LEVEL II SCOUR ANALYSIS FOR BRIDGE 37 (BRIDTH00050037) on TOWN HIGHWAY 5, crossing the NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-309

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

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By SCOTT A. OLSON and MICHAEL A. IVANOFF

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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

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Denver, CO 80225

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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 37 (BRIDTH00050037) ON TOWN HIGHWAY 5, CROSSING THE NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

By Scott A. Olson and Michael A. Ivanoff

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00050037 on town highway 5 crossing the North Branch Ottauquechee River, Bridgewater, 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). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Bridgewater. The 10.5-mi^2 drainage area is a predominantly rural basin. In the vicinity of the study site, the left and right banks are forested. Town highway 5 runs parallel to the upstream left and downstream right banks.

In the study area, the North Branch Ottauquechee River has a sinuous channel with a slope of approximately 0.013 ft/ft, an average channel top width of 50 ft and an average channel depth of 5 ft. The predominant channel bed materials are gravel and cobble (D_{50} is 79.3 mm or 0.260 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 2, 1994, indicated that the reach was stable.

The town highway 5 crossing of the North Branch Ottauquechee River is a 38-ft-long, one-lane bridge consisting of one 35-foot steel beam span (Vermont Agency of Transportation, written commun., August 25, 1994). The bridge is supported by vertical, stone abutments with wingwalls. The right abutment has settled due to scour. Type-3 stone fill (less than 36 inches diameter) provides protection to the upstream end of the upstream left wingwall and the base of the downstream right wingwall. The channel is skewed approximately 35 degrees; the opening-skew-to-roadway is 20 degrees. Additional details describing conditions at the site are included in the Level II Summary and Appendix E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). 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 0.4 to 1.5 ft. The worst-case contraction scour occurred at the incipient overtopping discharge, which was less than the 100-year discharge. Abutment scour ranged from 11.0 to 14.9 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, 1993, p. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

Delectable Mountain, 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 BRIDTH00050037 ***Stream*** N. Br. Ottauquechee River

County Windsor ***Road*** TH05 ***District*** 04

Description of Bridge

Bridge length 38 ***ft*** ***Bridge width*** 14 ***ft*** ***Max span length*** 35 ***ft***

Alignment of bridge to road (on curve or straight) S-curve

Abutment type vertical, stone ***Embankment type*** vertical

Stone fill on abutment? no ***Date of inspection*** 11/02/94

Description of stone fill Type-3 at the upstream end of the upstream left wingwall and along the base of the downstream right wingwall. Stone fill on the downstream right road approach embankment was assessed as slumping.

Brief description of piers/abutments The left and right abutments are stone with concrete caps. The right abutment has settled.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 35

The channel has a mild bend. Opening skew to roadway is 20 degrees.

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	11/02/94	0	0
Level II	11/02/94	-	-

Potential for debris Low

Describe any features near or at the bridge that may affect flow (include observation date)

Description of the Geomorphic Setting

General topography The bridge is in a steep, narrow valley with moderate relief and little or no flood plains.

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

Date of inspection 11/2/94

DS left: Steep valley wall.

DS right: Mild sloping bank to town highway 05, then steep valley wall.

US left: Moderately steep bank intersected by town highway 05.

US right: Steep valley wall.

Description of the Channel

Average top width 50 ***ft*** ***Average depth*** 5 ***ft***

Predominant bed material cobble and gravel ***Bank material*** cobble/ bedrock

Narrow, incised channel with only slight sinuosity.

11/2/94

Vegetative co

DS left: Forest.

DS right: Forest.

US left: Forest.

US right: Forest.

Do banks appear stable? Y 11/2/94 ***If not, describe location and type of instability and date of observation.***

11/2/94--None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 10.5 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
Green Mountain Prov.	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 2,500 ***ft³/s*** ***Q500*** 3,400 ***ft³/s***

Q100 and Q500 were determined by use of an area relationship [(10.5/26.6) to the 0.7 power] with the discharges determined at bridge 49 also on the North Branch Ottauquechee River, but with a drainage area of 26.6 square miles. The Q100 and Q500 discharges at bridge 049, 4800 and 6500 cubic feet per second, were extrapolated from flood frequency estimates available from VTAOT (VTAOT, written communication, May 1995).

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 Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on exposed bedrock on the left bank and 30 feet upstream of the upstream bridge face at about the same elevation as the bridge deck (elev. 98.98 ft, arbitrary datum). RM2 is a chiseled X on exposed bedrock on the left bank and 55 feet upstream of the upstream bridge face near the bottom of the stream bank (elev. 92.29 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-39	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	10	1	Road Grade section
APPRO	50	2	Modelled Approach section (Templated from APTEM)
APTEM	92	1	Approach section as surveyed (Used as a template)

[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 analysis 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, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.035 to 0.045, and overbank "n" values ranged from 0.025 to 0.100.

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 0.013 ft/ft which was determined from surveyed thalweg points downstream of the bridge.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.021 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

For the incipient overtopping discharge of 1,760 cfs, WSPRO assumes critical depth at the bridge section. Further analysis, in which the water surface is shown to pass through critical depth in the constriction, suggests the critical depth assumption at the bridge section is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 99.6 *ft*
Average low steel elevation 97.3 *ft*

100-year discharge 2,500 *ft^3/s*
Water-surface elevation in bridge opening 97.3 *ft*
Road overtopping? Y *Discharge over road* 519 *ft^3/s*
Area of flow in bridge opening 196 *ft^2*
Average velocity in bridge opening 10.4 *ft/s*
Maximum WSPRO tube velocity at bridge 14.6 *ft/s*

Water-surface elevation at Approach section with bridge 100.6
Water-surface elevation at Approach section without bridge 95.9
Amount of backwater caused by bridge 4.7 *ft*

500-year discharge 3,400 *ft^3/s*
Water-surface elevation in bridge opening 97.3 *ft*
Road overtopping? Y *Discharge over road* 1,250 *ft^3/s*
Area of flow in bridge opening 196 *ft^2*
Average velocity in bridge opening 11.1 *ft/s*
Maximum WSPRO tube velocity at bridge 15.7 *ft/s*

Water-surface elevation at Approach section with bridge 101.4
Water-surface elevation at Approach section without bridge 96.8
Amount of backwater caused by bridge 4.6

Incipient overtopping discharge 1,760 *ft^3/s*
Water-surface elevation in bridge opening 94.6 *ft*
Area of flow in bridge opening 132 *ft^2*
Average velocity in bridge opening 13.4 *ft/s*
Maximum WSPRO tube velocity at bridge 16.3 *ft/s*

Water-surface elevation at Approach section with bridge 97.4
Water-surface elevation at Approach section without bridge 94.9
Amount of backwater caused by bridge 2.5 *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, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

The 100-year and 500-year discharges resulted in submerged 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). Therefore, contraction scour for these two discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the incipient road-overflow discharge. 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 results of Laursen's clear-water contraction scour for the 100-year and 500-year events were also computed and can be found in appendix F.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). 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.

The incipient overtopping model resulted in worst-case contraction scour. The worst-case total scour occurred at the 500-year discharge.

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	0.4	0.9	1.5
Depth to armoring	4.4	6.4	37.3
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	13.6	14.9	11.0
Right abutment	12.6	13.2	11.5
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	2.5	2.9	2.3
Right abutment	2.5	2.9	2.3
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

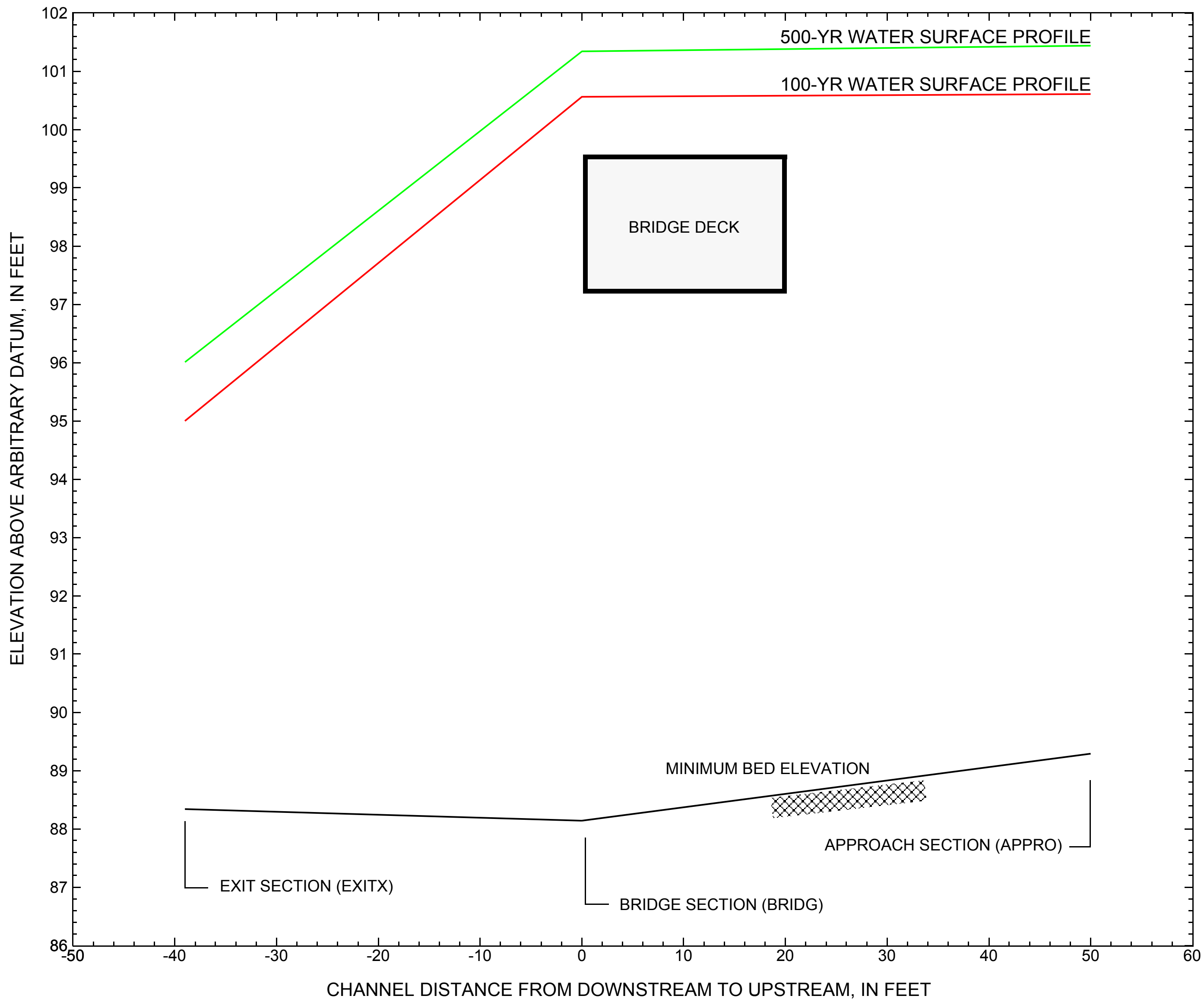

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00050037 on town highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.

