LEVEL II SCOUR ANALYSIS FOR BRIDGE 34 (BRIDTH00050034) on TOWN HIGHWAY 5, crossing NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-190

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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By JOSEPH D. AYOTTE

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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 03275-3718

Copies of this report may be
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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 34 (BRIDTH00050034) ON TOWN HIGHWAY 5, CROSSING NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

By Joseph D. Ayotte

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00050034 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 division of central Vermont in the town of Bridgewater. The 5.45-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, left and right banks are forested. Upstream of bridge 34, Town Highway 5 runs parallel to the right bank and DS of the bridge, parallel to the left bank.

In the study area, the North Branch Ottauquechee River has an incised channel with a slope of approximately 0.015 ft/ft, an average channel top width of 32 ft and an average channel depth of 7 ft. The predominant channel bed material is sand and gravel (D_{50} is 105 mm or 0.345 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 3, 1994, indicated that the reach was stable.

The town highway 5 crossing of the North Branch Ottauquechee River is a 40-ft-long, one-lane bridge consisting of one 29-foot steel beam span with timber deck (Vermont Agency of Transportation, written commun., August 24, 1994). The bridge is supported by stone (left) and log-crib (right) abutments with no wingwalls. The left abutment is sitting on bedrock and therefore may not experience scour as calculated and shown. Additionally, the channel under the bridge has bedrock outcropping and this may limit the amount of contraction scour that can occur. Abutments are not protected by stone fill.

The DS left road approach and bank is protected by type-2 stone fill (less than 36 inches). The DS right road approach is protected by type-1 stone fill (less than 12 inches). The right abutment is reported as undermined at the upstream end. One foot of channel scour was reported approximately 22 ft downstream of the bridge.

The channel approach to the bridge is skewed approximately 50 degrees; the opening-skew-to-roadway is 20 degrees. The resultant left abutment attack angle is approximately 30 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, 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 BRIDTH00050034 ***Stream*** North Branch Ottauquechee R.

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

Description of Bridge

Bridge length 40 ***ft*** ***Bridge width*** 14 ***ft*** ***Max span length*** 29 ***ft***

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

Abutment type vertical ***Embankment type*** none

Stone fill on abutment? no ***Date of inspection*** 11/03/94

Description of stone fill Type-2, in good condition, on DS left road approach. Type-1 on DS right road approach in good condition.

Brief description of piers/abutments Abutments are stone (left) and log crib (right). The right abutment is noted as having some undermining.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 50

The stream bends sharply immediately upstream of the bridge. 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	11/03/94	0	0
Level II	11/03/94	-	-

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

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

Date of inspection 11/03/94

DS left: narrow terrace to steep valley wall

DS right: steep valley wall

US left: steep valley wall

US right: narrow terrace to steep valley wall

Description of the Channel

Average top width 32 ***ft*** ***Average depth*** 7 ***ft***

Predominant bed material cobbles ***Bank material*** gravel/cobbles

Narrow, incised channel with only slight sinuosity.

11/03/94

Vegetative co

forest

DS left: forest

DS right: forest

US left: forest

US right: Y

Do banks appear stable? 11/03/94--Both the US left and right banks are reported to have no erosion. Only the DS right bank is reported eroded by light fluvial erosion and the right bank is reported to have moderate fluvial erosion.

date of observation.

11/03/94--none.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 5.45 ***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 1540 ***ft³/s*** ***Q500*** 2170 ***ft³/s***

Q100 and Q500 were determined by use of a drainage area relationship [(5.4/5.0) to the 0.7 power] with the dischages for bridge 33 just downstream of this site. The 100-year discharge at bridge 33 was from VTAOT files (VTAOT, written communication, May 1995). The 500-year discharge at bridge 33 was selected from a range defined by several different empirical methods (Talbot, 1887; Potter, 1957a; Potter, 1957b; Johnson and Laraway, 1971, written commun.; Johnson and Tasker, 1974; Federal Highway Administration, 1983, Richardson and others, 1993).

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 nail in the base of a hemlock tree 17 ft from US left side of deck (elev. 103.34, arbitrary datum). RM2 is a chiseled square in top of bedrock exposure 3 ft US of bridge on left side (elev. 96.02, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[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 0.053 to 0.090.

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

The surveyed approach section (SURVA) was moved along the approach channel slope (0.043 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.

