LEVEL II SCOUR ANALYSIS FOR BRIDGE 32 (BRIDTH00050032) on TOWN HIGHWAY 5, crossing the NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-152

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

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By SCOTT A. OLSON

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Pembroke, New Hampshire
1996

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

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

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

OTHER ABBREVIATIONS

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

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

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

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 32 (BRIDTH00050032) ON TOWN HIGHWAY 5, CROSSING THE NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

By **Scott A. Olson**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00050032 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. The 4.37-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the US left bank is lawn; DS left bank is pasture; US right bank is shrub and brushland and the DS right bank is forested.

In the study area, the North Branch Ottauquechee River has an incised channel with a slope of approximately 0.0148 ft/ft, an average channel top width of 25 ft and an average channel depth of 9 ft. The predominant channel bed materials are gravel and cobbles (D_{50} is 79.6 mm or 0.261 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 4, 1994, indicated that the reach was stable.

The town highway 5 crossing of the North Branch Ottauquechee River is a 27-ft-long, one-lane bridge consisting of one 25-foot steel-beam span with a timber deck (Vermont Agency of Transportation, written commun., August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The DS left road approach is protected by type-1 stone fill (less than 12 inches). The DS right road approach is not protected and is eroded slightly by road wash. The US left bank is protected by type-2 stone fill (less than 36 inches). A stream confluence is located approximately 130 US of the bridge. The channel is skewed approximately 30 degrees to the opening. 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, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

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 BRIDTH00050032 ***Stream*** North Branch Ottauquechee R.

County Windsor ***Road*** TH005 ***District*** 04

Description of Bridge

Bridge length 27 ***ft*** ***Bridge width*** 13 ***ft*** ***Max span length*** 25 ***ft***

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

Abutment type vertical ***Embankment type*** sloping

Stone fill on abutment? no ***Date of inspection*** 11/04/94

Description of stone fill On DS left road approach,Type-1. Also, Type-2 on US and DS wingwalls.

Brief description of piers/abutments Abutments are concrete and the left abutment is noted as having an exposed footing with approximately 1 foot of scour.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 30

Bridge is located on a mild bend in the channel. (Opening skew to roadway is also 30 degrees).

11/04/94

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	0 94	0 --	11/04/ --
Level II	Low		

Potential for debris

--

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 at the headwaters of the N. Br. Ottauquechee R. in a steep, upland, incised channel.

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

Date of inspection 11/04/94

DS left: flood plain

DS right: wide terrace to valley wall

US left: terrace to valley wall

US right: wide terrace to valley wall

Description of the Channel

Average top width 25 ***ft*** ***Average depth*** 9 ***ft***

Predominant bed material gravel and cobbles ***Bank material*** gravel

Narrow, incised channel with only slight sinuosity.

Vegetative co... 11/04/94

lawn and pasture

DS left: forest

DS right: lawn

US left: shrubs and brush

US right:

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

11/04/94--Both the US banks are reported to have light fluvial erosion and only the left bank is protected by type-2 stone fill. Only the DS right bank is reported eroded by light fluvial erosion and neither bank is protected.

Describe any obstructions in channel and date of observation.

11/04/94--Small rock dam constructed to create swimming hole approx. 50 ft DS of the bridge and 20 ft DS of the EXIT cross-section.

Hydrology

Drainage area 4.4 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	*Percent of drainage area*
Green Mountain	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: None. Area is mostly forested, high-elevation, headwater drainage.

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 1320 ***ft³/s*** ***Q500*** 1860 ***ft³/s***

Q100 was taken from VTAOT files. Q500 was determined by extrapolating data from empirical methods (Talbot, 1887; Potter, 1957a; Potter, 1957b; Johnson and Laraway, 1971, written commun.; Johnson and Tasker, 1974; Federal Highway Administration, 1983).

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

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

Datum tie between USGS survey and VTAOT plans Add 403 ft to USGS datum to get VTAOT datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled X at the junction between the right abutment and the US right wingwall (elev. 99.42 feet, arbitrary datum). RM2 is a chiseled square on the DS end of the left abutment on high concrete surface (elev. 99.54 feet, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-33	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	6	1	Road Grade section
APPRO	65	1	Approach section

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

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). 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 0.050 to 0.060, and overbank "n" values ranged from 0.035 to 0.115.

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 0.0148 ft/ft which was derived from analysis of surveyed thalweg points, edge of water points and the measured channel slope from the topographic map (U.S. Geological Survey, 1966).

The modelled 100-year disharge of 1,320 cfs was also the incipient overtopping discharge.

Bridge Hydraulics Summary

Average bridge embankment elevation 100.1 ***ft***
Average low steel elevation 98.0 ***ft***

100-year discharge 1320 ***ft^3/s***
Water-surface elevation in bridge opening 98.0 ***ft***
Road overtopping? N ***Discharge over road*** -- ***ft³/s***
Area of flow in bridge opening 162 ***ft^2***
Average velocity in bridge opening 8.1 ***ft/s***
Maximum WSPRO tube velocity at bridge 10.0 ***ft/s***

Water-surface elevation at Approach section with bridge 99.6
Water-surface elevation at Approach section without bridge 96.7
Amount of backwater caused by bridge 2.9 ***ft***

500-year discharge 1860 ***ft^3/s***
Water-surface elevation in bridge opening 98.0 ***ft***
Road overtopping? Y ***Discharge over road*** 321 ***ft³/s***
Area of flow in bridge opening 162 ***ft^2***
Average velocity in bridge opening 9.4 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.2 ***ft/s***

Water-surface elevation at Approach section with bridge 100.5
Water-surface elevation at Approach section without bridge 97.4
Amount of backwater caused by bridge 3.1

Incipient overtopping discharge -- ***ft^3/s***
Water-surface elevation in bridge opening -- ***ft***
Area of flow in bridge opening -- ***ft^2***
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, 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.

Contraction scour was computed by use of the Chang pressure-flow scour equation (Richardson and others, 1995, p. 145-146). For each of the modelled discharges, there was orifice flow at the bridge. 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). The results of Laursen's clear-water contraction scour equation (Richardson and others, 1995, p. 32, equation 20) were also computed and can be found in appendix F. 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.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). 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 Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.0	0.2	--
Depth to armoring	1.1	2.9	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	9.4	11.9	--
Right abutment	5.8	7.4	--
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	1.5	2.0	--
Right abutment	1.5	2.0	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

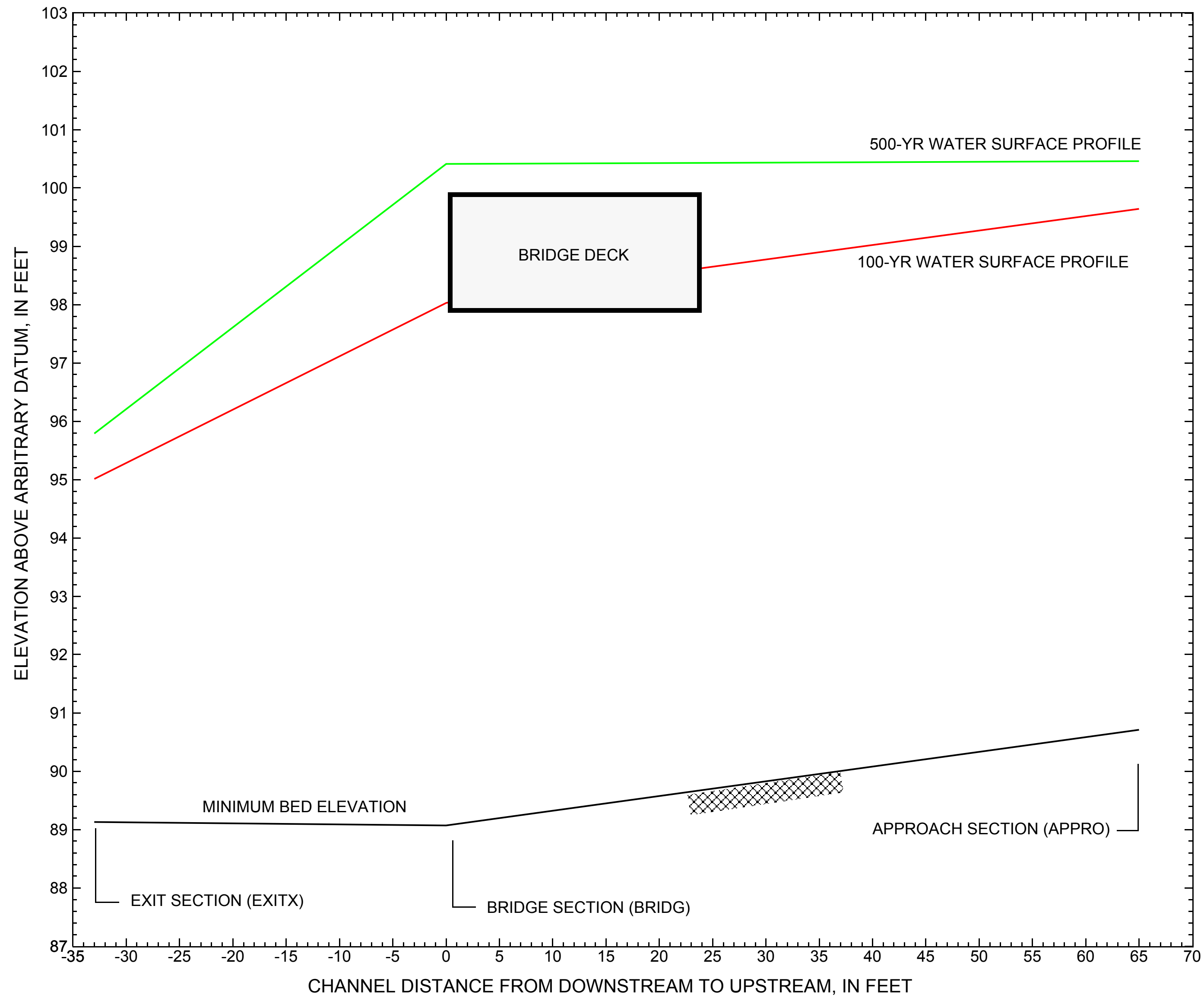

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00050032 on town highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.

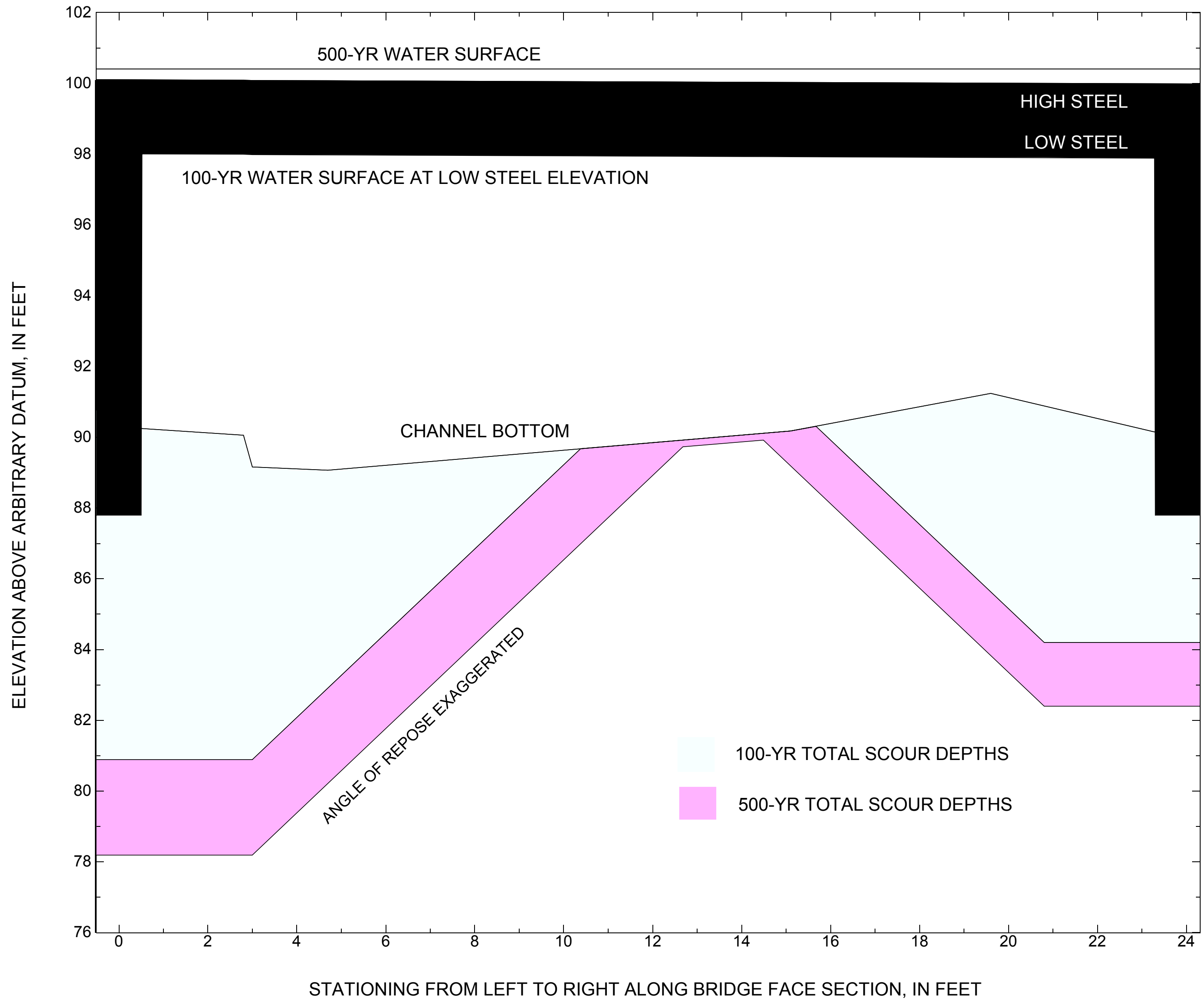

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00050032 on town highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00050032 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.
[VTAOT, Vermont Agency of Transportation; --,no data]

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 1,320 cubic-feet per second											
Left abutment	0.0	500.5	98.0	88	90.3	0.0	9.4	--	9.4	80.9	-7
Right abutment	23.8	500.9	97.9	88	90.0	0.0	5.8	--	5.8	84.2	-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 BRIDTH00050032 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 1,860 cubic-feet per second											
Left abutment	0.0	500.5	98.0	88	90.3	0.2	11.9	--	12.1	78.2	-10
Right abutment	23.8	500.9	97.9	88	90.0	0.2	7.4	--	7.6	82.4	-6

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

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APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid032.wsp
T2        CREATED ON 24-JUL-95 FOR BRIDGE BRIDTH00050032 USING FILE brid032.dca
T3        hydraulic analysis for bridge 032 crossing N. Br Ottauquechee R.
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          1320 1860
SK         0.0148  0.0148
*
XS   EXITX   -33
GR         -184.0, 132.59   -124.1,  99.07   -106.5,  96.08    -77.6,  96.43
GR          -66.2,  97.63    -44.1,  98.41    -26.4,  93.95     -9.3,  93.78
GR           -5.8,  92.33      0.0,  89.72      6.2,  89.25     10.5,  89.47
GR           13.1,  89.13     19.2,  89.78     21.7,  92.11     23.0,  93.65
GR           34.1,  95.74     62.4,  99.19    117.2,  98.13    180.9,  97.12
GR          245.0,  96.44    257.7, 106.18
N           0.035        0.060       0.115
SA               -9.3            23
*
XS   FULLV   0 * * *  0.0148
*
BR   BRIDG   0 98.0 30
GR            0.0,  98.03      0.2,  90.29      2.8,  90.06      3.0,  89.16
GR            4.7,  89.07      9.1,  89.55     15.1,  90.18     19.6,  91.24
GR           23.5,  90.00     23.8,  97.88      0.0,  98.03
N              0.050
CD            1 38 * * 67.5 1.9
*
*           (RDWAY stations -129 and -117.4 are from the approach left over-
*           bank since the "control of flow" bypassing the opening is best
*           represented by this line)
*
XR   RDWAY   6 13 2
GR         -129.0, 107.55   -117.4, 100.04    -35.1,  99.25      0.0, 100.15
GR           24.6,  99.96     99.1, 101.78    166.9, 102.95    241.9, 106.19
BP           0
*
*              (station 99.1 of RDWAY is actually 17.3 feet from approach
*               station 65.3. The last three points of approach are from
*               the roadway section adjusted as shown)
*
AS   APPRO   65 * 0.7
GR          -43.3, 107.55    -31.7, 100.04     -7.4,  98.41     -2.9,  93.83
GR            0.0,  91.52      0.5,  90.87      4.0,  90.71      8.7,  91.57
GR           12.2,  92.02     16.8,  92.30     21.5,  93.35     23.7,  95.06
GR           27.0,  99.14     65.3, 101.12     82.6, 101.78    151.9, 102.95
GR           228.5, 106.19
N            0.052        0.060        0.035
SA               -7.4        44.3
BP           0
*
HP 1 BRIDG    98.03 1 98.03
HP 2 BRIDG    98.03 * * 1320
HP 1 APPRO    99.64 1 99.64
HP 2 APPRO    99.64 * * 1320
*
HP 1 BRIDG    98.00 1 98.00
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid032.wsp
       CREATED ON 24-JUL-95 FOR BRIDGE BRIDTH00050032 USING FILE brid032.dca
       hydraulic analysis for bridge 032 crossing N. Br Ottauquechee R.
          *** RUN DATE & TIME: 09-12-95  13:48
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     162.    9585.     0.    58.                          0.
   98.03          162.    9585.     0.    58.  1.00     0.    24.      0.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
       WSEL     LEW     REW    AREA        K        Q    VEL
      98.03     0.0    23.8   161.7    9585.    1320.   8.16
X STA.         0.0         2.2         3.5         4.5         5.5         6.4
  A(I)            14.3         9.4         7.8         7.3         6.8
  V(I)            4.60        7.05        8.45        9.02        9.70

X STA.         6.4         7.3         8.2         9.1        10.0        10.9
  A(I)             6.8         6.8         6.6         6.7         6.6
  V(I)            9.67        9.74       10.02        9.90       10.03

X STA.        10.9        11.9        12.8        13.9        14.9        16.0
  A(I)             6.8         6.7         6.9         7.1         7.2
  V(I)            9.70        9.83        9.51        9.36        9.14

X STA.        16.0        17.1        18.4        19.9        21.4        23.8
  A(I)             7.5         7.9         8.4         9.5        14.5
  V(I)            8.82        8.30        7.83        6.98        4.54

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      65.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      11.     233.    18.    18.                         50.
            2     228.   15572.    44.    50.                       2940.
   99.64          239.   15805.    62.    68.  1.05   -26.    37.   2586.

  VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      65.
       WSEL     LEW     REW    AREA        K        Q    VEL
      99.64   -25.7    36.7   239.1   15805.    1320.   5.52
X STA.       -25.7        -3.4        -1.3         0.1         1.3         2.3
  A(I)            24.2        13.0        11.0        10.0         8.9
  V(I)            2.73        5.08        5.97        6.61        7.39

X STA.         2.3         3.3         4.2         5.2         6.2         7.3
  A(I)             8.7         8.7         8.6         8.8         8.9
  V(I)            7.60        7.59        7.67        7.50        7.43

X STA.         7.3         8.4         9.5        10.8        12.1        13.4
  A(I)             9.0         9.4         9.7        10.1        10.2
  V(I)            7.33        7.05        6.83        6.52        6.48

X STA.        13.4        14.9        16.5        18.4        20.7        36.7
  A(I)            11.2        12.0        13.1        15.9        27.8
  V(I)            5.91        5.48        5.05        4.15        2.38

       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid032.wsp
       CREATED ON 24-JUL-95 FOR BRIDGE BRIDTH00050032 USING FILE brid032.dca
       hydraulic analysis for bridge 032 crossing N. Br Ottauquechee R.
          *** RUN DATE & TIME: 09-12-95  13:48
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     162.   10069.     4.    53.                       5742.
   98.00          162.   10069.     4.    53.  1.00     0.    24.   5742.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
       WSEL     LEW     REW    AREA        K        Q    VEL
      98.00     0.0    23.8   161.6   10069.    1522.   9.42
X STA.         0.0         2.1         3.3         4.1         5.0         5.8
  A(I)            13.6         8.3         6.6         6.2         6.7
  V(I)            5.60        9.16       11.46       12.20       11.36

X STA.         5.8         6.7         7.6         8.5         9.5        10.4
  A(I)             6.8         6.7         6.8         6.8         6.9
  V(I)           11.22       11.38       11.22       11.27       11.06

X STA.        10.4        11.4        12.4        13.4        14.5        15.6
  A(I)             6.9         7.0         7.2         7.4         7.7
  V(I)           11.02       10.82       10.64       10.26        9.91

X STA.        15.6        16.9        18.2        19.7        21.3        23.8
  A(I)             7.8         8.3         8.8         9.7        15.5
  V(I)            9.73        9.17        8.67        7.84        4.93
```

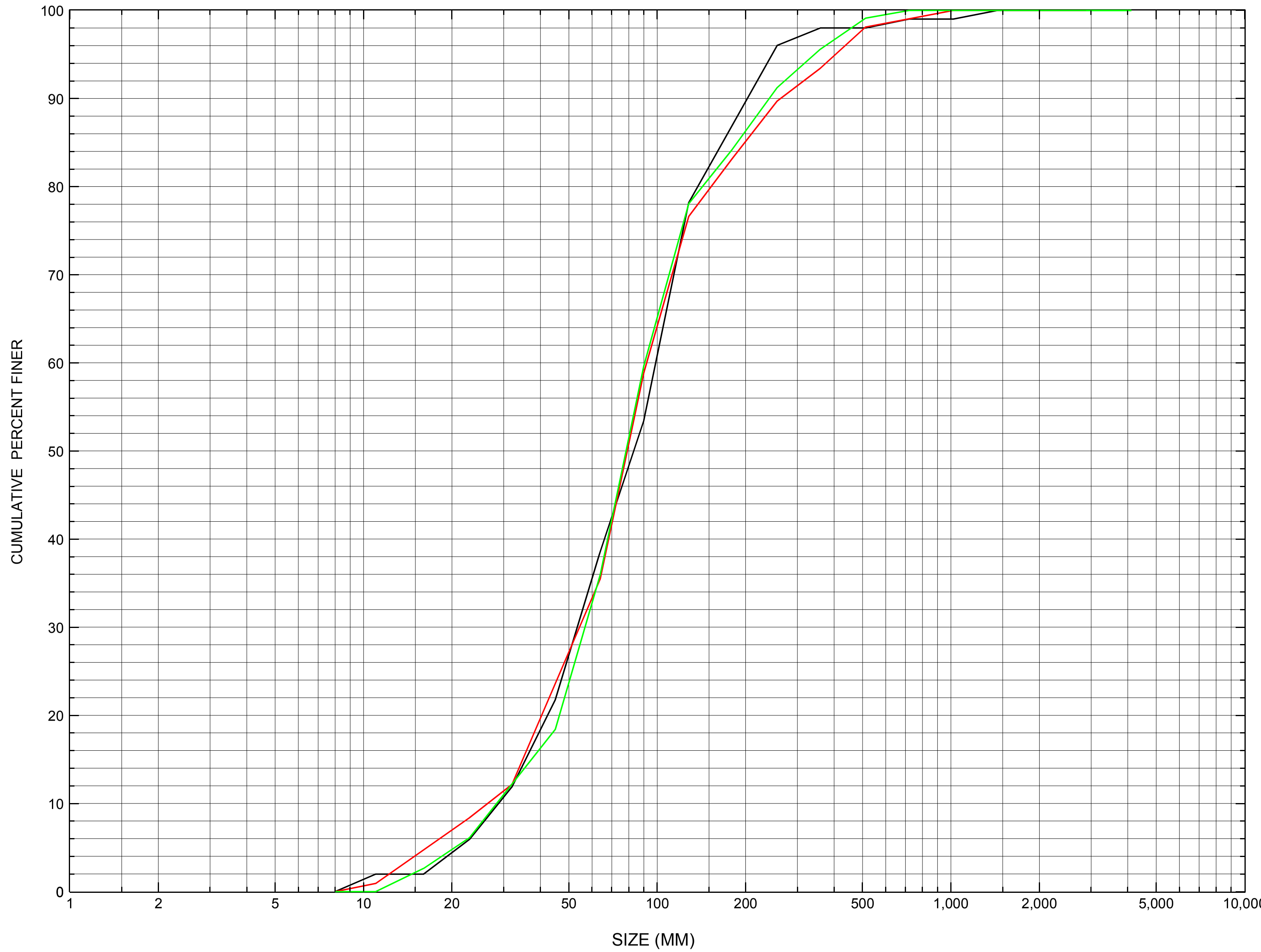
```
   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       6.
        WSEL     LEW     REW    AREA        K        Q    VEL
      100.41  -118.0    43.0   100.9    3206.     321.   3.18
 X STA.      -118.0     -102.2      -92.1      -83.9      -77.0      -71.1
  A(I)            6.8        5.7        5.3        5.0        4.7
  V(I)           2.35       2.82       3.00       3.19       3.45

 X STA.       -71.1      -65.8      -60.9      -56.4      -52.3      -48.4
  A(I)            4.5        4.3        4.2        4.0        3.9
  V(I)           3.60       3.70       3.83       3.99       4.09

 X STA.       -48.4      -44.8      -41.4      -38.1      -34.9      -31.6
  A(I)            3.8        3.7        3.7        3.6        3.7
  V(I)           4.23       4.36       4.35       4.43       4.30

 X STA.       -31.6      -27.8      -23.3      -17.5       -8.4       43.0
  A(I)            3.9        4.1        4.5        5.4       16.0
  V(I)           4.15       3.89       3.54       2.99       1.01

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      65.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      30.     975.    25.    25.                         188.
            2     269.   18646.    52.    58.                        3477.
            3       2.      27.     8.     8.                           5.
  100.46          301.   19648.    85.    91.  1.08   -32.    53.   3087.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      65.
        WSEL     LEW     REW    AREA        K        Q    VEL
      100.46   -32.3    52.5   300.6   19648.    1860.   6.19
 X STA.       -32.3       -7.2       -2.9       -1.1        0.4        1.5
  A(I)           30.6       19.1       13.6       12.5       10.8
  V(I)           3.04       4.86       6.86       7.46       8.62

 X STA.         1.5        2.6        3.6        4.7        5.8        6.9
  A(I)           10.2       10.4       10.2       10.3       10.7
  V(I)           9.10       8.93       9.10       9.03       8.66

 X STA.         6.9        8.1        9.4       10.7       12.1       13.7
  A(I)           10.9       11.3       11.6       12.2       12.9
  V(I)           8.56       8.24       7.99       7.62       7.23

 X STA.        13.7       15.3       17.2       19.3       22.1       52.5
  A(I)           13.6       15.1       16.7       20.2       37.8
  V(I)           6.83       6.17       5.58       4.61       2.46

++ BEGINNING PROFILE CALCULATIONS --   2
  XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
        SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

 EXITX:XS   ******   -31.     177.  0.94 *****   95.95   94.49   1320.   95.01
      -33. ******    30.   10843.  1.08 ***** *******    0.80    7.47

  ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.80      95.51      94.98

  ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    94.51     133.08    0.50

  ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    94.51     133.08      94.98

 FULLV:FV      33.   -31.     176.  0.95  0.49   96.43   94.98   1320.   95.48
        0.    33.    30.   10750.  1.08  0.01   -0.02    0.81    7.52
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.90      96.67      96.35

  ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    94.98     107.55    0.50

  ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    94.98     107.55      96.35

  ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  0.70

 APPRO:AS      65.    -6.     127.  1.68  1.40   98.34   96.35   1320.   96.66
       65.    65.    25.    7511.  1.00  0.51    0.00    0.90   10.39
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>
```

```
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =    95.12      98.38      98.87      98.00

 ===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      33.     0.     162.  1.03 *****   99.06   95.10   1312.   98.03
        0. ******    24.    9585.  1.00 ***** *******    0.55    8.12

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.443  0.000   98.00 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       6.        <<<<<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      27.   -26.     239.  0.50  0.32  100.14   96.35   1320.   99.64
       65.    28.    37.   15807.  1.05  1.41   -0.01    0.51    5.52

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ******    99.28

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -33.   -31.    30.   1320.   10843.     177.    7.47   95.01
   FULLV:FV       0.   -31.    30.   1320.   10750.     176.    7.52   95.48
   BRIDG:BR       0.     0.    24.   1312.    9585.     162.    8.12   98.03
   RDWAY:RG       6.**************      0.       0.       0.    2.00********
   APPRO:AS      65.   -26.    37.   1320.   15807.     239.    5.52   99.64

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS     94.49    0.80   89.13  132.59************  0.94   95.95   95.01
   FULLV:FV     94.98    0.81   89.62  133.08  0.49  0.01  0.95   96.43   95.48
   BRIDG:BR     95.10    0.55   89.07   98.03************  1.03   99.06   98.03
   RDWAY:RG  ****************   99.25  107.55************  0.50   99.78********
   APPRO:AS     96.35    0.51   90.71  107.55  0.32  1.41  0.50  100.14   99.64


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

EXITX:XS   ******   -34.     227.  1.15 *****   96.94   95.27   1860.   95.79
      -33. ******    35.   15277.  1.10 ***** *******    0.83    8.18

 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     0.83      96.29      95.76

 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    95.29     133.08    0.50

 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    95.29     133.08      95.76

FULLV:FV      33.   -34.     226.  1.16  0.49   97.42   95.76   1860.   96.26
        0.    33.    34.   15160.  1.10  0.01   -0.02    0.84    8.23
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     1.00      97.44      97.43

 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    95.76     107.55    0.50

 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    95.76     107.55      97.43

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            “APPRO”     KRATIO =  0.64

APPRO:AS      65.    -6.     151.  2.36  1.54   99.79   97.43   1860.   97.43
       65.    65.    26.    9652.  1.00  0.84   -0.01    1.00   12.31
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>
```

```
 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   100.99       0.00      96.42      99.25

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                   WS,QBO,QRD =   101.98         0.      1860.

 ===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      33.     0.     162.  1.38 *****   99.38   95.63   1522.   98.00
        0. ******    24.   10069.  1.00 ***** *******    0.64    9.42

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.476  0.000   98.00 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       6.    52.  0.47  0.64  100.64   -0.01    321.  100.41

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    321.   117.  -117.     0.   1.2   0.7   4.2   3.7   1.0   2.8
   RT:      0.    14.    11.    25.   0.5   0.5   3.4   3.5   0.7   2.7

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

APPRO:AS      27.   -32.     301.  0.64  0.40  101.11   97.43   1860.  100.46
       65.    28.    53.   19663.  1.08  0.00   -0.01    0.60    6.18

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

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -33.    -34.    35.   1860.   15277.     227.    8.18   95.79
   FULLV:FV       0.    -34.    34.   1860.   15160.     226.    8.23   96.26
   BRIDG:BR       0.      0.    24.   1522.   10069.     162.    9.42   98.00
   RDWAY:RG       6.*******   321.    321.*********       0.    2.00  100.41
   APPRO:AS      65.    -32.    53.   1860.   19663.     301.    6.18  100.46

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  **********************
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS     95.27    0.83   89.13  132.59************  1.15    96.94   95.79
   FULLV:FV     95.76    0.84   89.62  133.08  0.49  0.01  1.16    97.42   96.26
   BRIDG:BR     95.63    0.64   89.07   98.03************  1.38    99.38   98.00
   RDWAY:RG  ***************    99.25  107.55  0.47******  0.64   100.64  100.41
   APPRO:AS     97.43    0.60   90.71  107.55  0.40  0.00  0.64   101.11  100.46
  ER

1  NORMAL  END  OF  WSPRO  EXECUTION.
```

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 BRIDTH00050032, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM