LEVEL II SCOUR ANALYSIS FOR BRIDGE 99 (LUDLVT01000099) on STATE HIGHWAY 100, crossing BRANCH BROOK, LUDLOW, VERMONT

U.S. Geological Survey
Open-File Report 96-572

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 99 (LUDLVT01000099) on STATE HIGHWAY 100, crossing BRANCH BROOK, LUDLOW, VERMONT

By SCOTT A. OLSON

U.S. Geological Survey
Open-File Report 96-572

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, 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	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 99 (LUDLVT01000099) ON STATE HIGHWAY 100, CROSSING BRANCH BROOK, LUDLOW, VERMONT

By **Scott A. Olson**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure LUDLVT01000099 on State Highway 100 crossing Branch Brook, Ludlow, 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 Green Mountain section of the New England physiographic province in central Vermont. The 15.7-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the channel banks are densely covered by trees and brush. The overbanks are primarily covered by field grasses.

In the study area, Branch Brook has an incised, straight channel with a slope of approximately 0.003 ft/ft, an average channel top width of 73 ft and an average channel depth of 5 ft. The predominant channel bed materials are cobble and gravel with a median grain size (D_{50}) of 60.5 mm (0.198 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 13, 1995, indicated that the reach was stable.

The State Highway 100 crossing of Branch Brook is a 84-ft-long, two-lane bridge consisting of one 82-foot steel-beam span (Vermont Agency of Transportation, written communication, March 13, 1995). The bridge is supported by vertical, concrete abutments. The abutments are set back from the channel edge and have a spill-through slope consisting of type-4 stone fill (median size less than 60 inches in diameter). The channel skew and the opening-skew-to-roadway is zero degrees. 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 1.5 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 1.0 to 7.4 ft. The worst-case abutment scour occurred at the 500-year discharge. 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.

Ludlow, VT. Quadrangle, 1:24,000, 1971

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 LUDLVT01000099 *Stream* Branch Brook

County Windsor *Road* VT100 *District* 3

Description of Bridge

Bridge length 84 *ft* *Bridge width* 39.1 *ft* *Max span length* 82 *ft*

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

Abutment type Vertical, concrete *Embankment type* Sloping

Stone fill on abutment? Yes *Date of inspection* 10/13/95

Description of stone fill Type-4, along both abutments. The stone fill acts as a spill-through slope.

Brief description of piers/abutments Abutments are concrete and do not have wingwalls. The abutments are set back slightly from the channel's edge.

Is bridge skewed to flood flow according to N *survey?* N *Angle* 0

Is bridge located on a bend in channel? If so, describe (mild, moderate, severe) --

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	10/13/95	0	0
Level II	10/13/95	0	0

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) October 13, 1995. Downstream of the structure the channel flattens as it enters a swampy reach. In addition the confluence of Branch Brook and Black River is about 900 feet downstream of bridge 99. Beaver dam about 400 feet downstream.

Description of the Geomorphic Setting

General topography The channel is located within an upland, high relief valley. At the structure the channel is entering the flood plain of the Black River.

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

Date of inspection 10/13/95

DS left: Flood plain.

DS right: Moderately slope bank.

US left: Flood plain.

US right: Moderately sloped bank.

Description of the Channel

Average top width 73 *ft* ***Average depth*** 5 *ft*

Predominant bed material Cobbles/Gravel ***Bank material*** Cobbles/Gravel

Straight. The US reach is incised. The DS reach is swampy as it enters the Black River flood plain.

8/13/95

Vegetative co Brush and trees on immediate bank and field grasses on the overbank.

DS left: Brush and trees on immediate bank and field grasses on the overbank.

DS right: Brush and trees on immediate bank and field grasses on the overbank.

US left: Brush and trees on immediate bank and field grasses on the overbank.

US right:

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

October 13, 1995.

Beaver dam about 400 feet downstream of bridge. Dam is ignored in analyses.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 15.7 ***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***: None.

Is there a USGS gage on the stream of interest? No

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi²***

Is there a lake/p No -

Calculated Discharges

Q100 3,400 ***ft³/s*** ***Q500*** 5,000 ***ft³/s***

The 100- and 500-year discharges were based on the median of several empirical methods which are applicable for estimating flood discharges in a stream with basin characteristics such as this one's. (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) sea level (NGVD29)

Datum tie between USGS survey and VTAOT plans Add 31.56 feet to USGS arbitrary survey datum to obtain NGVD29 and VTAOT plans datum.

Description of reference marks used to determine USGS datum.

RM1 is a VTAOT brass disk in the top of the left end of the upstream bridge curbing stamped "Proj#F025-1[6] Tablet#T-13 1965" (elev. 1001.10, arbitrary survey datum). RM2 is a chiseled X on top of the right end of the downstream bridge curbing (elev. 1003.00 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXTEM	-70	1	Surveyed exit section (Used as a template)
EXITX	-70	3	Exit section as surveyed with left end of section ending at station -270.3 (Templated from EXTEM)
FULLV	0		Downstream Full-valley section (Templated from EXTEM)
BRIDG	0	1	Bridge section
RDWAY	19	1	Road Grade section
APPRO	119	3	Approach section. Left overbank modified to end section at -270.3.

[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. The beaver dam, about 400 feet downstream, was ignored in the analyses. 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 0.043 to 0.045, and overbank "n" values ranged from 0.045 to 0.069.

Branch Brook drains into the Black River approximately 1000 feet downstream of this site. The close proximity of the confluence may affect the Branch Brook hydraulics, especially if the flow peaks are simultaneous. However, an analysis of potential backwater from the Black River is outside of the scope of this study and 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 0.0031 ft/ft which was determined from surveyed thalweg points.

Downstream of Ludlow bridge 99, there is a levee along the left bank. In the model, the left end of the exit section was set in the flood plain at station -270.3. This station was selected in order that the 100-year water surface elevation approxiamated the top of the levee embankment. Modeling the exit with a longer left overbank resulted in flow conveyance in the overbank with the 100-year water surface below the top of the levee which is not possible. Modelling the exit with a shorter overbank resulted in a water surface elevation significantly above the levee, which is also not possible. Thus, the model assumes levee overtopping, without failure, for the 100-year event.

The surveyed approach section (APPRO) was surveyed approximately one bridge length upstream of the upstream bridge face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables. The left end of the approach section was also set at -270.3, similar to the exit section. Left of station -270.3 is considered ineffective flow. In addition, the left overbank, as surveyed, sloped gradually downward away from the channel. This causes problems in a one-dimensional model, thus the overbank was modelled as if it were flat

For the 500-year discharge, WSPRO assumes critical depth at the bridge section. A Supercritical model was developed. Analyzing both the supercritical and subcritical profiles, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumption of critical depth at the bridge is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 1001.0 *ft*
Average low steel elevation 996.9 *ft*

100-year discharge 3,400 *ft³/s*
Water-surface elevation in bridge opening 991.6 *ft*
Road overtopping? N *Discharge over road* 0 *ft³/s*
Area of flow in bridge opening 361 *ft²*
Average velocity in bridge opening 9.4 *ft/s*
Maximum WSPRO tube velocity at bridge 11.3 *ft/s*

Water-surface elevation at Approach section with bridge 993.2
Water-surface elevation at Approach section without bridge 992.5
Amount of backwater caused by bridge 0.7 *ft*

500-year discharge 5,000 *ft³/s*
Water-surface elevation in bridge opening 992.0 *ft*
Road overtopping? N *Discharge over road* 0
Area of flow in bridge opening 393 *ft²*
Average velocity in bridge opening 12.7 *ft/s*
Maximum WSPRO tube velocity at bridge 15.3 */s*

Water-surface elevation at Approach section with bridge 995.8
Water-surface elevation at Approach section without bridge 993.9
Amount of backwater caused by bridge 1.9

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.

Contraction scour for the 100-year and 500-year events were computed by use of the clear-water contraction scour equation (Richardson and others, 1995, p. 32, equation 20). For contraction scour computations, the average depth in the contracted section (AREA/ TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour. The large depths to armoring computed indicate that armoring will not limit the amount of contraction scour.

Abutment scour for the right 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 left 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.

The computed abutment scour depths were subtracted from the toe of the spill-through slope to determine the scour elevation at the abutment (Written communication, D. Mueller, December 8, 1994).

The angle of repose shown in Figure 8 was exaggerated for plotting purposes. The plotted angle is 45 degrees; the true angle would be smaller.

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	1.5	--
Depth to armoring	6.3	34.5	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
Abutment scour			
Left abutment	1.0	7.0	--
Right abutment	6.1	7.4	--
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	1.5	1.9	--
Right abutment	1.5	1.9	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

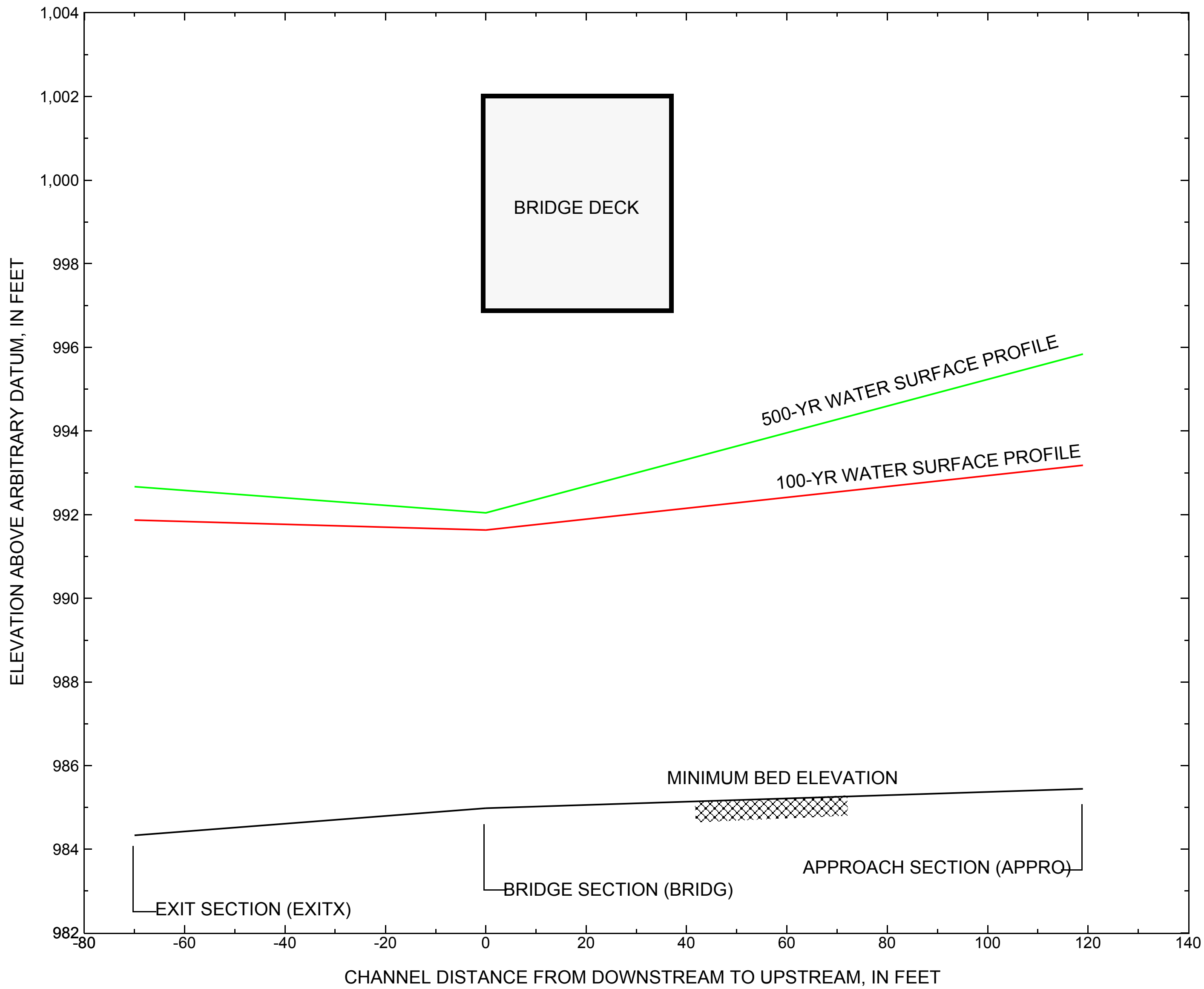


Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure LUDLVT01000099 on State Highway 100, crossing Branch Brook, Ludlow, Vermont.

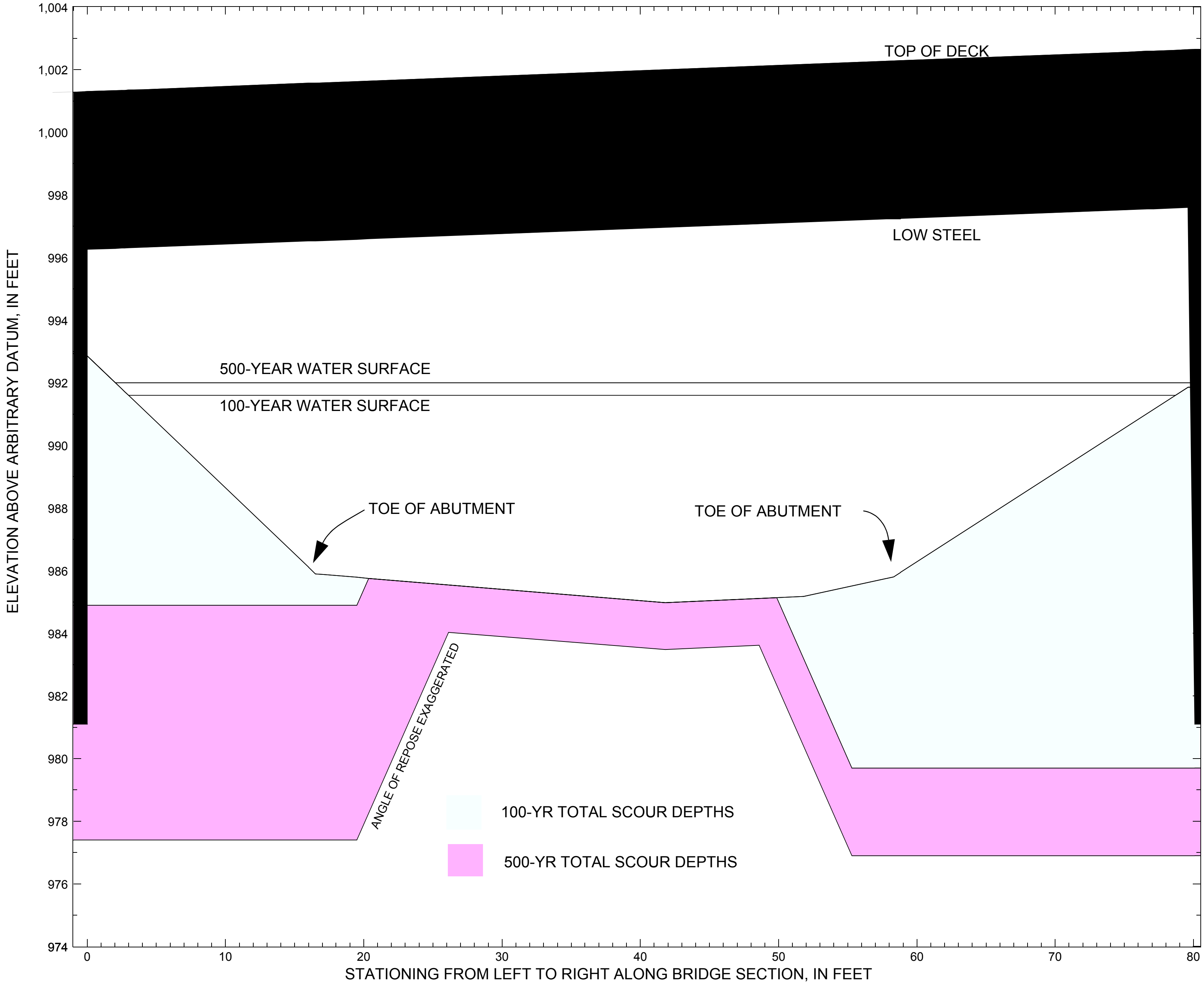


Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure LUDLVT01000099 on State Highway 100, crossing Branch Brook, Ludlow, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure LUDLVT01000099 on State Highway 100, crossing Branch Brook, Ludlow, 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 3,400 cubic-feet per second											
Left abutment	0.0	--	996.3	981.1	--	--	--	--	--	--	3.8
Left abutment toe	16.5	--	--	--	985.9	0.0	1.0	--	1.0	984.9	--
Right abutment toe	58.3	--	--	--	985.8	0.0	6.1	--	6.1	979.7	--
Right abutment	79.6	--	997.6	981.1	--	--	--	--	--	--	-1.4

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 LUDLVT01000099 on State Highway 100, crossing Branch Brook, Ludlow, 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 5,000 cubic-feet per second											
Left abutment	0.0	--	996.3	981.1	--	--	--	--	--	--	-3.7
Left abutment toe	16.5	--	--	--	985.9	1.5	7.0	--	8.5	977.4	--
Right abutment toe	58.3	--	--	--	985.8	1.5	7.4	--	8.9	976.9	--
Right abutment	79.6	--	997.6	981.1	--	--	--	--	--	--	-4.2

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

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. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

U.S. Geological Survey, 1971, Ludlow, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File ludl099.wsp
T2        Hydraulic analysis for structure LUDLVT01000099   Date: 19-JUN-96
T3        Hydraulic Analysis of LUDL099 over Branch Brook     SAO
Q           3400 5000
SK          0.00310  0.00310
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XT   EXTEM    -70
GR         -663.3, 997.53   -477.4, 995.64   -434.3, 989.94   -270.3, 990.21
GR          -83.0, 989.84    -47.3, 991.28    -12.6, 991.60      0.0, 987.53
GR            7.1, 985.73     14.0, 984.96     23.8, 984.55     32.2, 984.33
GR           43.2, 984.61     52.2, 985.78     56.6, 986.91     67.4, 991.41
GR          125.9, 992.07    157.3,1002.81    194.0,1003.63    230.7,1002.66
*
*           assuming left end of effective flow is at -270.3 (see GT below)
*
XS   EXITX    -70
GT            0 -270.3
N           0.050        0.045   0.045
SA                 -12.6      67.4
*
XS   FULLV      0  * * *   0.0093
*
BR   BRIDG     0    996.93       0.0
GR             0.0, 996.26      0.0, 992.86     16.5, 985.85     28.9, 985.43
GR            41.8, 984.98     51.8, 985.18     58.3, 985.83     79.6, 991.86
GR            79.6, 997.60      0.0, 996.26
N           0.043
CD            3 38.5 2 1002
*
XR   RDWAY     19      39.1     1
GR         -710.1,1034.52   -647.7, 994.21   -430.8, 992.16   -339.5, 995.45
GR         -144.1, 998.47    -16.1,1000.11    -16.0,1000.57    -14.1,1000.96
GR            0.0,1001.27     80.0,1002.66     97.7,1002.88     99.7,1002.50
GR           99.7,1002.02    156.3,1003.48    227.3,1003.30    261.8,1002.73
GR          294.5,1009.86
*
*           Commented GR data below is the actual surveyed left overbank.
*           Left end of effective flow was also assumed to be at -270.3.
*           Also left overbank was modeled as flat due to critical depth
*           problems when modeled with overbank sloping away from channel.
*
AS   APPRO    119
*          -482.8,1002.37   -447.5, 991.56   -245.0, 992.03      0.0, 993.00
GR         -270.3,1000.00   -270.3, 993.00      0.0, 993.00     13.0, 987.61
GR           28.9, 986.09     35.4, 985.71     42.9, 985.44     50.6, 985.80
GR           59.0, 986.34     78.8, 994.53    134.0,1003.01    142.8,1003.66
GR          176.3,1004.81    212.9,1004.07    245.2,1008.84
N           0.069        0.045
SA                   0.0
*
HP 1 BRIDG   991.63 1 991.63
HP 2 BRIDG   991.63 * * 3400
HP 1 APPRO   993.18 1 993.18
HP 2 APPRO   993.18 * * 3400
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. Geological Survey WSPRO Input File ludl099.wsp
        Hydraulic analysis for structure LUDLVT01000099   Date: 19-JUN-96
        Hydraulic Analysis of LUDL099 over Branch Brook     SAO
           *** RUN DATE & TIME: 06-20-96  12:52
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#    AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1    361.  34796.   76.    78.                        4472.
   991.63         361.  34796.   76.    78.  1.00     3.    79.   4472.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA         K        Q    VEL
       991.63     2.9    78.8   361.2   34796.    3400.   9.41
 X STA.        2.9       14.7       18.2       21.2       24.0       26.7
   A(I)            29.7       19.6       17.6       17.0       16.3
   V(I)            5.73       8.68       9.65      10.01      10.46

 X STA.       26.7       29.3       31.8       34.2       36.6       38.9
   A(I)            15.9       15.5       15.2       15.5       15.2
   V(I)           10.71      10.95      11.17      10.98      11.18

 X STA.       38.9       41.2       43.5       45.8       48.2       50.7
   A(I)            15.1       15.2       15.2       15.7       16.1
   V(I)           11.29      11.21      11.15      10.86      10.55

 X STA.       50.7       53.2       56.1       59.2       63.7       78.8
   A(I)            16.5       17.3       18.5       21.8       32.3
   V(I)           10.29       9.81       9.17       7.79       5.26

     WSEL  SA#    AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1     49.     335.  270.   270.                        117.
             2    417.  42164.   76.    78.                        5557.
   993.18         466.  42498.  346.   349.  1.22  -270.    76.   2777.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     119.
         WSEL     LEW     REW    AREA         K        Q    VEL
       993.18  -270.3    75.5   465.5   42498.    3400.   7.30
 X STA.     -270.3       11.8       16.2       19.9       23.1       26.0
   A(I)            79.8       24.6       22.1       20.4       19.7
   V(I)            2.13       6.91       7.68       8.31       8.62

 X STA.       26.0       28.8       31.3       33.8       36.2       38.5
   A(I)            19.0       18.5       18.0       17.5       17.7
   V(I)            8.96       9.17       9.45       9.71       9.59

 X STA.       38.5       40.8       43.1       45.4       47.7       50.2
   A(I)            17.6       17.3       17.7       18.0       18.4
   V(I)            9.65       9.85       9.62       9.43       9.24

 X STA.       50.2       52.8       55.5       58.5       62.4       75.5
   A(I)            18.8       19.5       20.6       24.4       35.8
   V(I)            9.06       8.74       8.24       6.96       4.75
```

```
        U.S. Geological Survey WSPRO Input File ludl099.wsp
        Hydraulic analysis for structure LUDLVT01000099   Date: 19-JUN-96
        Hydraulic Analysis of LUDL099 over Branch Brook      SAO
           *** RUN DATE & TIME: 06-20-96  12:52
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     393.   39313.    78.    80.                        5012.
   992.04          393.   39313.    78.    80.  1.00     2.    80.   5012.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       992.04     1.9    79.6   392.8   39313.    5000.  12.73
X STA.         1.9       14.2       17.9       21.1       23.9       26.6
  A(I)            32.2       21.7       19.7       17.9       17.7
  V(I)            7.76      11.51      12.69      13.93      14.15

X STA.        26.6       29.2       31.7       34.2       36.6       39.0
  A(I)            17.2       16.9       16.9       16.3       16.5
  V(I)           14.49      14.83      14.79      15.30      15.12

X STA.        39.0       41.4       43.7       46.1       48.5       51.0
  A(I)            16.4       16.5       16.6       16.7       17.5
  V(I)           15.22      15.13      15.05      14.96      14.31

X STA.        51.0       53.6       56.5       59.9       64.5       79.6
  A(I)            17.9       18.8       20.5       23.9       34.8
  V(I)           13.99      13.33      12.17      10.45       7.18

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     119.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     768.   33014.   270.   273.                        7341.
             2     630.   76169.    87.    90.                        9599.
   995.84         1398.  109182.   358.   363.  1.76  -270.    87.  11806.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     119.
         WSEL     LEW     REW    AREA        K        Q    VEL
       995.84  -270.3    87.3  1397.5  109182.    5000.   3.58
X STA.      -270.3     -224.1     -179.3     -134.5      -90.8      -46.3
  A(I)           131.2      127.3      127.1      124.1      126.3
  V(I)            1.91       1.96       1.97       2.01       1.98

X STA.       -46.3       -1.5       11.3       16.5       21.1       25.3
  A(I)           127.2       62.7       43.4       39.8       39.2
  V(I)            1.96       3.99       5.76       6.28       6.38

X STA.        25.3       29.3       33.2       36.9       40.6       44.3
  A(I)            38.4       38.3       37.5       37.9       38.4
  V(I)            6.52       6.53       6.67       6.59       6.51

X STA.        44.3       48.2       52.4       56.8       62.6       87.3
  A(I)            39.3       42.5       43.3       52.8       80.9
  V(I)            6.37       5.89       5.78       4.74       3.09
```

WSPRO OUTPUT FILE (continued)

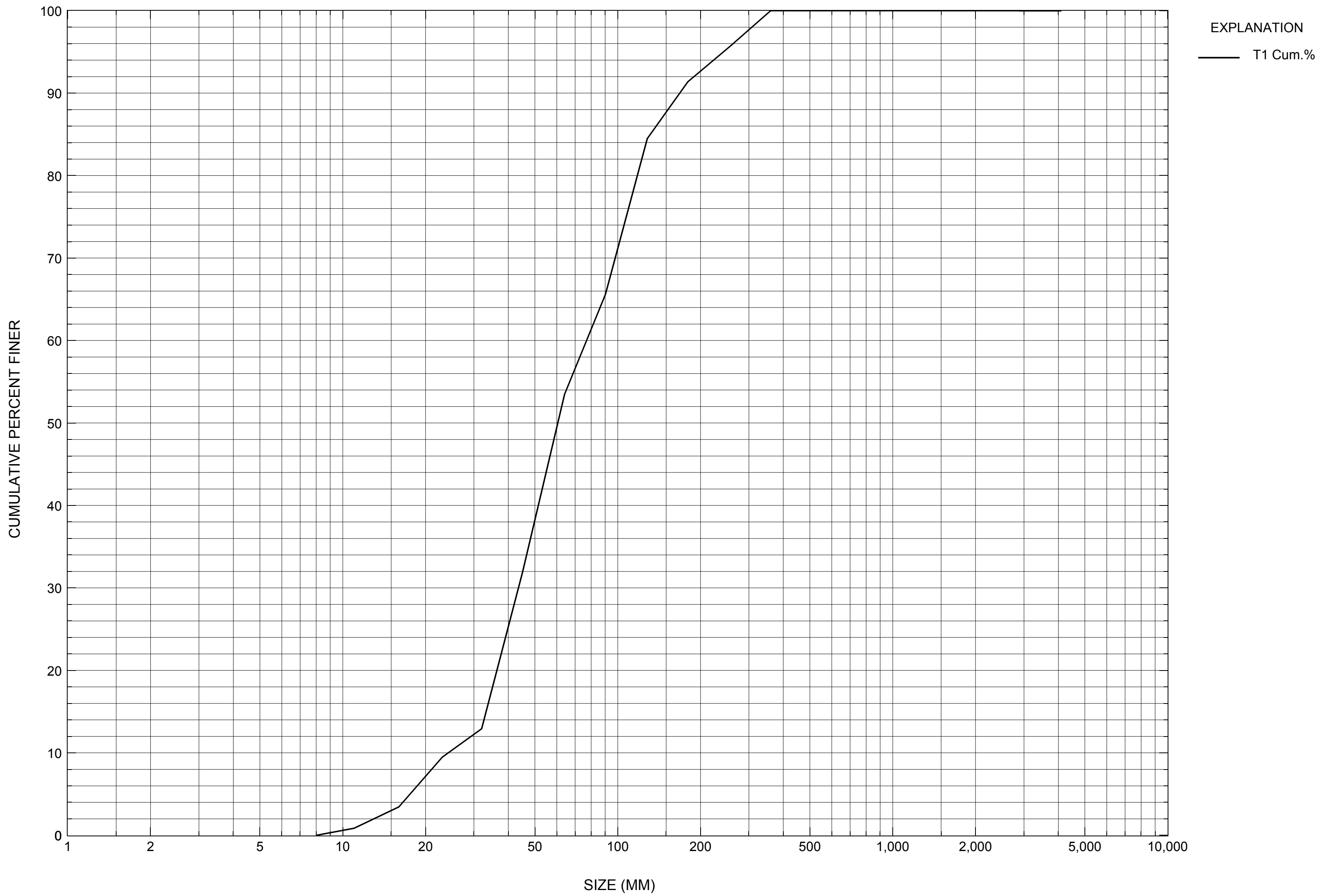
```
        U.S. Geological Survey WSPRO Input File ludl099.wsp
        Hydraulic analysis for structure LUDLVT01000099   Date: 19-JUN-96
        Hydraulic Analysis of LUDL099 over Branch Brook     SAO
           *** RUN DATE & TIME: 06-20-96  12:52

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

EXITX:XS   ******  -270.     857.  0.38 *****  992.26  990.83   3400.  991.87
      -70. ******   109.   61038.  1.56 ***** *******    0.58    3.97

FULLV:FV      70.  -270.     688.  0.59  0.28  992.63 *******   3400.  992.05
        0.    70.    67.   48137.  1.54  0.10    0.00    0.73    4.94
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS     119.     1.     365.  1.35  0.82  993.83 *******   3400.  992.49
      119.   119.    74.   34793.  1.00  0.38    0.00    0.73    9.30
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   993.18       0.00     991.63     992.16

 ===260 ATTEMPTING FLOW CLASS 4 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.     3.     361.  1.38  0.38  993.01  990.71   3400.  991.63
        0.    70.    79.   34759.  1.00  0.38    0.02    0.76    9.42

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       3. ****   4.  1.000 ******  996.93 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      19.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      81.  -270.     465.  1.01  0.63  994.19  991.41   3400.  993.18
      119.    81.    76.   42487.  1.22  0.54    0.00    1.23    7.31

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.000  0.000   42874.     3.    79. ********

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
   EXITX:XS     -70.  -270.   109.  3400.   61038.     857.    3.97  991.87
   FULLV:FV       0.  -270.    67.  3400.   48137.     688.    4.94  992.05
   BRIDG:BR       0.     3.    79.  3400.   34759.     361.    9.42  991.63
   RDWAY:RG      19.**************     0.       0.       0.    1.00********
   APPRO:AS     119.  -270.    76.  3400.   42487.     465.    7.31  993.18

    XSID:CODE   XLKQ   XRKQ      KQ
   APPRO:AS       3.    79.  42874.

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXITX:XS    990.83    0.58  984.33 1003.63************  0.38  992.26  991.87
   FULLV:FV  ********    0.73  984.98 1004.28  0.28  0.10  0.59  992.63  992.05
   BRIDG:BR    990.71    0.76  984.98  997.60  0.38  0.38  1.38  993.01  991.63
   RDWAY:RG  ****************  992.16 1034.52  0.52******  1.02  993.67********
   APPRO:AS    991.41    1.23  985.44 1008.84  0.63  0.54  1.01  994.19  993.18
```

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File ludl099.wsp
        Hydraulic analysis for structure LUDLVT01000099   Date: 19-JUN-96
        Hydraulic Analysis of LUDL099 over Branch Brook     SAO
           *** RUN DATE & TIME: 06-20-96  12:52

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

EXITX:XS   ******  -270.    1171.  0.42 *****  993.09  991.44   5000.  992.67
      -70. ******   128.   89784.  1.47 ***** *******    0.53    4.27

FULLV:FV      70.  -270.     979.  0.62  0.27  993.46 *******   5000.  992.84
        0.    70.   126.   71506.  1.53  0.10    0.00    0.71    5.10
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    2.01     993.01     993.87

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   992.34    1008.84    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   992.34    1008.84     993.87

 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
              ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "APPRO"
                   WSBEG,WSEND,CRWS =   993.87    1008.84     993.87

APPRO:AS     119.  -270.     706.  1.36 *****  995.23  993.87   5000.  993.87
      119.   119.    77.   55312.  1.74 ***** *******    1.16    7.09
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   995.84       0.00     992.04     992.16
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   996.25         0.      5000.
 ===280 REJECTED FLOW CLASS 4 SOLUTION.
 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.
 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   996.93         0.      6829.
 ===270 REJECTED 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.     2.     393.  2.82  0.50  994.86  985.18   5000.  992.04
        0.    70.    80.   39321.  1.12  1.27    0.00    1.06   12.73

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       3. ****   1.  0.946 ******  996.93 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      19.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      81.  -270.    1397.  0.35  0.51  996.19  993.87   5000.  995.84
      119.    88.    87.  109124.  1.76  0.82    0.00    0.42    3.58

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.771  0.256   81174.    -1.    76.   995.67

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -70.  -270.   128.   5000.   89784.    1171.    4.27  992.67
   FULLV:FV       0.  -270.   126.   5000.   71506.     979.    5.10  992.84
   BRIDG:BR       0.     2.    80.   5000.   39321.     393.   12.73  992.04
   RDWAY:RG      19.**************      0.*********       0.    1.00********
   APPRO:AS     119.  -270.    87.   5000.  109124.    1397.    3.58  995.84
    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -1.    76.   81174.

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    991.44    0.53  984.33 1003.63************  0.42  993.09  992.67
   FULLV:FV  ********    0.71  984.98 1004.28  0.27  0.10  0.62  993.46  992.84
   BRIDG:BR    985.18    1.06  984.98  997.60  0.50  1.27  2.82  994.86  992.04
   RDWAY:RG ****************  992.16 1034.52************  0.19  997.03********
   APPRO:AS    993.87    0.42  985.44 1008.84  0.51  0.82  0.35  996.19  995.84
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for one pebble count transect at the approach cross-section for structure LUDLVT01000099, in Ludlow, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number LUDLVT01000099

General Location Descriptive

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

Date *(MM/DD/YY)* 03 / 13 / 95

Highway District Number *(I - 2; nn)* 03

County *(FIPS county code; I - 3; nnn)* 027

Town *(FIPS place code; I - 4; nnnnn)* 41275

Mile marker *(I - 11; nnn.nnn)* 005070

Waterway *(I - 6)* BRANCH BROOK

Road Name *(I - 7):* -

Route Number VT100

Vicinity *(I - 9)* 0.1 MI N JCT. VT.103 N

Topographic Map Ludlow

Hydrologic Unit Code: 01080106

Latitude *(I - 16; nnnn.n)* 43252

Longitude *(i - 17; nnnnn.n)* 72424

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 20001300991410

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

Maximum span length *(I - 48; nnnn)* 0082

Year built *(I - 27; YYYY)* 1966

Structure length *(I - 49; nnnnnn)* 000084

Average daily traffic, ADT *(I - 29; nnnnnn)* 003540

Deck Width *(I - 52; nn.n)* 391

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)* 7

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

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

Structure type *(I - 43; nnn)* 302

Year Reconstructed *(I - 106)* 0000

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

Clear span (*nnn.n ft*) 80.0

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

Vertical clearance from streambed (*nnn.n ft*) 11.25

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

Waterway of full opening (*nnn.n* ft^2) 900.0

Comments:

The structural inspection report of 10/5/93 indicates the structure is a single span steel stringer type bridge with a concrete deck. The left abutment is noted as showing some minor staining and concrete scaling. Both left wingwalls are in good condition. The same condition is noted for the right abutment and wingwalls. Both abutments are protected with stone fill. The channel is aligned straight with the abutment walls.

Bridge Hydrologic Data

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

Terrain character: **Mountainous**

Stream character & type: -

Streambed material: -

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*): **Not rapidly**

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

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

Are there other structures nearby? (*Yes, No, Unknown*): **U** *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:

Some data on the hydrology was present on the plans. The drainage area was quoted in acres as 9432.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **15.71** mi^2

Lake and pond area **0.04** mi^2

Watershed storage *(ST)* **0.3** %

Bridge site elevation **1035** ft

Headwater elevation **3169** ft

Main channel length **8.89** mi

10% channel length elevation **1080** ft

85% channel length elevation **2224** ft

Main channel slope *(S)* **171.56** 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)*: **06** / **1964**

Project Number **F 028-S** Minimum channel bed elevation: **1017.0**

Low superstructure elevation: USLAB ****** DSLAB **-** USRAB **-** DSRAB **-**

Benchmark location description:

Tablet on top of left end of upstream bridge curbing stamped Proj#F025-1[6] Tablet # T-13 1965. (elevation 1032.66 ft NGVD29).

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

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

If 1: Footing Thickness **2.0** Footing bottom elevation: **1012.7**

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

Briefly describe material at foundation bottom elevation or around piles:

-

Comments:

****There are no elevations provided on the plans that are in a location where they might be reusable. The footing thickness, based on the vertical scale, probably is about 2.0 feet. The thickness is not explicitly shown on the plans. The plans are listed under the last project number which is "F DECK 3BLT33".**

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: MAI Date: 11/27/95
Computerized by: MAI Date: 11/27/95
Reviewd by: SAO Date: 8/19/96

Structure Number LUDLVT01000099

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* T. Severance Date *(MM/DD/YY)* 10 / 13 / 1995

2. Highway District Number 03 Mile marker 005070

County Windsor (027) Town Ludlow (41275)

Waterway *(I - 6)* Branch Brook Road Name ______

Route Number VT 100 Hydrologic Unit Code: 01080106

3. Descriptive comments:

The bridge is located 0.1 miles from junction with Vermont State Route 103.

B. Bridge Deck Observations

4. Surface cover... LBUS 5 RBUS 5 LBDS 5 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 2 DS 1 *(**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 84.0 *(feet)* Span length 82.0 *(feet)* Bridge width 39.1 *(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)*

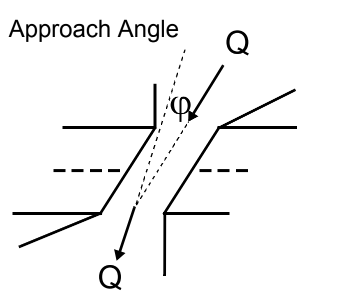
10. Embankment slope (*run / rise in feet / foot*):
US left --:1 US right --:1

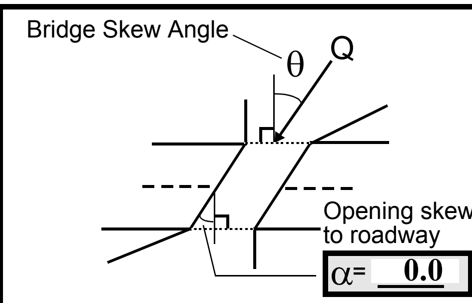
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	2	1	0	-
RBUS	2	1	2	1
RBDS	2	1	2	1
LBDS	2	1	0	-

*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: 0





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

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**

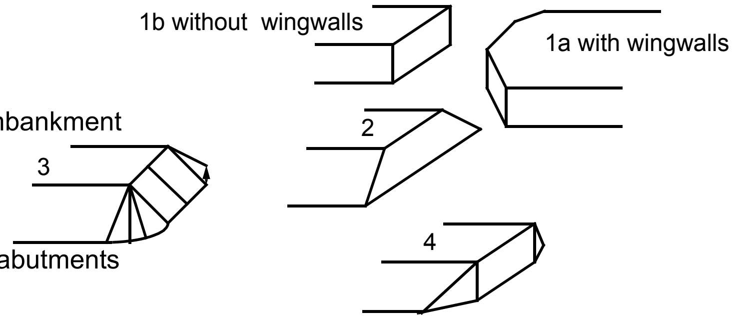
1a- Vertical abutments with wingwalls

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.)

4. Overbanks in the near vicinity are covered by field grasses, however, immediate channel banks have dense woody vegetation

7. Measured bridge length: 84.5, span: 81.8, and width: 39.0 feet.

There is a granite curbing 0.8 feet high with steel rails above.

Route 103 parallels the river on the right bank. The channel is straight from US to DS of the bridge with a wide flood plain on the left 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
80.0	**5.5**			**8.0**	**4**	**3**	**43**	**43**	**1**	**1**

23. Bank width **20.0** 24. Channel width **20.0** 25. Thalweg depth **79.0** 29. Bed Material **435**

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.):

30. Protection along both banks extends more than 300 feet US.

28. Light fluvial erosion of fines around stone along the banks.

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 2 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
46.0		1.0		2	-	-	-

58. Bank width (BF) 7.0 59. Channel width (Amb) 6.0 60. Thalweg depth (Amb) 25.0 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.):

43

There is placed stone fill protection along both abutments continuing up to the road approach areas.

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? 1___ *(Y or N)* Ice Blockage Potential N____ *(1- Low; 2- Moderate; 3- High)*

70. Debris and Ice Comments:

1

The channel is wide with the abutments set back.

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		0	90	1	0	-	-	15.0
RABUT	1	0	90			1	0	79.5

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.):

-

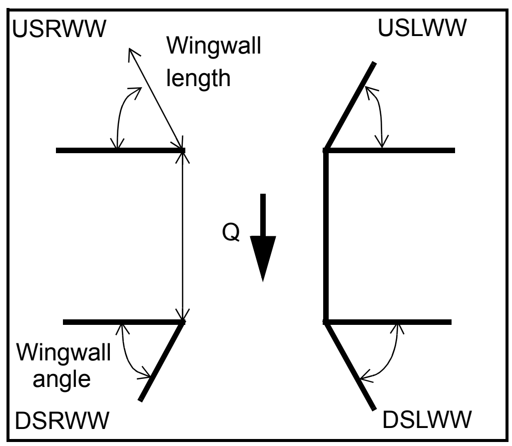
-

1

Abutments and stone fill protection in like new condition.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						42.0	
USRWW:	N		-		-	1.0	
DSLWW:	-		-		N	38.5	
DSRWW:	-		-		-	38.5	



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	-	-	-	1	1
Condition	N	-	-	-	-	-	1	1
Extent	-	-	-	-	-	4	4	-

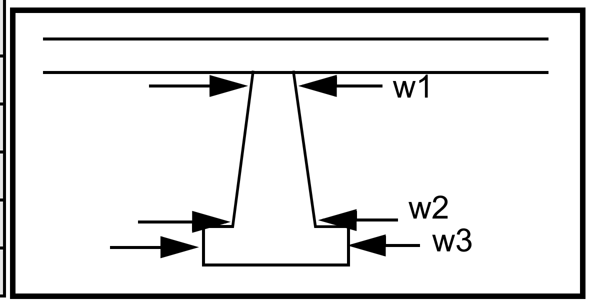
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

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

Piers:

84. Are there piers? **No** *(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	-	-	-	-	-	-
Pier 3	-	-	-	-	-	-
Pier 4	-	-	-	-	-	-



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

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
-	-			-	-	-	-	NO	PIE	RS

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.):

3
2
43
43
1
0
432
2
2
1
1

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

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

105. Drop structure comments (eg. downstream scour depth):
fill bank protection extends to about 300 feet downstream.
Several fallen trees from a beaver exist just DS of the Exit section about 140 feet DS of the bridge.
There is a beaver dam 400 feet DS of the bridge.
The Black River is about 900 feet DS.

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: N

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

-

NO DROP STRUCTURE

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

Cut bank extent: N 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.):

-
-
-
-

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

Scour dimensions: Length POI Width NT Depth: BA Positioned RS %LB to ____ %RB

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

N

-

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

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

Confluence 2: Distance - Enters on NO *(LB or RB)* Type CU *(**1**- perennial; **2**- ephemeral)*

Confluence comments (eg. confluence name):

T BANKS

F. Geomorphic Channel Assessment

107. Stage of reach evolution ____

__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)*:

N
-
-
-
-
-
-
NO CHANNEL SCOUR

N

109. G. Plan View Sketch

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:	LUDLVT01000099	Town:	Ludlow
Road Number:	VT100	County:	Windsor
Stream:	Branch Brook		

Initials SAO   Date: 7/2/96   Checked: EMB   7/23/96

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	3400	5000	0
Main Channel Area, ft2	417	630	0
Left overbank area, ft2	49	768	0
Right overbank area, ft2	0	0	0
Top width main channel, ft	76	87	0
Top width L overbank, ft	270	270	0
Top width R overbank, ft	0	0	0
D50 of channel, ft	0.198	0.198	0
D50 left overbank, ft	--	--	0
D50 right overbank, ft	--	--	0
y1, average depth, MC, ft	5.5	7.2	ERR
y1, average depth, LOB, ft	0.2	2.8	ERR
y1, average depth, ROB, ft	ERR	ERR	ERR
Total conveyance, approach	42498	109182	0
Conveyance, main channel	42164	76169	0
Conveyance, LOB	335	33014	0
Conveyance, ROB	0	0	0
Percent discrepancy, conveyance	-0.0024	-0.0009	ERR
Qm, discharge, MC, cfs	3373.3	3488.2	ERR
Ql, discharge, LOB, cfs	26.8	1511.9	ERR
Qr, discharge, ROB, cfs	0.0	0.0	ERR
Vm, mean velocity MC, ft/s	8.1	5.5	ERR
Vl, mean velocity, LOB, ft/s	0.5	2.0	ERR
Vr, mean velocity, ROB, ft/s	ERR	ERR	ERR
Vc-m, crit. velocity, MC, ft/s	8.7	9.1	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
Left Overbank	N/A	N/A	N/A
Right Overbank	N/A	N/A	N/A

Live-Bed Contraction Scour

Laursen’s Live Bed Contraction Scour
y2/y1 = (Q2/Q1)^(6/7)*(W1/W2)^(k1)
ys=y2-y_bridge
(Richardson and others, 1995, p. 30, eq. 17 and 18)

Characteristic	Approach 100 yr	500 yr	Other Q	Bridge 100 yr	500 yr	Other Q
Q1, discharge, cfs	3400	5000	0	3400	5000	0
Total conveyance	42498	109182	0	34796	39313	0
Main channel conveyance	42164	76169	0	34796	39313	0
Main channel discharge	3373	3488	ERR	3400	5000	ERR
Area - main channel, ft2	417	630	0	361	393	0
(W1) channel width, ft	76	87	0	76	78	0
(Wp) cumulative pier width, ft	0	0	0	0	0	0
W1, adjusted bottom width(ft)	76	87	0	76	78	0
D50, ft	0.198	0.198	0.198			
w, fall velocity, ft/s (p. 32)	3.6	3.6	0			
y, ave. depth flow, ft	5.49	7.24	N/A	4.75	5.04	ERR
S1, slope EGL	0.01	0.015	0			
P, wetted perimeter, MC, ft	78	90	0			
R, hydraulic Radius, ft	5.346	7.000	ERR			
V*, shear velocity, ft/s	1.312	1.839	N/A			
V*/w	0.364	0.511	ERR			
Bed transport coeff., k1, (0.59 if V*/w<0.5; 0.64 if .5<V*/w<2; 0.69 if V*/w>2.0 p. 33)						
k1	0.59	0.59	0			
y2,depth in contraction, ft	5.52	10.52	ERR			
ys, scour depth, ft (y2-y_bridge)	0.77	5.48	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)

Approach Section	Q100	Q500	Qother
Main channel Area, ft2	417	630	0
Main channel width, ft	76	87	0
y1, main channel depth, ft	5.49	7.24	ERR

Bridge Section			
(Q) total discharge, cfs	3400	5000	0
(Q) discharge thru bridge, cfs	3400	5000	
Main channel conveyance	34796	39313	

Total conveyance	34796	39313	
Q2, bridge MC discharge,cfs	3400	5000	ERR
Main channel area, ft2	361	393	0
Main channel width (skewed), ft	76.0	78.0	0.0
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	76	78	0
y_bridge (avg. depth at br.), ft	4.75	5.04	ERR
Dm, median (1.25*D50), ft	0.2475	0.2475	0
y2, depth in contraction,ft	4.79	6.53	ERR
ys, scour depth (y2-ybridge), ft	0.04	1.49	N/A
ARMORING			
D90	0.552	0.552	
D95	0.794	0.794	
Critical grain size,Dc, ft	0.4129	0.7348	ERR
Decimal-percent coarser than Dc	0.164	0.06	
Depth to armoring,ft	6.32	34.54	ERR

Abutment Scour

Froehlich's Abutment Scour

$$Ys/Y1 = 2.27 \cdot K1 \cdot K2 \cdot (a'/Y1)^{0.43} \cdot Fr1^{0.61}+1$$

(Richardson and others, 1995, p. 48, eq. 28)

Characteristic	Left Abutment 100 yr Q	Left Abutment 500 yr Q	Left Abutment Other Q	Right Abutment 100 yr Q	Right Abutment 500 yr Q	Right Abutment Other Q
(Qt), total discharge, cfs	3400	5000	0	3400	5000	0
a', abut.length blocking flow, ft	280	279.5	0	6.9	18.3	0
Ae, area of blocked flow ft2	79.2	815.6	0	18.9	59.9	0
Qe, discharge blocked abut.,cfs	168.7	1709	0	89.5	185.2	0
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	2.13	2.10	ERR	4.74	3.09	ERR
ya, depth of f/p flow, ft	0.28	2.92	ERR	2.74	3.27	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	0.706	0.216	ERR	0.504	0.301	ERR
ys, scour depth, ft	5.83	13.10	N/A	6.09	7.39	N/A

HIRE equation (a'/ya > 25)

$$ys = 4 \cdot Fr^{0.33} \cdot y1 \cdot K/0.55$$

(Richardson and others, 1995, p. 49, eq. 29)

a'(abut length blocked, ft)	280	279.5	0	6.9	18.3	0
y1 (depth f/p flow, ft)	0.28	2.92	ERR	2.74	3.27	ERR
a'/y1	989.90	95.78	ERR	2.52	5.59	ERR
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.71	0.22	N/A	0.50	0.30	N/A
Ys w/ corr. factor K1/0.55:						
vertical	1.83	12.80	ERR	ERR	ERR	ERR
vertical w/ ww's	1.50	10.50	ERR	ERR	ERR	ERR
spill-through	1.01	7.04	ERR	ERR	ERR	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	0.76	1		0.76	1	
(Fr from the characteristic V and y in contracted section--mc, bridge section)						
y, depth of flow in bridge, ft	4.75	5.04		4.75	5.04	
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	1.70	ERR	0.00	1.70	ERR	0
Fr>0.8 (vertical abut.)	ERR	2.11	ERR	ERR	2.11	ERR
Fr<=0.8 (spillthrough abut.)	1.48	ERR	0.00	1.48	ERR	0
Fr>0.8 (spillthrough abut.)	ERR	1.86	ERR	ERR	1.86	ERR