Bridge Hydraulics Summary

Average bridge embankment elevation 99.2 *ft*
Average low steel elevation 97.5 *ft*

100-year discharge 1,540 ft^3/s
Water-surface elevation in bridge opening 97.7 *ft*
Road overtopping? Y *Discharge over road* 325 ft^3/s
Area of flow in bridge opening 121.4 ft^2
Average velocity in bridge opening 9.9 *ft/s*
Maximum WSPRO tube velocity at bridge 11.9 *ft/s*

Water-surface elevation at Approach section with bridge 100.3
Water-surface elevation at Approach section without bridge 98.8
Amount of backwater caused by bridge 1.5 *ft*

500-year discharge 2,170 ft^3/s
Water-surface elevation in bridge opening 97.7 *ft*
Road overtopping? Y *Discharge over road* 931 ft^3/s
Area of flow in bridge opening 121.4 ft^2
Average velocity in bridge opening 10.1 *ft/s*
Maximum WSPRO tube velocity at bridge 12.2 *ft/s*

Water-surface elevation at Approach section with bridge 101.3
Water-surface elevation at Approach section without bridge 99.7
Amount of backwater caused by bridge 1.6

Incipient overtopping discharge 833 ft^3/s
Water-surface elevation in bridge opening 96.3 *ft*
Area of flow in bridge opening 89 ft^2
Average velocity in bridge opening 9.4 *ft/s*
Maximum WSPRO tube velocity at bridge 11.7 *ft/s*

Water-surface elevation at Approach section with bridge 98.0
Water-surface elevation at Approach section without bridge 97.5
Amount of backwater caused by bridge 0.5 *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 the 100-year and 500-year discharges was computed by use ofthe 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. The channel under the bridge has bedrock outcropping and this may limit the amount of contraction scour that can occur.

Abutment scour for all modelled discharges 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. The left abutment is founded on bedrock and therefore may not experience scour as calculated and shown.

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	0.2	0.1	0
Depth to armoring	6.3	6.5	7.0
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	7.0	7.5	5.4
Right abutment	9.7	12.0	5.5
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	1.8	1.8	1.3
Right abutment	1.8	1.8	1.3
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