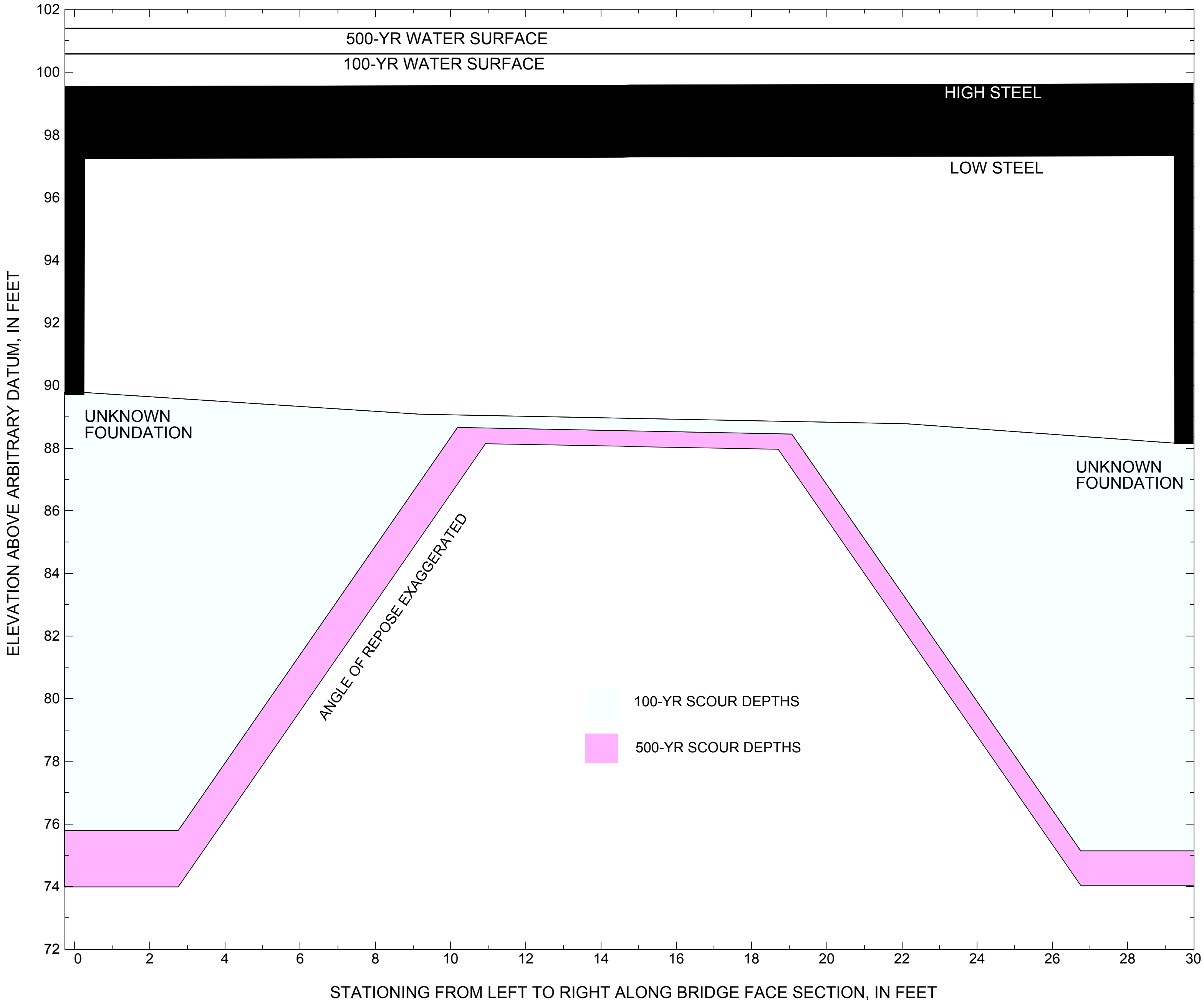

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00050037 on town highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00050037 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, 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 2,500 cubic-feet per second											
Left abutment	0.0	--	97.5	--	89.8	0.4	13.6	--	14.0	75.8	--
Right abutment	29.5	--	97.0	--	88.1	0.4	12.6	--	13.0	75.1	--

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 BRIDTH00050037 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, 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 3,400 cubic-feet per second											
Left abutment	0.0	--	97.5	--	89.8	0.9	14.9	--	15.8	74.0	--
Right abutment	29.5	--	97.0	--	88.1	0.9	13.2	--	14.1	74.0	--

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

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U.S. Geological Survey, 1966, Delectable Mountain, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Photoinspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
T2        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
T3        HYDRAULIC ANALYSIS OF BRID037
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          2500 3400 1760
SK         0.013 0.013 0.013
*
XS   EXITX    -39
GR          -69.8, 107.87    -63.1, 101.60    -54.2, 101.38    -46.4,  97.48
GR          -13.9,  96.00    -12.2,  94.21     -7.7,  91.71     -3.5,  90.69
GR           -2.8,  89.54      0.0,  89.57      1.9,  88.82      5.5,  88.36
GR           12.3,  88.93     17.3,  88.34     23.4,  89.06     26.9,  89.52
GR           39.5,  93.31     64.5,  96.22     86.3, 101.68    114.9, 103.61
N             0.099        0.045        0.100
SA                 -13.9        86.3
*
XS   FULLV      0 * * * 0.006
*
BR   BRIDG   0 97.3 35
GR            0.0,  97.53      1.0,  89.79      9.2,  89.08     22.1,  88.78
GR           29.5,  88.14     29.5,  97.00      0.0,  97.53
N            0.035
CD           1 26.2 * * 20 10.2
*
XR   RDWAY   10 14.0 2
GR          -84.4, 103.76    -63.3,  99.20    -24.8,  99.51      0.0,  99.51
GR           37.7,  99.66    122.6, 103.05
BP           4.1
*
XT   APTEM     92
GR          -65.0, 103.45    -50.5,  98.43    -48.6,  99.00    -16.8,  97.74
GR           -5.8,  91.98      0.0,  91.43      2.4,  90.91     13.6,  90.84
GR           21.6,  90.19     24.8,  90.62     26.9,  91.54     31.6,  94.25
GR           40.1,  99.57     50.0, 105.77
*
AS   APPRO     50
GT            -.90
N             0.025        0.041
SA                 -16.8
*
HP 1 BRIDG    97.30 1 97.30
HP 2 BRIDG    97.30 * * 2027
HP 2 RDWAY    100.56 * * 519
HP 1 APPRO    100.61 1 100.61
HP 2 APPRO    100.61 * * 2500
*
HP 1 BRIDG    97.30 1 97.30
HP 2 BRIDG    97.30 * * 2173
HP 2 RDWAY    101.34 * * 1249
HP 1 APPRO    101.44 1 101.44
HP 2 APPRO    101.44 * * 3400
*
HP 1 BRIDG    94.55 1 94.55
HP 2 BRIDG    94.55 * * 1760
HP 1 APPRO    97.44 1 97.44
```

APPENDIX B:

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
        HYDRAULIC ANALYSIS OF BRID037
           *** RUN DATE & TIME: 09-26-95  14:21
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     196.  19791.    10.    54.                         4806.
    97.30          196.  19791.    10.    54.  1.00     0.    30.   4806.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        97.30     0.0    29.5   195.8   19791.    2027.  10.35

X STA.         0.0         3.2         4.7         5.9         7.1         8.2
  A(I)             16.4         9.6         8.1         7.6         7.4
  V(I)             6.18       10.57       12.51       13.26       13.70

X STA.         8.2         9.3        10.3        11.3        12.4        13.6
  A(I)              7.0         7.1         6.9         6.9         8.4
  V(I)            14.39       14.32       14.61       14.61       12.07

X STA.        13.6        15.0        16.4        17.8        19.2        20.6
  A(I)              9.4         9.4         9.6         9.5         9.9
  V(I)            10.73       10.73       10.59       10.66       10.20

X STA.        20.6        22.1        23.5        25.1        26.8        29.5
  A(I)             10.0        10.2        11.0        12.1        19.2
  V(I)            10.17        9.96        9.22        8.41        5.28

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      10.
         WSEL     LEW     REW    AREA        K        Q    VEL
       100.56   -69.6    60.2   123.6    2801.     519.   4.20

X STA.       -69.6       -59.1       -53.0       -46.7       -39.6       -32.1
  A(I)              9.9         8.0         7.9         8.4         8.6
  V(I)             2.63        3.23        3.30        3.07        3.03

X STA.       -32.1       -23.8       -15.4       -10.6        -6.6        -2.6
  A(I)              8.9         8.9         5.0         4.2         4.2
  V(I)             2.91        2.93        5.17        6.21        6.21

X STA.        -2.6         1.3         5.4         9.7        14.1        18.7
  A(I)              4.2         4.3         4.3         4.5         4.5
  V(I)             6.22        6.10        6.01        5.81        5.75

X STA.        18.7        23.5        28.5        33.9        40.1        60.2
  A(I)              4.6         4.7         5.0         5.5         8.1
  V(I)             5.59        5.50        5.16        4.74        3.20

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     119.  13905.    43.    43.                         1127.
             2     502.  71593.    60.    65.                         8238.
   100.61          621.  85499.   103.   108.  1.02   -59.    43.   8599.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       100.61   -59.4    43.2   620.8   85499.    2500.   4.03

X STA.       -59.4       -39.3       -28.2       -19.0       -10.7        -6.6
  A(I)             44.0        34.4        32.3        40.8        33.0
  V(I)             2.84        3.63        3.87        3.06        3.79

X STA.        -6.6        -3.6        -0.9         1.7         4.1         6.5
  A(I)             28.4        27.0        26.6        25.5        25.5
  V(I)             4.40        4.63        4.70        4.91        4.89

X STA.         6.5         8.9        11.3        13.7        16.1        18.5
  A(I)             25.3        25.4        25.7        25.8        26.8
  V(I)             4.93        4.92        4.86        4.85        4.67

X STA.        18.5        20.9        23.4        26.2        30.0        43.2
  A(I)             26.3        28.1        29.8        35.7        54.3
  V(I)             4.75        4.45        4.20        3.50        2.30
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      U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
       CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
       HYDRAULIC ANALYSIS OF BRID037
          *** RUN DATE & TIME: 09-26-95  14:21
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =      0.
    WSEL  SA#    AREA       K   TOPW   WETP  ALPH    LEW    REW     QCR
            1    196.  19791.    10.    54.                        4806.
   97.30         196.  19791.    10.    54.  1.00     0.    30.   4806.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =      0.
        WSEL     LEW     REW    AREA       K       Q    VEL
       97.30     0.0    29.5   195.8   19791.   2173.  11.10

X STA.        0.0        3.2        4.7        5.9        7.1        8.2
  A(I)           16.4        9.6        8.1        7.6        7.4
  V(I)           6.63      11.33      13.41      14.22      14.68

X STA.        8.2        9.3       10.3       11.3       12.4       13.6
  A(I)            7.0        7.1        6.9        6.9        8.4
  V(I)          15.42      15.36      15.66      15.66      12.94

X STA.       13.6       15.0       16.4       17.8       19.2       20.6
  A(I)            9.4        9.4        9.6        9.5        9.9
  V(I)          11.51      11.50      11.35      11.43      10.94

X STA.       20.6       22.1       23.5       25.1       26.8       29.5
  A(I)           10.0       10.2       11.0       12.1       19.2
  V(I)          10.90      10.68       9.89       9.02       5.66

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =     10.
        WSEL     LEW     REW    AREA       K       Q    VEL
      101.34   -73.2    79.8   233.9    7525.   1249.   5.34

X STA.      -73.2      -58.9      -51.1      -43.0      -34.6      -26.1
  A(I)           20.0       16.2       16.2       16.3       16.0
  V(I)           3.12       3.86       3.87       3.83       3.91

X STA.      -26.1      -17.0      -11.1       -6.9       -2.6        1.7
  A(I)           16.7       10.8        7.7        7.9        7.9
  V(I)           3.74       5.77       8.14       7.95       7.95

X STA.        1.7        6.1       10.7       15.3       20.1       25.1
  A(I)            8.0        8.2        8.3        8.3        8.7
  V(I)           7.82       7.66       7.50       7.50       7.15

X STA.       25.1       30.2       35.6       41.7       50.5       79.8
  A(I)            8.8        9.2        9.9       11.8       17.1
  V(I)           7.09       6.77       6.29       5.30       3.65

    WSEL  SA#    AREA       K   TOPW   WETP  ALPH    LEW    REW     QCR
            1    155.  20883.    45.    46.                        1636.
            2    552.  82629.    61.    66.                        9405.
  101.44         708. 103512.   106.   112.  1.01   -62.    45.  10329.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     50.
        WSEL     LEW     REW    AREA       K       Q    VEL
      101.44   -61.8    44.5   707.5  103512.   3400.   4.81

X STA.      -61.8      -43.0      -33.2      -24.5      -17.1       -9.8
  A(I)           48.4       36.7       35.8       32.9       46.3
  V(I)           3.51       4.63       4.75       5.17       3.67

X STA.       -9.8       -6.0       -2.9       -0.1        2.6        5.1
  A(I)           35.7       31.8       30.5       30.1       28.9
  V(I)           4.76       5.35       5.58       5.65       5.87

X STA.        5.1        7.7       10.2       12.8       15.4       18.0
  A(I)           29.3       29.4       29.8       29.7       30.8
  V(I)           5.79       5.79       5.71       5.72       5.52

X STA.       18.0       20.6       23.3       26.3       30.4       44.5
  A(I)           30.3       32.5       35.6       40.3       62.7
  V(I)           5.61       5.23       4.78       4.22       2.71
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         U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
        HYDRAULIC ANALYSIS OF BRID037
           *** RUN DATE & TIME: 09-26-95  14:21
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      132.   13691.    24.    35.                      1759.
    94.55           132.   13691.    24.    35.  1.00     0.    30.   1759.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        94.55     0.4    29.5   131.9   13691.    1760.  13.35

X STA.         0.4        3.6        5.4        7.0        8.4        9.7
  A(I)            11.7        7.5        6.5        6.2        5.8
  V(I)            7.53      11.78      13.45      14.29      15.19

X STA.         9.7       10.9       12.2       13.4       14.6       15.8
  A(I)             5.8        5.4        5.6        5.4        5.4
  V(I)           15.22      16.19      15.62      16.28      16.21

X STA.        15.8       16.9       18.1       19.3       20.5       21.7
  A(I)             5.4        5.5        5.5        5.5        5.7
  V(I)           16.21      16.13      15.87      15.92      15.53

X STA.        21.7       22.9       24.2       25.5       27.0       29.5
  A(I)             5.8        6.0        6.5        7.5       13.0
  V(I)           15.08      14.61      13.44      11.76       6.76

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1        5.     121.    15.    15.                        14.
             2      320.   36027.    55.    59.                      4378.
    97.44           324.   36149.    70.    74.  1.02   -32.    38.   3923.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
        97.44   -31.9    38.1   324.3   36149.    1760.   5.43

X STA.       -31.9       -8.0       -4.8       -2.4       -0.1        2.0
  A(I)            30.2       18.9       16.1       15.6       14.8
  V(I)            2.91       4.66       5.47       5.65       5.93

X STA.         2.0        3.9        5.8        7.6        9.5       11.3
  A(I)            14.0       14.2       13.7       13.6       13.6
  V(I)            6.30       6.21       6.41       6.48       6.47

X STA.        11.3       13.1       14.9       16.7       18.4       20.1
  A(I)            13.6       13.7       13.6       13.5       13.8
  V(I)            6.47       6.43       6.46       6.51       6.38

X STA.        20.1       21.9       23.7       25.8       28.7       38.1
  A(I)            14.1       14.8       16.1       18.8       27.7
  V(I)            6.25       5.96       5.47       4.69       3.18
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WSPRO OUTPUT FILE (continued)

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
        HYDRAULIC ANALYSIS OF BRID037
           *** RUN DATE & TIME: 09-26-95  14:21

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

EXITX:XS   ******   -13.     269.  1.34 *****   96.34   94.36   2500.   95.00
      -39. ******    54.   21918.  1.00 ***** *******    0.82    9.29

FULLV:FV      39.   -13.     301.  1.08  0.44   96.76 *******   2500.   95.69
        0.    39.    58.   25277.  1.00  0.00   -0.02    0.71    8.32
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.86      95.88      95.38

 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    95.19     104.87    0.50

 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    95.19     104.87      95.38

APPRO:AS      50.   -15.     237.  1.74  0.53   97.61   95.38   2500.   95.88
       50.    50.    36.   23165.  1.00  0.33   -0.02    0.86   10.56
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =    99.71       0.00      96.02      99.20

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   102.71         0.      2500.

 ===280 REJECTED FLOW CLASS 4 SOLUTION.

 ===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      39.     0.     196.  1.67 *****   98.97   95.10   2027.   97.30
        0. ******    30.   19791.  1.00 ***** *******    0.71   10.35

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.494  0.000   97.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      10.    36.  0.03  0.26  100.84    0.02    519.  100.56

            Q    WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    411.    89.   -70.    20.   1.4   1.1   5.1   4.2   1.4   2.9
   RT:    108.    41.    20.    60.   1.0   0.7   4.2   4.0   0.9   2.9

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

APPRO:AS      24.   -59.     621.  0.26  0.07  100.87   95.38   2500.  100.61
       50.    25.    43.   85537.  1.02  0.00    0.02    0.29    4.03

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW     REW       Q        K      AREA     VEL    WSEL
   EXITX:XS     -39.   -13.     54.   2500.   21918.     269.     9.29   95.00
   FULLV:FV       0.   -13.     58.   2500.   25277.     301.     8.32   95.69
   BRIDG:BR       0.     0.     30.   2027.   19791.     196.    10.35   97.30
   RDWAY:RG      10.*******   411.    519.******************     2.00  100.56
   APPRO:AS      50.   -59.     43.   2500.   85537.     621.     4.03  100.61

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS     94.36    0.82   88.34  107.87************  1.34   96.34   95.00
   FULLV:FV  ********    0.71   88.57  108.10  0.44  0.00  1.08   96.76   95.69
   BRIDG:BR     95.10    0.71   88.14   97.53************  1.67   98.97   97.30
   RDWAY:RG  ****************   99.20  103.76  0.03******  0.26  100.84  100.56
   APPRO:AS     95.38    0.29   89.29  104.87  0.07  0.00  0.26  100.87  100.61
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WSPRO OUTPUT FILE (continued)

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
        HYDRAULIC ANALYSIS OF BRID037
           *** RUN DATE & TIME: 09-26-95  14:21

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

EXITX:XS   ******   -14.     342.  1.54 *****   97.55   95.36   3400.   96.01
      -39. ******    63.   29809.  1.00 ***** *******    0.83    9.96

FULLV:FV      39.   -25.     381.  1.25  0.44   97.97 *******   3400.   96.72
        0.    39.    66.   34619.  1.01  0.00   -0.02    0.77    8.91
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.92      96.79      96.45

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    96.22     104.87    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    96.22     104.87      96.45

APPRO:AS      50.   -17.     284.  2.23  0.56   99.01   96.45   3400.   96.78
       50.    50.    37.   30022.  1.00  0.49   -0.01    0.92   11.97
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   102.40       0.00      97.10      99.20

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   103.24         0.      3400.

 ===280 REJECTED FLOW CLASS 4 SOLUTION.

 ===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      39.     0.     196.  1.92 *****   99.22   95.39   2173.   97.30
        0. ******    30.   19791.  1.00 ***** *******    0.76   11.10

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.498  0.000   97.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      10.    36.  0.04  0.36  101.76    0.01    1249.  101.34

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    911.    93.    -73.    20.   2.1   1.8   6.6   5.5   2.2   3.0
   RT:    338.    60.     20.    80.   1.7   1.1   5.5   5.1   1.5   3.0

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

APPRO:AS      24.   -62.     707.  0.36  0.09  101.80   96.45   3400.  101.44
       50.    25.    45.  103509.  1.01  0.00    0.01    0.33    4.81

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -39.   -14.    63.   3400.   29809.     342.    9.96   96.01
   FULLV:FV       0.   -25.    66.   3400.   34619.     381.    8.91   96.72
   BRIDG:BR       0.     0.    30.   2173.   19791.     196.   11.10   97.30
   RDWAY:RG      10.*******   911.   1249.******************    2.00  101.34
   APPRO:AS      50.   -62.    45.   3400.  103509.     707.    4.81  101.44

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS      95.36    0.83   88.34  107.87************  1.54   97.55   96.01
   FULLV:FV   ********    0.77   88.57  108.10  0.44  0.00  1.25   97.97   96.72
   BRIDG:BR      95.39    0.76   88.14   97.53************  1.92   99.22   97.30
   RDWAY:RG   ****************   99.20  103.76  0.04******  0.36  101.76  101.34
   APPRO:AS      96.45    0.33   89.29  104.87  0.09  0.00  0.36  101.80  101.44
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid037.wsp
        CREATED ON 26-SEP-95 FOR BRIDGE BRIDTH00050037 USING FILE brid037.dca
        HYDRAULIC ANALYSIS OF BRID037
           *** RUN DATE & TIME: 09-26-95  14:21

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

EXITX:XS   ******   -12.     204.  1.16 *****   95.10   93.30   1760.   93.94
      -39. ******    45.   15424.  1.00 ***** *******    0.80    8.64

FULLV:FV      39.   -12.     229.  0.92  0.44   95.53 *******   1760.   94.61
        0.    39.    49.   17874.  1.00  0.00   -0.01    0.70    7.68
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.82      94.90      94.35

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    94.11     104.87    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    94.11     104.87      94.35

APPRO:AS      50.   -13.     190.  1.34  0.51   96.25   94.35   1760.   94.91
       50.    50.    34.   16829.  1.00  0.21    0.00    0.82    9.28
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID "BRIDG"     Q,CRWS =    1760.      94.55

            <<<<<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      39.     0.     132.  2.78 *****   97.32   94.55   1760.   94.55
        0.    39.    30.   13674.  1.00 ***** *******    1.00   13.36

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******   97.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      10.        <<<<<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      24.   -32.     325.  0.47  0.16   97.91   94.35   1760.   97.44
       50.    25.    38.   36192.  1.02  0.43    0.00    0.45    5.42

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.383  0.161   30348.    -3.    26.    97.36

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -39.   -12.    45.   1760.   15424.     204.    8.64   93.94
   FULLV:FV       0.   -12.    49.   1760.   17874.     229.    7.68   94.61
   BRIDG:BR       0.     0.    30.   1760.   13674.     132.   13.36   94.55
   RDWAY:RG      10.**************       0.******************    2.00********
   APPRO:AS      50.   -32.    38.   1760.   36192.     325.    5.42   97.44

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS      FR#     YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS      93.30     0.80    88.34  107.87************  1.16    95.10   93.94
   FULLV:FV  ********     0.70    88.57  108.10  0.44  0.00  0.92    95.53   94.61
   BRIDG:BR      94.55     1.00    88.14   97.53************  2.78    97.32   94.55
   RDWAY:RG  ****************    99.20  103.76**********************************
   APPRO:AS      94.35     0.45    89.29  104.87  0.16  0.43  0.47    97.91   97.44
```
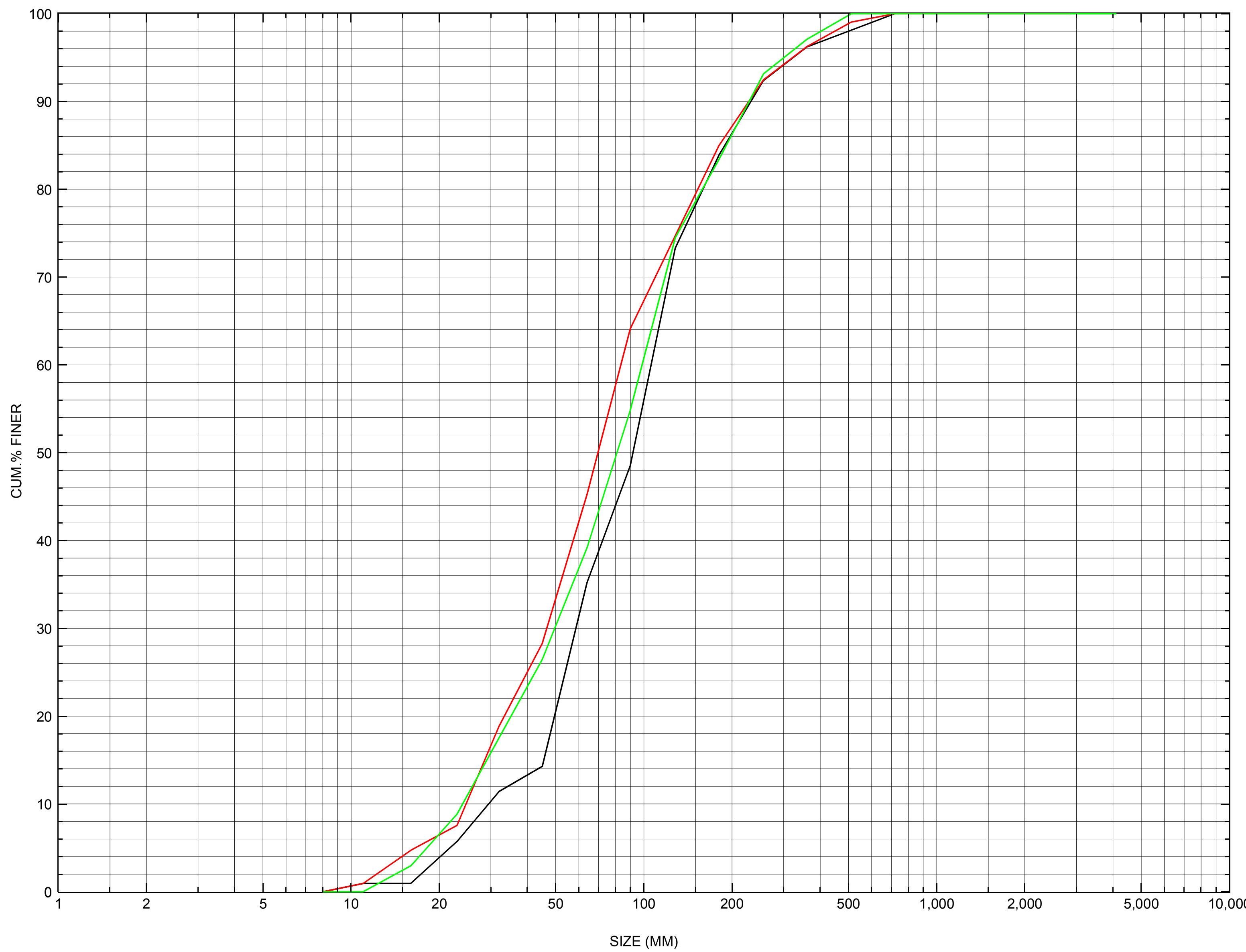

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00050037, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM