0.08  488.94  508.00  0.10  0.56  0.02  499.59  499.57
```

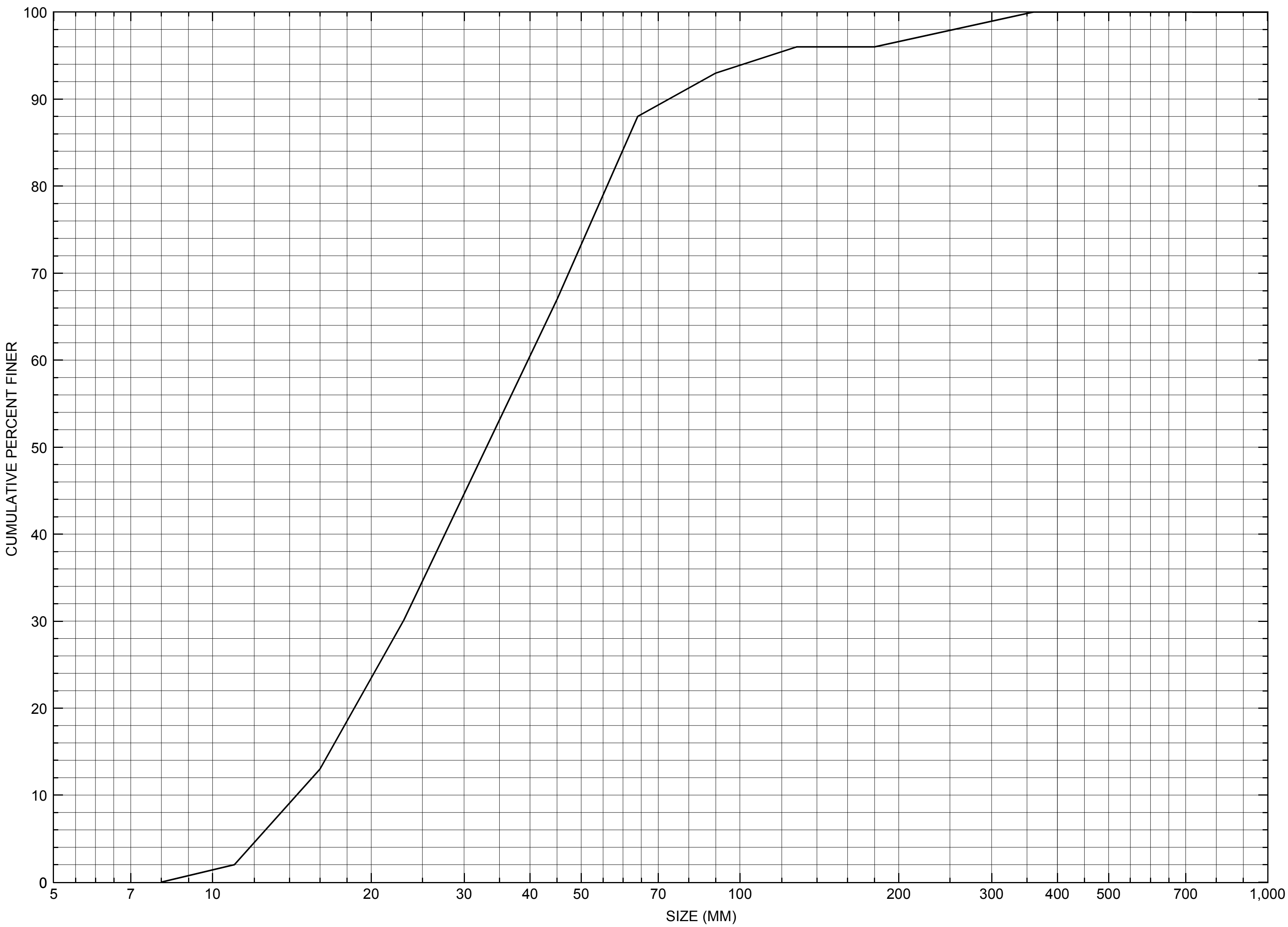
```
        U.S. Geological Survey WSPRO Input File lowe009.wsp
        Hydraulic analysis for structure LOWETH00020009   Date: 14-APR-97
        Town Highway 2 over the East Branch Missisquoi River, Lowell, VT   EMB
           *** RUN DATE & TIME: 06-20-97  10:50

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

EXITX:XS   ******   -200      865  0.30 *****  495.29  494.60    2770  494.99
       -25 ******    339    38048  1.88 ***** *******    0.61    3.20

FULLV:FV       26   -201      968  0.23  0.11  495.38 *******    2770  495.16
         0     26    339    45676  1.79  0.00   -0.02    0.50    2.86
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  0.54

APPRO:AS       53     -4      650  0.57  0.36  495.91 *******    2770  495.34
        53     53    325    24824  2.00  0.17    0.00    0.76    4.26
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   500.87       0.00     496.50     499.20

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.95     499.85     500.00     497.10

 ===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       26      0      209  1.58 *****  498.74  495.42    2109  497.16
         0 ******     30    15577  1.00 ***** *******    0.67   10.07

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   5.  0.491  0.000  497.10 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       13.    30.  0.01  0.02  500.22    0.00    663.  500.05

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   355.   205.  -205.     0.   0.9   0.5   3.8   3.3   0.7   3.0
   RT:   308.   292.    30.   321.   0.4   0.3   3.2   3.3   0.5   3.0

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

APPRO:AS       28   -128     2410  0.02  0.13  500.23  495.18    2770  500.21
        53     56    325   166684  1.19  0.52    0.00    0.10    1.15

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.

    XSID:CODE     SRD    LEW    REW       Q        K      AREA     VEL   WSEL
   EXITX:XS      -26.  -201.   339.   2770.   38048.     865.    3.20  494.99
   FULLV:FV        0.  -202.   339.   2770.   45676.     968.    2.86  495.16
   BRIDG:BR        0.     0.    30.   2109.   15577.     209.   10.07  497.16
   RDWAY:RG       13.*******   355.    663.*********       0.    1.00  500.05
   APPRO:AS       53.  -129.   325.   2770.  166684.    2410.    1.15  500.21

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXITX:XS    494.60    0.61  489.44  506.70************  0.30  495.29  494.99
   FULLV:FV  ********    0.50  487.15  506.70  0.11  0.00  0.23  495.38  495.16
   BRIDG:BR    495.42    0.67  487.15  497.16************  1.58  498.74  497.16
   RDWAY:RG  ****************  499.20  508.00  0.01******  0.02  500.22  500.05
   APPRO:AS    495.18    0.10  488.94  508.00  0.13  0.52  0.02  500.23  500.21
  ER
```

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File lowe009.io.wsp
        Hydraulic analysis for structure LOWETH00020009   Date: 14-APR-97
        Town Highway 2 over the East Branch Missisquoi River, Lowell, VT   EMB
           *** RUN DATE & TIME: 06-20-97  10:50

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

EXITX:XS   ******   -199      639  0.27 *****  494.84  494.20    1880  494.57
       -25 ******    339    25811  2.04 ***** *******    0.68    2.94

FULLV:FV       26   -200      756  0.19  0.11  494.95 *******    1880  494.76
         0     26    339    32742  1.95  0.00    0.00    0.52    2.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.56

APPRO:AS       53     -4      513  0.47  0.31  495.40 *******    1880  494.92
        53     53    325    18467  2.26  0.14   -0.01    0.78    3.66
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.02     498.42     498.56     497.10

 ===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       26      0      209  1.25 *****  498.41  495.01    1874  497.16
         0 ******     30    15577  1.00 ***** *******    0.59    8.95

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   5.  0.472  0.000  497.10 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      13.    30.  0.01  0.02  499.24    0.00      0.  499.23

           Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    0.     9.  -205.  -196.   0.0   0.0   0.7   0.8   0.0   2.9
   RT:    0.   216.   105.   321.   0.0   0.0   1.6   5.2   0.1   2.9

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

APPRO:AS       28    -11     1946  0.02  0.09  499.25  494.76    1880  499.23
        53     52    325   125547  1.20  0.57    0.00    0.08    0.97

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.

    XSID:CODE     SRD    LEW    REW       Q         K      AREA      VEL    WSEL
   EXITX:XS      -26.  -200.   339.   1880.    25811.      639.     2.94  494.57
   FULLV:FV        0.  -201.   339.   1880.    32742.      756.     2.49  494.76
   BRIDG:BR        0.     0.    30.   1874.    15577.      209.     8.95  497.16
   RDWAY:RG       13.*******     0.      0.*********        0.     1.00  499.23
   APPRO:AS       53.   -12.   325.   1880.   125547.     1946.     0.97  499.23

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX     HF    HO   VHD      EGL    WSEL
   EXITX:XS    494.20    0.68  489.44  506.70************  0.27  494.84  494.57
   FULLV:FV  ********    0.52  487.15  506.70  0.11  0.00  0.19  494.95  494.76
   BRIDG:BR    495.01    0.59  487.15  497.16************  1.25  498.41  497.16
   RDWAY:RG  ****************  499.20  508.00  0.01******  0.02  499.24  499.23
   APPRO:AS    494.76    0.08  488.94  508.00  0.09  0.57  0.02  499.25  499.23
  ER

 NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure LOWETH00020009, in Lowell, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number LOWETH00020009

General Location Descriptive

Data collected by (First Initial, Full last name) L. MEDALIE

Date (MM/DD/YY) 03 / 07 / 95

Highway District Number (I - 2; nn) 09

County (FIPS county code; I - 3; nnn) 019

Town (FIPS place code; I - 4; nnnnn) 40525

Mile marker (I - 11; nnn.nnn) 000000

Waterway (I - 6) East Branch Missisquoi River

Road Name (I - 7): -

Route Number TH002

Vicinity (I - 9) 0.05 MI TO JCT W VT100

Topographic Map Lowell

Hydrologic Unit Code: 02010007

Latitude (I - 16; nnnn.n) 44478

Longitude (i - 17; nnnnn.n) 72270

Select Federal Inventory Codes

FHWA Structure Number (I - 8) 10101300091013

Maintenance responsibility (I - 21; nn) 03

Maximum span length (I - 48; nnnn) 0030

Year built (I - 27; YYYY) 1952

Structure length (I - 49; nnnnnn) 000033

Average daily traffic, ADT (I - 29; nnnnnn) 000250

Deck Width (I - 52; nn.n) 231

Year of ADT (I - 30; YY) 94

Channel & Protection (I - 61; n) 5

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

Waterway adequacy (I - 71; n) 7

Operational status (I - 41; X) A

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

Structure type (I - 43; nnn) 104

Year Reconstructed (I - 106) 0000

Approach span structure type (I - 44; nnn) 000

Clear span (nnn.n ft) 30.0

Number of spans (I - 45; nnn) 001

Vertical clearance from streambed (nnn.n ft) 7.5

Number of approach spans (I - 46; nnnn) 0000

Waterway of full opening (nnn.n ft^2) 225.0

Comments:

The structural inspection report of 6/1/93 indicates the structure is a concrete T-beam type bridge. The concrete along the top of each upstream wingwall reportedly has spalled. The front faces of the upstream wingwalls have numerous cracks with leakage noted. The entire length of the left abutment footing is exposed. The streambed is between 1 and 1.5 feet below the top of the footing with no apparent undermining. The waterway makes a sharp turn into the structure. The resulting impact of the flow is mainly on the left abutment. There is a 3 foot high silt and sand point bar that extends along the right abutment with some vegetation growing on it. The streambed consists of sand and gravel, **(Continued, page 34)**

Bridge Hydrologic Data

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

Terrain character: -

Stream character & type: -

Streambed material: **Sand and gravel, some random stones**

Discharge Data *(cfs)*: $Q_{2.33}$ - Q_{10} - Q_{25} -

Q_{50} - Q_{100} - 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*): -%

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*)	-	-	-	-	-
Velocity (*ft / sec*)	-	-	-	-	-

Long term stream bed changes: -

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

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

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

Upstream distance (*miles*): - Town: - Year Built: -

Highway No. : - Structure No. : - Structure Type: -

Clear span (*ft*): - Clear Height (*ft*): - Full Waterway (*ft^2*): -

Downstream distance (*miles*): - Town: - Year Built: -

Highway No. : - Structure No. : - Structure Type: -

Clear span (*ft*): - Clear Height (*ft*): - Full Waterway (ft^2): -

Comments:

with some small cobbles. Some minor bank erosion is noted at the up- and downstream ends of the left abutment. Not much stone fill protection is present. The bridge opening is constricted somewhat by the point bar under the bridge.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **13.50** mi^2 Lake and pond area **0.01** mi^2

Watershed storage *(ST)* **0.1** %

Bridge site elevation **908** ft   Headwater elevation **2618** ft

Main channel length **5.76** mi

10% channel length elevation **925** ft   85% channel length elevation **1437** ft

Main channel slope *(S)* **118.45** ft / mi

Watershed Precipitation Data

Average site precipitation - in   Average headwater precipitation - in

Maximum 2yr-24hr precipitation event *(I24,2)* **2.23** in

Average seasonal snowfall *(Sn)* **8.33** ft

Bridge Plan Data

Are plans available? Y *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: - / 1953

Project Number SA 38 1952 Minimum channel bed elevation: 190.5

Low superstructure elevation: USLAB 198.8 DSLAB 198.8 USRAB 198.9 DSRAB 198.9

Benchmark location description:

BM #1 - Spike in trunk of a 24 inch elm tree, located about 180 feet right bankward of bridge on left bank of a side brook, elevation 200.00.

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: 165.0

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? N *If no, type ctrl-n bi* Number of borings taken: -

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

Briefly describe material at foundation bottom elevation or around piles:

-

Comments:

The streambed material was graded under the bridge such that the bed elevation was between 1 and 3 feet above the top of both abutment footings. The streambed is higher over the right abutment footing than the left.

Cross-sectional Data

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

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

Comments: **Upstream bridge cross section at stationing 0 + 80, nearest the upstream bridge face. The channel baseline runs along the left bank 1 foot from the streamward left abutment face.**

Station	1.0	1.5	3.0	7.0	10.5	29.0	30.6	31.0			
Feature	LCL	BLB	footing edge			footing edge	BRB	LCR			
Low cord elevation	199.5		t189.5			t189.5		199.5			
Bed elevation		191.5	b187.5	190.5	191.0	b187.5	191.0				
Low cord to bed length											

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

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

Comments: **Downstream bridge cross section at stationing 0 + 70, most representable for the downstream bridge face.**

Station	1.0	1.5	3.0	10.5	29.0	30.6	31.0				
Feature	LCL	BLB	footing edge		footing edge	BRB	LCR				
Low cord elevation	199.5		t189.5		t189.5		199.5				
Bed elevation		190.5	b187.5	190.5	b187.5	190.5					
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: **RB** Date: **4/8/96**
Computerized by: **RB** Date: **4/12/96**
Reviewd by: **EMB** Date: **5/12/97**

Structure Number **LOWETH00020009**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **E**. **BOEHMLER** Date *(MM/DD/YY)* **6** / **13** / 19**95**
2. Highway District Number **09** Mile marker **000**
County **ORLEANS (019)** Town **LOWELL (40525)**
Waterway *(I - 6)* **East Branch Missisquoi River** Road Name **-**
Route Number **TH 2** Hydrologic Unit Code: **02010007**
3. Descriptive comments:
The bridge is located about 0.05 miles west of the intersection of TH 2 with VT Route 100.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **5** LBDS **4** RBDS **5** Overall **5**
*(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 **1** *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*
7. Bridge length **33** *(feet)* Span length **30** *(feet)* Bridge width **23.1** *(feet)*

Road approach to bridge:

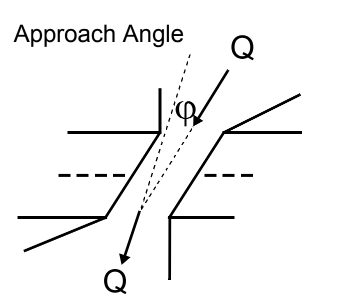
8. LB **0** RB **0** *(**0** even, **1**- lower, **2**- higher)*
9. LB **1** RB **1** *(**1**- Paved, **2**- Not paved)*
10. Embankment slope (*run / rise in feet / foot*):
US left **1.5:1** US right **2.0:1**

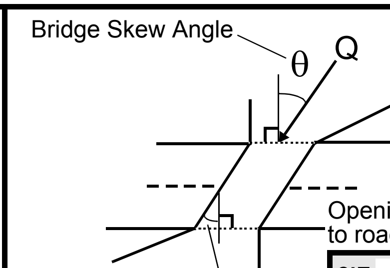
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	0	-	2	1
RBUS	0	-	0	0
RBDS	0	-	0	0
LBDS	0	-	2	2

*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: **30** 16. Bridge skew: **10**





α= **0.0**

17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **2**
Range? **2** feet **US** *(US, UB, DS)* to **40** feet **US**
Channel impact zone 2: Exist? **Y** *(Y or N)*
Where? **RB** *(LB, RB)* Severity **1**
Range? **35** feet **DS** *(US, UB, DS)* to **75** feet **DS**

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

18. Bridge Type: **4**

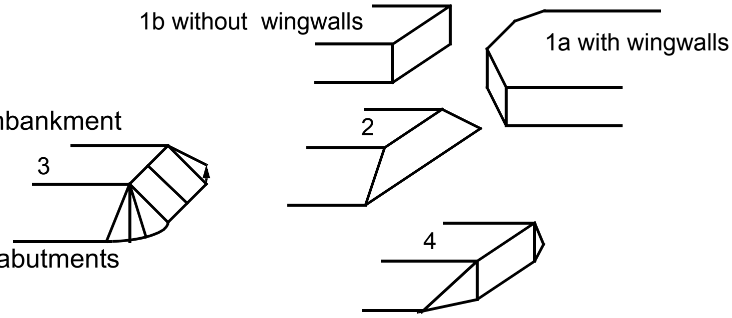
1a- Vertical abutments with wingwalls

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.)

The bridge dimensions measured were the same as the VTOAT values shown on the previous page.
The US left bank surface cover is mainly trees on the bank and a gravel parking lot on the overbank. The US right overbank is a low-lying area with mostly shrubs and a few trees. The right overbank DS is occupied mostly by shrubs with a few trees. The downstream left overbank surface cover consists of pasture with a few trees and shrubs on the immediate bank.

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
28.5	**8.0**			**3.0**	**3**	**2**	**231**	**231**	**2**	**1**

23. Bank width **35.0** 24. Channel width **30.0** 25. Thalweg depth **46.0** 29. Bed Material **342**

30 .Bank protection type: LB **0** RB **0** 31. Bank protection condition: LB **-** RB **-**

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 bed material is mainly medium to coarse gravel with some medium to coarse sand and a few cobbles.
The bank material is mainly medium sand with some fine gravel.
There is a zone of channel transition where the US end of the point bar is eroding.
A large debris jam, composed of whole trees and lots of branches, spans the entire channel about 140 feet US. One fallen tree forms the backbone of the debris jam. It fell from the right bank to the left bank where the top of the tree is braced by a live tree and prevents it from dislodging. Other trees and branches have accumulated on the braced tree during recent flood events. The debris jam blocks the entire channel such that the flow deflected under the jam has eroded the stream bed about 2 feet below the ambient depth of the channel.

33. Point/Side bar present? Y (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: 50 35. Mid-bar width: 15

36. Point bar extent: 72 feet US (US, UB) to 2 feet DS (US, UB, DS) positioned 60 %LB to 100 %RB

37. Material: 342

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

The point bar material at the upstream end is coarse gravel and cobbles. The material size grades finer to fine gravel and sand from 30 feet upstream to the upstream bridge face and medium to fine sand and silt along the right abutment.

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

41. Mid-bank distance: 45 42. Cut bank extent: 115 feet US (US, UB) to 20 feet US (US, UB, DS)

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

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

Most of the trees and shrubs on the bank are leaning at an angle greater than 45 degrees from vertical toward the channel. The cut bank is evident particularly in the range of 72 feet US to 20 feet US.

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

Some channel scour is evident under the debris jam about 140 feet upstream.

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 2 RB (**1**- natural bank; **2**- abutment; **3**- artificial levee)

56. Height (BF)		57 Angle (BF)		61. Material (BF)		62. Erosion (BF)	
LB	RB	LB	RB	LB	RB	LB	RB
28.5		1.5		2	7	7	-

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

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.):

324

The bed material is medium to coarse gravel and sand with some cobbles. The bed material grades coarser from right to left under the bridge. The point bar, along the right abutment, is silt and fine sand.

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

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

2

The capture efficiency is moderate because the left abutment protrudes and there is a point bar on the right abutment. Also the water is pooled under the bridge and the velocity is low. The debris potential is high because there are many trees on unstable banks and some sticks and branches are present on the point bar. Ice may also accumulate on the point bar. About 30 feet US there is a small debris pile.

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	2	2	1	1	90.0
RABUT	1	-	90			0	0	29.5

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

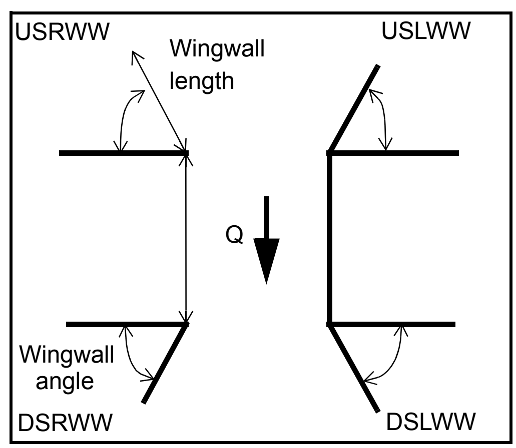
0

1

The entire length of the left abutment footing is exposed from 1.5 feet at the upstream end to 0.5 feet at the downstream end.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						29.5	
USRWW:	Y		1		2	3.5	
DSLWW:	1		0.5		Y	25.5	
DSRWW:	1		0		-	25.0	



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	-	2	Y	-	-	-	-	-
Condition	Y	1	1	-	-	-	-	-
Extent	1	0.5	0	0	0	0	0	-

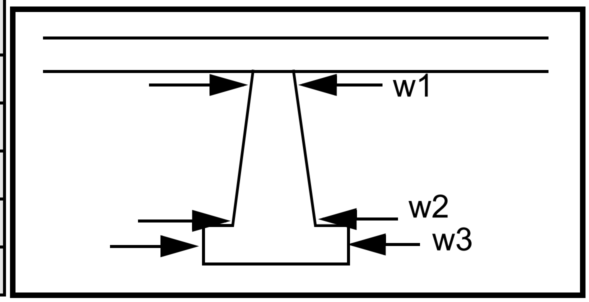
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
-
-
-
-
-
0
-
-
0
-
-

Piers:

84. Are there piers? **Th** (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				**50.0**	**13.5**	**45.0**
Pier 2				**14.0**	**45.0**	**11.0**
Pier 3			-	**50.0**	**11.0**	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	**ere is**	**any of**		-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	**very**	**the**		-	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	**little**	**wing**		-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	**pro-**	**walls**	**N**	-	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	**tec-**	**.**	-	-	*Y- yes; N- no*
91. Attack ∠ (BF)	**tion**		-	-	
92. Pushed	**unde**		-	-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	**r the**		-	-	
95. Cross-members	**brid**		-	-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	**ge or**		-	-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	**alon**		-	-	
98. Exposure depth	**g**		-	-	

99. Pier comments (eg. undermined penetration, protection and protection extent, unusual scour processes, etc.):
-
-
-
-
-
-
-
-
-
-

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
-	-			-	-	-	-	-	-	-

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

Bank protection type (Qmax): LB - RB - Bank protection condition: LB - RB -

*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.):
-
-
-
-
-
-
-
NO PIERS

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):
1
1
231
231
0
2

106. Point/Side bar present? 34 (Y or N. if N type ctrl-n pb) Mid-bar distance: 2 Mid-bar width: 0

Point bar extent: 0 feet - (US, UB, DS) to - feet Th (US, UB, DS) positioned e %LB to DS %RB

Material: rea

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

ch makes a slight bend to the left at the downstream point bar. The right bank is cut by stream erosion, which is greatest near the point bar.

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

Cut bank extent: _____ feet ____ (US, UB, DS) to _____ feet ____ (US, UB, DS)

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

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

N

Is channel scour present? - (Y or if N type ctrl-n cs) Mid-scour distance: NO

Scour dimensions: Length DRO Width P Depth: STR Positioned UC %LB to TU %RB

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

RE

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

Confluence 1: Distance Y Enters on 48 (LB or RB) Type 14 (**1**- perennial; **2**- ephemeral)

Confluence 2: Distance 36 Enters on DS (LB or RB) Type 80 (**1**- perennial; **2**- ephemeral)

Confluence comments (eg. confluence name):

DS
0

F. Geomorphic Channel Assessment

107. Stage of reach evolution 50

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)*:

342

The point bar is composed of medium to coarse gravel with some cobbles and coarse sand. The bar is not vegetated except along the immediate left bank edge.

Y
RB
55
34
DS
145
DS
3

109. G. Plan View Sketch

- T

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

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: LOWETH00020009 Town: Lowell
Road Number: TH 2 County: Orleans
Stream: East Branch Missisquoi River

Initials EMB Date: 5/12/97 Checked: RF 6/18/97

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	2000	2770	1880
Main Channel Area, ft2	361	390	346
Left overbank area, ft2	59	134	0
Right overbank area, ft2	1700	1887	1601
Top width main channel, ft	46	46	45
Top width L overbank, ft	114	117	0
Top width R overbank, ft	291	291	291
D50 of channel, ft	0.109	0.109	0.109
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	7.8	8.5	7.7
y1, average depth, LOB, ft	0.5	1.1	ERR
y1, average depth, ROB, ft	5.8	6.5	5.5
Total conveyance, approach	138840	166766	125583
Conveyance, main channel	36131	41030	33874
Conveyance, LOB	1425	5439	0
Conveyance, ROB	101284	120298	91710
Percent discrepancy, conveyance	0.0000	-0.0006	-0.0008
Qm, discharge, MC, cfs	520.5	681.5	507.1
Ql, discharge, LOB, cfs	20.5	90.3	0.0
Qr, discharge, ROB, cfs	1459.0	1998.2	1372.9
Vm, mean velocity MC, ft/s	1.4	1.7	1.5
Vl, mean velocity, LOB, ft/s	0.3	0.7	ERR
Vr, mean velocity, ROB, ft/s	0.9	1.1	0.9
Vc-m, crit. velocity, MC, ft/s	7.5	7.6	7.5
Vc-l, crit. velocity, LOB, ft/s	ERR	ERR	ERR
Vc-r, crit. velocity, ROB, ft/s	ERR	ERR	ERR

Results

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

Main Channel	0	0	0

Armoring
Dc=[(1.94*V^2)/(5.75*log(12.27*y/D90))^2]/[0.03*(165-62.4)]
Depth to Armoring=3*(1/Pc-1)

(Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	1964	2109	1880
Main channel area (DS), ft2	142.4	152.1	140.3
Main channel width (normal), ft	29.6	29.6	29.6
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	29.6	29.6	29.6
D90, ft	0.2407	0.2407	0.2407
D95, ft	0.3734	0.3734	0.3734
Dc, critical grain size, ft	0.6351	0.6268	0.6027
Pc, Decimal percent coarser than Dc	0.035	0.036	0.039
Depth to armoring, ft	N/A	N/A	N/A

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)

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	2000	2770	1880
(Q) discharge thru bridge, cfs	1964	2109	1880
Main channel conveyance	15577	15577	15577
Total conveyance	15577	15577	15577
Q2, bridge MC discharge,cfs	1964	2109	1880
Main channel area, ft2	209	209	209
Main channel width (normal), ft	29.6	29.6	29.6
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	29.6	29.6	29.6
y_bridge (avg. depth at br.), ft	7.07	7.07	7.07
Dm, median (1.25*D50), ft	0.13625	0.13625	0.13625
y2, depth in contraction,ft	7.97	8.47	7.68
ys, scour depth (y2-ybridge), ft	0.90	1.40	0.60

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation   Hb+Ys=Cq*qbr/Vc
Cq=1/Cf*Cc   Cf=1.5*Fr^0.43 (<=1)   Cc=SQRT[0.10(Hb/(ya-w)-0.56)]+0.79 (<=1)
Umbrell pressure flow equation
(Hb+Ys)/ya=1.1021*[(1-w/ya)*(Va/Vc)]^0.6031
(Richardson and other, 1995, p. 144-146)

	Q100	Q500	OtherQ
Q, total, cfs	2000	2770	1880
Q, thru bridge MC, cfs	1964	2109	1880
Vc, critical velocity, ft/s	7.55	7.65	7.52
Va, velocity MC approach, ft/s	1.44	1.75	1.47
Main channel width (normal), ft	29.6	29.6	29.6
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	29.6	29.6	29.6
qbr, unit discharge, ft2/s	66.4	71.3	63.5
Area of full opening, ft2	209.4	209.4	209.4
Hb, depth of full opening, ft	7.07	7.07	7.07
Fr, Froude number, bridge MC	0.62	0.67	0.59
Cf, Fr correction factor (<=1.0)	1.00	1.00	1.00
**Area at downstream face, ft2	142.4	152.1	140.3
**Hb, depth at downstream face, ft	4.81	5.14	4.74
**Fr, Froude number at DS face	1.11	1.08	1.08
**Cf, for downstream face (<=1.0)	1.00	1.00	1.00
Elevation of Low Steel, ft	497.1	497.1	497.1
Elevation of Bed, ft	490.03	490.03	490.03
Elevation of Approach, ft	499.57	500.21	499.23
Friction loss, approach, ft	0.1	0.13	0.09
Elevation of WS immediately US, ft	499.47	500.08	499.14
ya, depth immediately US, ft	9.44	10.05	9.11
Mean elevation of deck, ft	501.29	501.29	501.29
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	0.93	0.91	0.94
**Cc, for downstream face (<=1.0)	0.93	0.91	0.94
Ys, scour w/Chang equation, ft	2.40	3.17	1.94
Ys, scour w/Umbrell equation, ft	-3.24	-2.52	-3.33

**=for UNsubmerged orifice flow using estimated downstream bridge face properties.

**Ys, scour w/Chang equation, ft	4.64	5.10	4.24
**Ys, scour w/Umbrell equation, ft	-0.98	-0.59	-0.99

In UNsubmerged orifice flow, an adjusted scour depth using the Laursen equation results and the estimated downstream bridge face properties can also be computed (ys=y2-ybridgeDS)

y2, from Laursen's equation, ft	7.97	8.47	7.68
WSEL at downstream face, ft	494.83	495.16	494.76
Depth at downstream face, ft	4.81	5.14	4.74
Ys, depth of scour (Laursen), ft	3.16	3.33	2.94

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)

Characteristic	Left Abutment 100 yr Q	500 yr Q	Other Q	Right Abutment 100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	2000	2770	1880	2000	2770	1880
a', abut.length blocking flow, ft	12.1	129.3	11.6	295.4	295.4	295.4
Ae, area of blocked flow ft2	82.5	139.7	63.1	1729.5	1828.6	1629.1
Qe, discharge blocked abut.,cfs	--	--	68.2	1497.6	--	1408.9
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	0.72	0.81	1.08	0.87	1.07	0.86
ya, depth of f/p flow, ft	6.82	1.08	5.44	5.85	6.19	5.51
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)						
K1	0.82	0.82	0.82	0.82	0.82	0.82
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00
Fr, froude number f/p flow	0.123	0.117	0.082	0.063	0.074	0.065
ys, scour depth, ft	11.34	5.33	8.48	16.76	18.60	16.24

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)	12.1	129.3	11.6	295.4	295.4	295.4
y1 (depth f/p flow, ft)	6.82	1.08	5.44	5.85	6.19	5.51
a'/y1	1.77	119.67	2.13	50.45	47.72	53.56
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.12	0.12	0.08	0.06	0.07	0.06
Ys w/ corr. factor K1/0.55:						
vertical	ERR	3.87	ERR	17.11	19.07	16.27
vertical w/ ww's	ERR	3.17	ERR	14.03	15.63	13.34
spill-through	ERR	2.13	ERR	9.41	10.49	8.95

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)

Downstream bridge face property	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	1	1	1	1	1	1
y, depth of flow in bridge, ft	4.81	5.14	4.74	4.81	5.14	4.74
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	ERR	ERR	ERR	ERR	ERR
Fr>0.8 (vertical abut.)	2.01	2.15	1.98	2.01	2.15	1.98