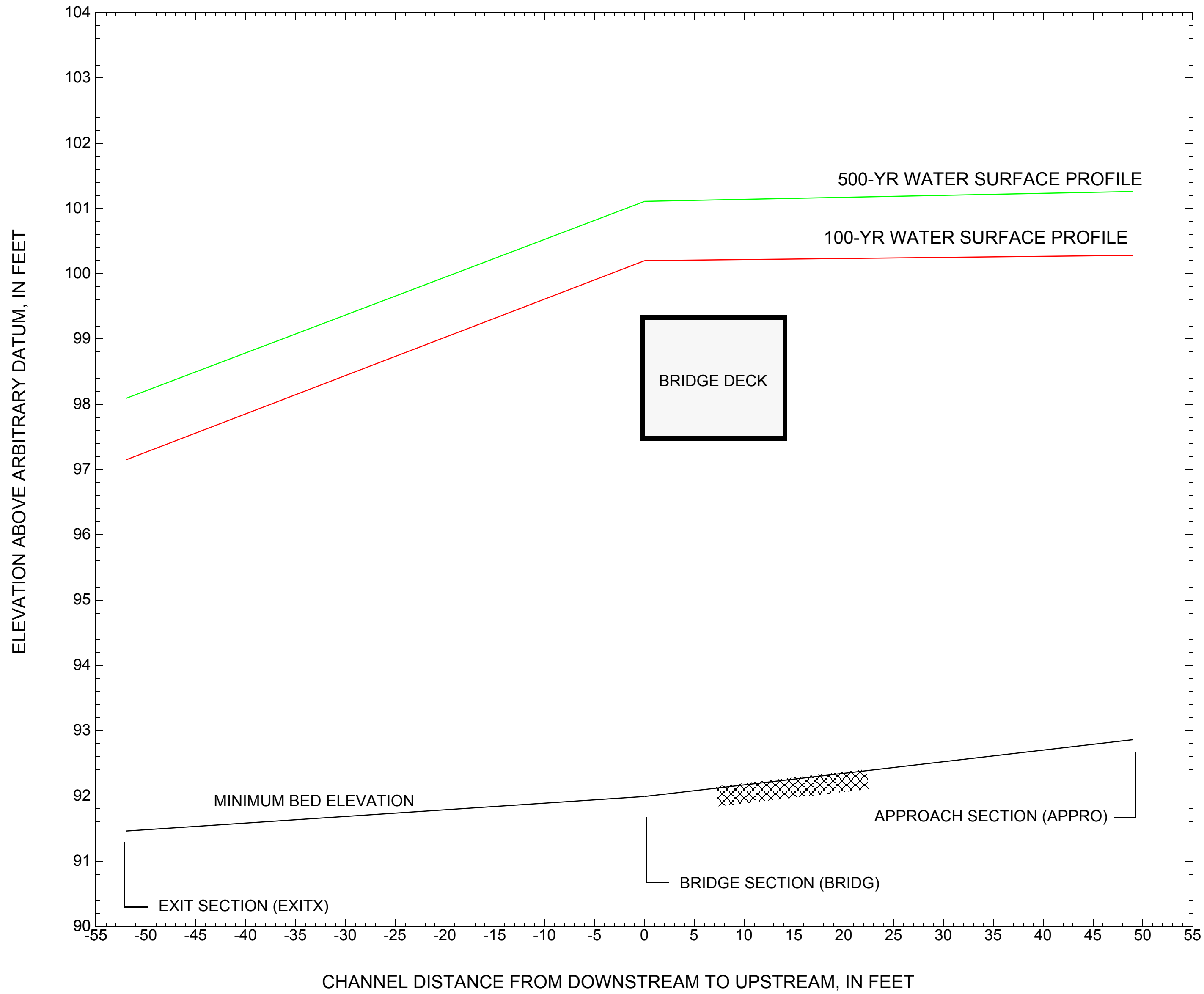

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00050034 on town highway 5, crossing North Branch Ottauquechee River, Bridgewater, Vermont.

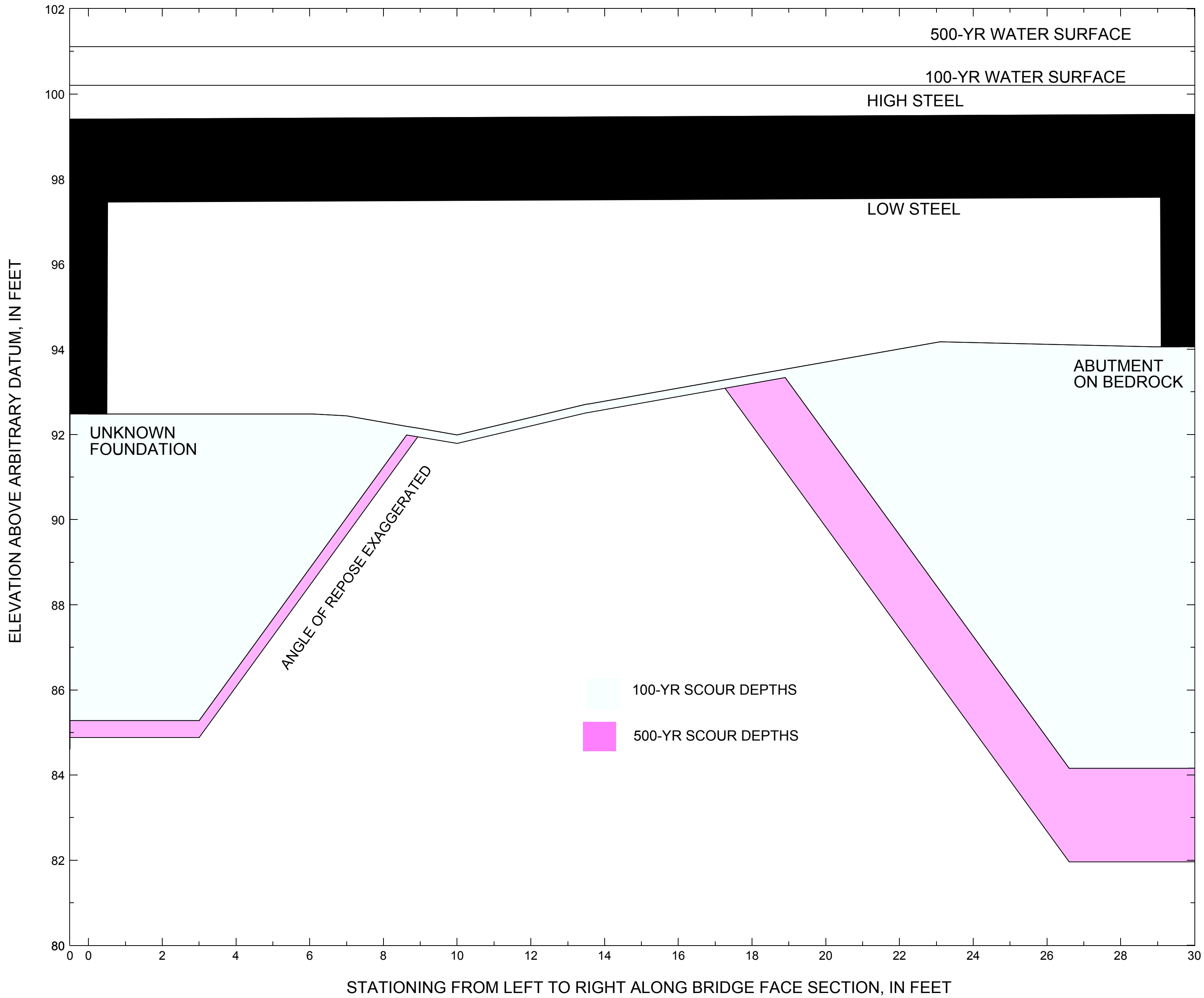

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00050034 on town highway 5, crossing North Branch Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00050034 on Town Highway 5, crossing 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 1,540 cubic-feet per second											
Left abutment	0.0	--	97.3	--	92.5	0.2	7.0	--	7.2	85.3	--
Right abutment	29.6	--	97.7	--	94.1	0.2	9.7	--	9.9	84.2	--

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure BRIDTH00050034 on Town Highway 5, crossing 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 2,170 cubic-feet per second											
Left abutment	0.0	--	97.3	--	92.5	0.1	7.5	--	7.6	84.9	--
Right abutment	29.6	--	97.7	--	94.1	0.1	12.0	--	12.1	82.0	--

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 brid034.wsp
T2        CREATED ON 24-JUL-95 FOR BRIDGE BRIDTH00050034 USING FILE brid034.dca
T3        hydraulic analysis for bridge 034 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            1540 2170 833
SK           0.015 0.015 0.015
*
XS   EXITX    -52
GR          -65.0, 110.92    -64.1, 110.56    -32.9,  97.69    -27.1,  98.27
GR          -19.2,  98.70     -9.9,  98.33      0.0,  94.82      6.7,  92.52
GR           11.5,  92.07     14.2,  91.75     19.4,  91.46     24.0,  91.61
GR           27.9,  92.13     30.1,  94.00     33.5,  94.86     43.2,  95.76
GR           56.9, 103.13     83.7, 109.24
N            0.065        0.035        0.053        0.080
SA                  -33.          0.0         33.5
*
XS   FULLV      0  * * * 0.015
*
BR   BRIDG      0 97.5 20
GR            0.0,  97.34      0.0,  92.48      6.1,  92.48      7.0,  92.44
GR           10.0,  91.99     13.5,  92.71     23.1,  94.18     28.9,  94.06
GR           29.6,  97.69      0.0,  97.34
N            0.045
CD           1 19 * * 0.0 0.0
*
XR   RDWAY   9  19   2
GR          -55.5, 102.87    -40.4,  97.81    -33.3,  98.52    -24.5,  99.08
GR            0.0,  99.31      0.0  102.00     28.1, 102.17     28.1,  99.98
GR           67.1, 100.46    100.8, 102.58    141.8, 109.40
BP           0
*
XT   SURVA     81
GR          -18.7, 110.30      0.2,  97.40      3.7,  95.19      6.1,  95.00
GR           15.1,  94.49     19.0,  94.24     22.9,  94.79     25.7,  95.18
GR           30.2,  97.81     33.7,  99.77     48.3, 100.87     54.1, 100.75
GR           61.1, 101.34    101.2, 108.06
*
AS   APPRO     49
GT             -1.38
N             0.060     0.035       0.090
SA                   33.7         61.1
BP            0
*
HP 1 BRIDG    97.69 1 97.69
HP 2 BRIDG    97.69 * * 1206
HP 2 RDWAY    100.20 * * 325
HP 1 APPRO    100.28 1 100.28
HP 2 APPRO    100.28 * * 1540
*
HP 1 BRIDG    97.69 1 97.69
```

```
HP 2 BRIDG    97.69 * * 1231
HP 2 RDWAY    101.11 * * 931
HP 1 APPRO    101.26 1 101.26
HP 2 APPRO    101.26 * * 2170
*
*
*

HP 1 BRIDG    96.33 1 96.33
HP 2 BRIDG    96.33 * * 833
HP 1 APPRO    98.00 1 98.00
HP 2 APPRO    98.00 * * 833
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid034.wsp
       CREATED ON 24-JUL-95 FOR BRIDGE BRIDTH00050034 USING FILE brid034.dca
       hydraulic analysis for bridge 034 crossing N. Br Ottauquechee R.
          *** RUN DATE & TIME: 08-09-95  09:43
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     121.    6172.     0.    64.                           0.
   97.69          121.    6172.     0.    64.  1.00     0.    30.      0.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
       97.69     0.0    29.6   121.4    6172.    1206.   9.94

X STA.        0.0        2.0        3.3        4.6        5.8        6.9
  A(I)             9.1        6.2        5.7        5.5        5.3
  V(I)            6.62       9.74      10.58      11.05      11.33

X STA.        6.9        8.0        9.0       10.0       11.1       12.1
  A(I)             5.2        5.1        5.1        5.1        5.2
  V(I)           11.51      11.90      11.72      11.89      11.60

X STA.       12.1       13.3       14.5       15.8       17.2       18.7
  A(I)             5.4        5.5        5.5        5.9        5.8
  V(I)           11.25      11.04      10.91      10.23      10.32

X STA.       18.7       20.4       22.3       24.4       26.5       29.6
  A(I)             6.2        6.6        6.7        7.1        9.2
  V(I)            9.69       9.12       8.99       8.55       6.57

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.
        WSEL     LEW     REW    AREA        K        Q    VEL
      100.20   -47.5    46.0    61.9    2367.     325.   5.25

X STA.      -47.5      -41.8      -40.1      -38.6      -37.0      -35.3
  A(I)             5.6        3.7        3.3        3.4        3.4
  V(I)            2.90       4.34       4.91       4.78       4.83

X STA.      -35.3      -33.3      -31.9      -30.5      -29.0      -27.3
  A(I)             3.6        2.2        2.1        2.2        2.4
  V(I)            4.55       7.28       7.59       7.27       6.91

X STA.      -27.3      -25.2      -22.8      -20.4      -17.9      -15.3
  A(I)             2.5        2.6        2.7        2.7        2.7
  V(I)            6.39       6.19       6.01       6.10       5.92

X STA.      -15.3      -12.5       -9.6       -6.6       -3.4       46.0
  A(I)             2.8        2.9        2.9        3.0        5.1
  V(I)            5.75       5.64       5.64       5.48       3.19

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     218.   16016.    40.    43.                        2904.
            2      29.    1265.    27.    27.                         168.
            3       0.       1.     2.     2.                           1.
  100.28          247.   17283.    69.    72.  1.05    -6.    63.   2593.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
        WSEL     LEW     REW    AREA        K        Q    VEL
      100.28    -6.0    63.0   247.5   17283.    1540.   6.22

X STA.       -6.0        1.9        4.2        6.1        7.8        9.4
  A(I)            21.5       14.2       12.0       11.3       11.0
  V(I)            3.59       5.43       6.40       6.84       7.01

X STA.        9.4       10.9       12.4       13.8       15.2       16.5
  A(I)            10.4       10.5        9.9       10.2        9.7
  V(I)            7.38       7.33       7.80       7.57       7.97

X STA.       16.5       17.9       19.2       20.6       22.0       23.5
  A(I)             9.8        9.9        9.9       10.1       10.5
  V(I)            7.88       7.79       7.80       7.59       7.31

X STA.       23.5       25.1       27.1       30.1       38.0       63.0
  A(I)            10.8       12.0       14.5       17.8       21.7
  V(I)            7.16       6.42       5.33       4.32       3.54
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WSPRO OUTPUT FILE (continued)

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CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     121.    6172.     0.    64.                          0.
     97.69          121.    6172.     0.    64.  1.00     0.    30.      0.

     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
          WSEL     LEW     REW    AREA        K        Q    VEL
         97.69     0.0    29.6   121.4    6172.    1231.  10.14

 X STA.         0.0        2.0        3.3        4.6        5.8        6.9
   A(I)              9.1        6.2        5.7        5.5        5.3
   V(I)             6.76       9.95      10.80      11.28      11.56

 X STA.         6.9        8.0        9.0       10.0       11.1       12.1
   A(I)              5.2        5.1        5.1        5.1        5.2
   V(I)            11.75      12.15      11.96      12.13      11.84

 X STA.        12.1       13.3       14.5       15.8       17.2       18.7
   A(I)              5.4        5.5        5.5        5.9        5.8
   V(I)            11.48      11.26      11.13      10.45      10.53

 X STA.        18.7       20.4       22.3       24.4       26.5       29.6
   A(I)              6.2        6.6        6.7        7.1        9.2
   V(I)             9.89       9.31       9.17       8.73       6.71

     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.

          WSEL     LEW     REW    AREA        K        Q    VEL
        101.11   -50.2    77.4   142.5    6436.     931.   6.53
 X STA.       -50.2      -41.8      -39.4      -36.9      -34.3      -32.2
   A(I)             11.8        7.8        7.5        7.3        5.7
   V(I)             3.93       5.96       6.19       6.41       8.23

 X STA.       -32.2      -30.4      -28.6      -26.6      -24.3      -21.9
   A(I)              4.2        4.4        4.5        4.7        4.8
   V(I)            11.02      10.66      10.34       9.96       9.69

 X STA.       -21.9      -19.5      -17.1      -14.5      -12.0       -9.4
   A(I)              4.8        4.8        5.0        5.0        5.0
   V(I)             9.60       9.71       9.38       9.40       9.40

 X STA.        -9.4       -6.6       -3.8       10.3       42.5       77.4
   A(I)              5.2        5.3        6.8       15.0       23.1
   V(I)             9.00       8.86       6.82       3.11       2.02

     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     258.   20600.    41.    45.                       3665.
              2      56.    3793.    27.    27.                        450.
              3       5.      62.     8.     8.                         23.
    101.26          319.   24455.    76.    80.  1.03    -7.    69.   3633.

     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
          WSEL     LEW     REW    AREA        K        Q    VEL
        101.26    -7.5    68.9   318.7   24455.    2170.   6.81

 X STA.        -7.5        1.5        4.2        6.3        8.2       10.0
   A(I)             27.5       18.8       15.6       14.6       13.9
   V(I)             3.94       5.78       6.96       7.45       7.80

 X STA.        10.0       11.7       13.4       15.0       16.5       18.1
   A(I)             13.8       13.2       13.2       12.7       12.9
   V(I)             7.85       8.24       8.23       8.52       8.42

 X STA.        18.1       19.6       21.2       22.8       24.6       26.5
   A(I)             12.7       12.8       13.3       13.3       14.6
   V(I)             8.56       8.46       8.15       8.17       7.41

 X STA.        26.5       29.2       34.5       40.6       49.8       68.9
   A(I)             16.7       20.6       15.9       18.5       24.1
   V(I)             6.50       5.26       6.82       5.88       4.50
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WSPRO OUTPUT FILE (continued)

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    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      89.    5602.    28.    34.                         901.
    96.33           89.    5602.    28.    34.  1.00     0.    29.    901.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        96.33     0.0    29.3    88.6    5602.     833.   9.41

X STA.         0.0        2.1        3.3        4.5        5.5        6.6
  A(I)             7.5        4.5        4.1        3.9        3.8
  V(I)            5.58       9.18      10.06      10.62      11.01

X STA.         6.6        7.6        8.5        9.4       10.3       11.2
  A(I)             3.7        3.6        3.6        3.6        3.6
  V(I)           11.15      11.70      11.70      11.71      11.68

X STA.        11.2       12.2       13.3       14.5       15.7       17.2
  A(I)             3.7        3.7        4.0        4.0        4.3
  V(I)           11.23      11.14      10.48      10.39       9.74

X STA.        17.2       18.8       20.7       23.0       25.7       29.3
  A(I)             4.5        4.8        5.1        5.6        7.1
  V(I)            9.30       8.64       8.23       7.49       5.84

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     132.    7467.    36.    38.                        1435.
    98.00          132.    7467.    36.    38.  1.00    -3.    33.   1435.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      49.
         WSEL     LEW     REW    AREA        K        Q    VEL
        98.00    -2.7    33.0   131.7    7467.     833.   6.33

X STA.        -2.7        3.1        4.9        6.4        7.8        9.2
  A(I)            11.2        7.4        6.6        6.4        5.9
  V(I)            3.71       5.60       6.29       6.54       7.02

X STA.         9.2       10.4       11.7       12.9       14.0       15.2
  A(I)             5.8        5.8        5.7        5.5        5.6
  V(I)            7.17       7.21       7.33       7.57       7.47

X STA.        15.2       16.3       17.4       18.4       19.5       20.7
  A(I)             5.4        5.5        5.5        5.5        5.8
  V(I)            7.65       7.54       7.61       7.58       7.16

X STA.        20.7       21.9       23.3       24.8       26.6       33.0
  A(I)             6.0        6.2        6.7        7.5       11.7
  V(I)            6.95       6.76       6.26       5.54       3.56

+++ BEGINNING PROFILE CALCULATIONS --   3
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******    -7.     182.  1.28 *****   98.43   96.69   1540.   97.15
      -52. ******    46.   12565.  1.14 ***** *******    0.86    8.47

 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.85      97.95      97.47

 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    96.65     111.70    0.50

 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    96.65     111.70      97.47

FULLV:FV       52.    -7.     183.  1.25  0.77   99.22   97.47   1540.   97.97
        0.    52.    46.   12731.  1.14  0.00    0.02    0.85    8.39
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.87      98.79      98.21

 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    97.47     108.92    0.50
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WSPRO OUTPUT FILE (continued)

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 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =     97.47     108.92      98.
APPRO:AS      49.    -4.     162.  1.41  0.91  100.21   98.21   1540.   98.80
       49.    49.    39.   10085.  1.01  0.08    0.01    0.87    9.49
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =     97.97      97.50

            <<<<<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      52.     0.     121.  1.54 *****   99.23   97.03   1206.   97.69
        0. ******    30.    6172.  1.00 ***** *******    0.87    9.94

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000   97.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    30.  0.24  0.63  100.67   -0.01    325.  100.20

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    325.    48.   -48.     0.   2.4   1.3   5.9   5.5   1.7   3.0
   RT:      0.    22.    28.    50.   0.3   0.1   3.2   9.8   0.6   2.7

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

APPRO:AS      30.    -6.     247.  0.63  0.55  100.91   98.21   1540.  100.28
       49.    31.    63.   17261.  1.05  0.00   -0.01    0.59    6.23

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -52.    -7.    46.   1540.   12565.     182.    8.47   97.15
   FULLV:FV       0.    -7.    46.   1540.   12731.     183.    8.39   97.97
   BRIDG:BR       0.     0.    30.   1206.    6172.     121.    9.94   97.69
   RDWAY:RG       9.*******   325.    325.*********       0.    2.00  100.20
   APPRO:AS      49.    -6.    63.   1540.   17261.     247.    6.23  100.28

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS     96.69    0.86   91.46  110.92************  1.28   98.43   97.15
   FULLV:FV     97.47    0.85   92.24  111.70  0.77  0.00  1.25   99.22   97.97
   BRIDG:BR     97.03    0.87   91.99   97.69************  1.54   99.23   97.69
   RDWAY:RG  ****************   97.81  109.40  0.24******  0.63  100.67  100.20
   APPRO:AS     98.21    0.59   92.86  108.92  0.55  0.00  0.63  100.91  100.28


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

EXITX:XS   ******   -34.     234.  1.59 *****   99.68   97.63   2170.   98.09
      -52. ******    48.   17703.  1.19 ***** *******    0.92    9.28

 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.91      98.90      98.41

 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    97.59     111.70    0.50

 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =     97.59     111.70      98.41

FULLV:FV      52.   -34.     236.  1.56  0.77  100.47   98.41   2170.   98.91
        0.    52.    48.   17951.  1.19  0.00    0.02    0.91    9.18
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.02      99.73      99.73
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WSPRO OUTPUT FILE (continued)

```
 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    98.41     108.92    0.50

 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    98.41     108.92      99.73

APPRO:AS      49.    -5.     211.  1.74  0.91  101.47   99.73   2170.   99.73
       49.    49.    58.  14092.  1.06  0.09    0.00    1.02   10.29
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =    98.91      97.50
          <<<<<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      52.     0.     121.  1.60 *****   99.29   97.09   1231.   97.69
        0. ******    30.    6172.  1.00 ***** *******    0.88   10.14

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000   97.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    30.  0.24  0.75  101.77    0.00    931.  101.11

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    683.    50.   -50.     0.   3.3   2.1   7.5   6.6   2.7   3.0
   RT:    248.    49.    28.    77.   1.1   0.8   5.3   6.5   1.4   2.9

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

APPRO:AS      30.    -7.     318.  0.75  0.60  102.00   99.73   2170.  101.26
       49.    31.    69.  24426.  1.03  0.00    0.00    0.60    6.81

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -52.   -34.    48.   2170.   17703.     234.    9.28   98.09
   FULLV:FV       0.   -34.    48.   2170.   17951.     236.    9.18   98.91
   BRIDG:BR       0.     0.    30.   1231.    6172.     121.   10.14   97.69
   RDWAY:RG       9.*******   683.    931.*********       0.    2.00  101.11
   APPRO:AS      49.    -7.    69.   2170.   24426.     318.    6.81  101.26

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS     97.63    0.92   91.46  110.92************  1.59   99.68   98.09
   FULLV:FV     98.41    0.91   92.24  111.70  0.77  0.00  1.56  100.47   98.91
   BRIDG:BR     97.09    0.88   91.99   97.69************  1.60   99.29   97.69
   RDWAY:RG  ****************   97.81  109.40  0.24******  0.75  101.77  101.11
   APPRO:AS     99.73    0.60   92.86  108.92  0.60  0.00  0.75  102.00  101.26



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

EXITX:XS   ******    -3.     117.  0.85 *****   96.69   95.28    833.   95.84
      -52. ******    43.    6799.  1.08 ***** *******    0.82    7.12
 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.81      96.63      96.06
 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =    95.34     111.70    0.50
 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    95.34     111.70      96.06
FULLV:FV      52.    -3.     118.  0.84  0.77   97.47   96.06    833.   96.64
        0.    52.    43.    6860.  1.08  0.00    0.01    0.81    7.08
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      49.    -2.     113.  0.84  0.83   98.31 *******    833.   97.46
       49.    49.    32.    6006.  1.00  0.00    0.01    0.71    7.37
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>
 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =    98.00       0.00      96.33      97.81
 ===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      52.     0.      89.  1.37  0.95   97.71   96.17    833.   96.33
        0.    52.    29.    5613.  1.00  0.07    0.00    0.92    9.39

    TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
      1. ****   4.  1.000 ******   97.50 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
  RDWAY:RG       9.        <<<<<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      30.    -3.     132.  0.62  0.51   98.62   96.69    833.   98.00
       49.    30.    33.    7476.  1.00  0.42    0.01    0.58    6.32

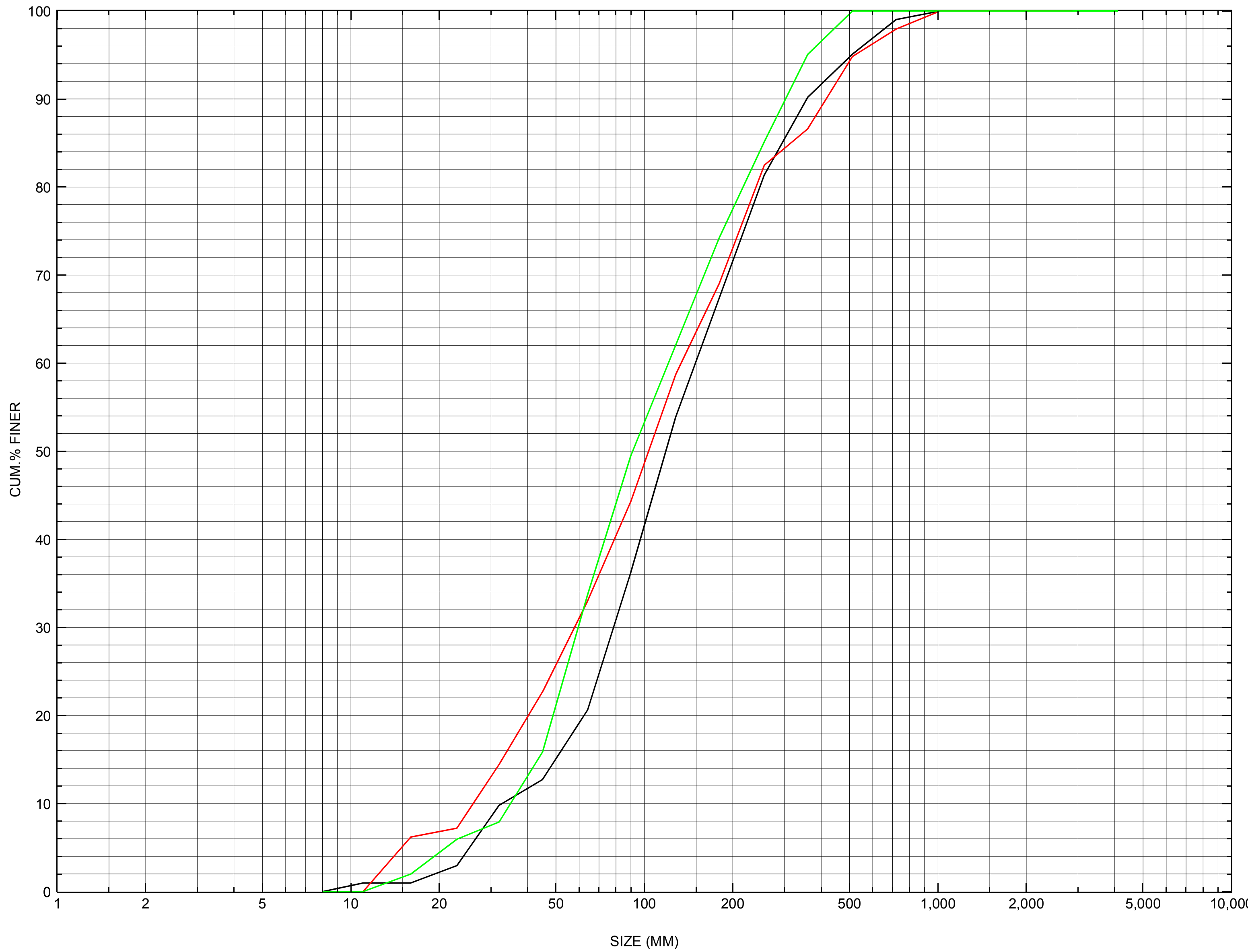
      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.135  0.032    7201.     4.    33. ********

  FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
  EXITX:XS     -52.    -3.    43.    833.    6799.     117.    7.12   95.84
  FULLV:FV       0.    -3.    43.    833.    6860.     118.    7.08   96.64
  BRIDG:BR       0.     0.    29.    833.    5613.      89.    9.39   96.33
  RDWAY:RG       9.**************      0.       0.       0.    2.00********
  APPRO:AS      49.    -3.    33.    833.    7476.     132.    6.32   98.00
   XSID:CODE   XLKQ   XRKQ      KQ
  APPRO:AS       4.    33.    7201.

 SECOND USER DEFINED TABLE.
   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
  EXITX:XS     95.28    0.82   91.46  110.92************  0.85   96.69   95.84
  FULLV:FV     96.06    0.81   92.24  111.70  0.77  0.00  0.84   97.47   96.64
  BRIDG:BR     96.17    0.92   91.99   97.69  0.95  0.07  1.37   97.71   96.33
  RDWAY:RG  ****************   97.81  109.40  0.38******  0.63   98.23********
  APPRO:AS     96.69    0.58   92.86  108.92  0.51  0.42  0.62   98.62   98.00
```

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 BRIDTH00050034, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM