LEVEL II SCOUR ANALYSIS FOR BRIDGE 23 (WODSTH00180023) on TOWN HIGHWAY 18, crossing NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

U.S. Geological Survey
Open-File Report 96-197

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 23 (WODSTH00180023) on TOWN HIGHWAY 18, crossing NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

By SCOTT A. OLSON and MATTHEW A. WEBER

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Pembroke, New Hampshire
1996

U.S. DEPARTMENT OF THE INTERIOR
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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 23 (WODSTH00180023) ON TOWN HIGHWAY 18, CROSSING NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

***By* Scott A. Olson**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure WODSTH00180023 on town highway 18 crossing North Bridgewater Brook, Woodstock, 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 New England Upland physiographic division of east-central Vermont. The 4.26-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left and right banks are covered by moderate tree cover.

In the study area, North Bridgewater Brook has a sinuous channel with a slope of approximately 0.03 ft/ft, an average channel top width of 38 ft and an average channel depth of 5 ft. The predominant channel bed materials are gravel and cobbles (D_{50} is 63.3 mm or 0.208 ft). The geomorphic assessment at the time of the Level I site visit on December 9, 1994 indicated that the reach was laterally unstable. Evidence of the instability included anabranching and extensive stone fill on channel bends.

The town highway 18 crossing of North Bridgewater Brook is a 25-ft-long, one-lane bridge consisting of one 22-ft steel-beam span (Vermont Agency of Transportation, written commun., August 3, 1994). The bridge is supported by vertical, concrete abutments with no wingwalls. Type-2 stone fill (less than 36 inches) was noted at the ends of the right abutment and type-1 stone fill (less than 12 inches) was noted at the ends of the left abutment. A stone wall of type-2 and -3 stone fill (less than 36 inches and 48 inches, respectively), carefully placed, protects the upstream right channel bank extending from the bridge to more than 50 feet upstream. Although significant protection has been placed, both abutments are experiencing undermining. The channel is skewed approximately 15 degrees to the opening while the opening-skew-to-roadway is 5 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.

Woodstock North, VT. Quadrangle, 1:24,000, 1966

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 WODSTH00180023 ***Stream*** North Bridgewater Brook

County Windsor ***Road*** TH0018 ***District*** 04

Description of Bridge

Bridge length 25 ***ft*** ***Bridge width*** 14 ***ft*** ***Max span length*** 22 ***ft***

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

Abutment type concrete, vertical ***Embankment type*** vertical

Stone fill on abutment? yes ***Date of inspection*** 12/09/94

Description of stone fill Type-2 stone fill at ends of right abutment and upstream right road embankment. Type-1 stone fill at ends of left abutment and downstream left and right road embankments.

Brief description of piers/abutments Abutments are concrete, however, the concrete appears to be facing over a laid stone abutment. Both abutments are experiencing undermining.

Y

Is bridge skewed to flood flow according to Y ***survey?*** ***Angle*** 15

There is a moderate bend in the channel on its approach to the bridge. The right bank and abutment get impacted by flood flows.

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	12/09/94	0	0
Level II	8/17/94	--	--

Potential for debris Moderate due to basin being primarily forested

Describe any features near or at the bridge that may affect flow (include observation date) December 9, 1994. There is a man made levee of gravel, cobbles, and boulders along the downstream right bank.

Description of the Geomorphic Setting

General topography The bridge is in a steep, narrow valley with moderate relief.

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

Date of inspection 12/09/94

DS left: narrow flood plain to valley wall

DS right: narrow flood plain to valley wall

US left: narrow flood plain to valley wall

US right: narrow flood plain to valley wall

Description of the Channel

Average top width 38 ***ft*** ***Average depth*** 5 ***ft***

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

high gradient, slightly sinuous, upland stream with narrow flood plains.

Vegetative co 12/09/94

forested

DS left: forested

DS right: forested

US left: forested

US right:

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

12/09/94--Cut banks and anabranching were noted outside of the immediate reach. Within the reach, banks were well protected in areas of instability.

Describe any obstructions in channel and date of observation.

There was a wire fence across the channel downstream of the bridge on 08/17/94. No obstruction were noted on 12/09/94.

Hydrology

Drainage area 4.26 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
New England Upland	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: None. Basin is primarily forested with some open areas for agricultural uses.

No

Is there a USGS gage on the stream of interest?

USGS gage description

USGS gage number

No

Gage drainage area ***mi²***

Is there a lake/p

1,090

Calculated Discharges

1,850 Q100

Q100 ***ft³/s*** ***Q500*** ***ft³/s***

was estimated from a drainage area relationship with Woodstock bridge 22 which is just downstream of the study site [1100cfs*(4.26/4.34) to the 0.7 power]. Bridge 22, with a drainage area of 4.34 square miles, had a 100-year discharge of 1100 cfs determined by the Vermont Agency of Transportation (VTAOT, written communication, March 8, 1995). Q500 was estimated by multiplying the Q100 by 1.7 (Richardson and others, 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 Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a chiseled square on the top of the upstream end of the right subfooter (elev. 497.69 feet, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
EXIT	0	1	Exit section
FV	25	2	Downstream Full-valley section (Templated from EXIT)
BRO	25	1	Bridge section
RDWAY	32	1	Road Grade section
APPR	60	2	Modelled Approach section (Templated from APTEM)
APTEM	90	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 0.045 to 0.060, and overbank "n" values ranged from 0.048 to 0.065.

Normal depth at the exit section (EXIT) 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 0.029 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 (0.040 ft/ft) to establish the modelled approach section (APPR), 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.

The field surveyed exit section included a man made levee of gravel, cobbles, and boulders along the right bank. Since the modelled water surface elevations did not overtop the levee for the 100-year event and just overtopped the levee for the 500-year event, the section geometry right of the levee was deleted from the model. Without removing this part of the section the model incorrectly assumed significant conveyance right of the levee.

For the incipient overtopping discharge of 895 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 bridge, suggests the critical depth assumption at the bridge section is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 502.3 *ft*
Average low steel elevation 500.2 *ft*

100-year discharge 1,090 *ft³/s*
Water-surface elevation in bridge opening 500.2 *ft*
Road overtopping? Y *Discharge over road* 67 *ft³/s*
Area of flow in bridge opening 117 *ft²*
Average velocity in bridge opening 8.8 *ft/s*
Maximum WSPRO tube velocity at bridge 11.4 *ft/s*

Water-surface elevation at Approach section with bridge 502.3
Water-surface elevation at Approach section without bridge 499.4
Amount of backwater caused by bridge 2.9 *ft*

500-year discharge 1,850 *ft³/s*
Water-surface elevation in bridge opening 500.6 *ft*
Road overtopping? Y *Discharge over road* 616 *ft³/s*
Area of flow in bridge opening 120 *ft²*
Average velocity in bridge opening 10.3 *ft/s*
Maximum WSPRO tube velocity at bridge 12.5 *ft/s*

Water-surface elevation at Approach section with bridge 503.8
Water-surface elevation at Approach section without bridge 501.7
Amount of backwater caused by bridge 2.1

Incipient overtopping discharge 895 *ft³/s*
Water-surface elevation in bridge opening 498.0 *ft*
Area of flow in bridge opening 76.6 *ft²*
Average velocity in bridge opening 11.7 *ft/s*
Maximum WSPRO tube velocity at bridge 14.6 *ft/s*

Water-surface elevation at Approach section with bridge 500.5
Water-surface elevation at Approach section without bridge 498.9
Amount of backwater caused by bridge 1.6 *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 unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Therefore, contraction scour for the 100-year and 500-year discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). For the incipient road-overflow discharge, contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18). 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). 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 500-year model resulted in worst case contraction scour with a scour depth of 1.4 feet. It was also the worst case total scour.

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	0.5	1.4	1.1
Depth to armoring	2.9	5.9	19.9
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	8.7	11.5	8.0
Right abutment	12.2	14.3	9.2
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	1.8
Right abutment	1.5	2.0	1.8
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

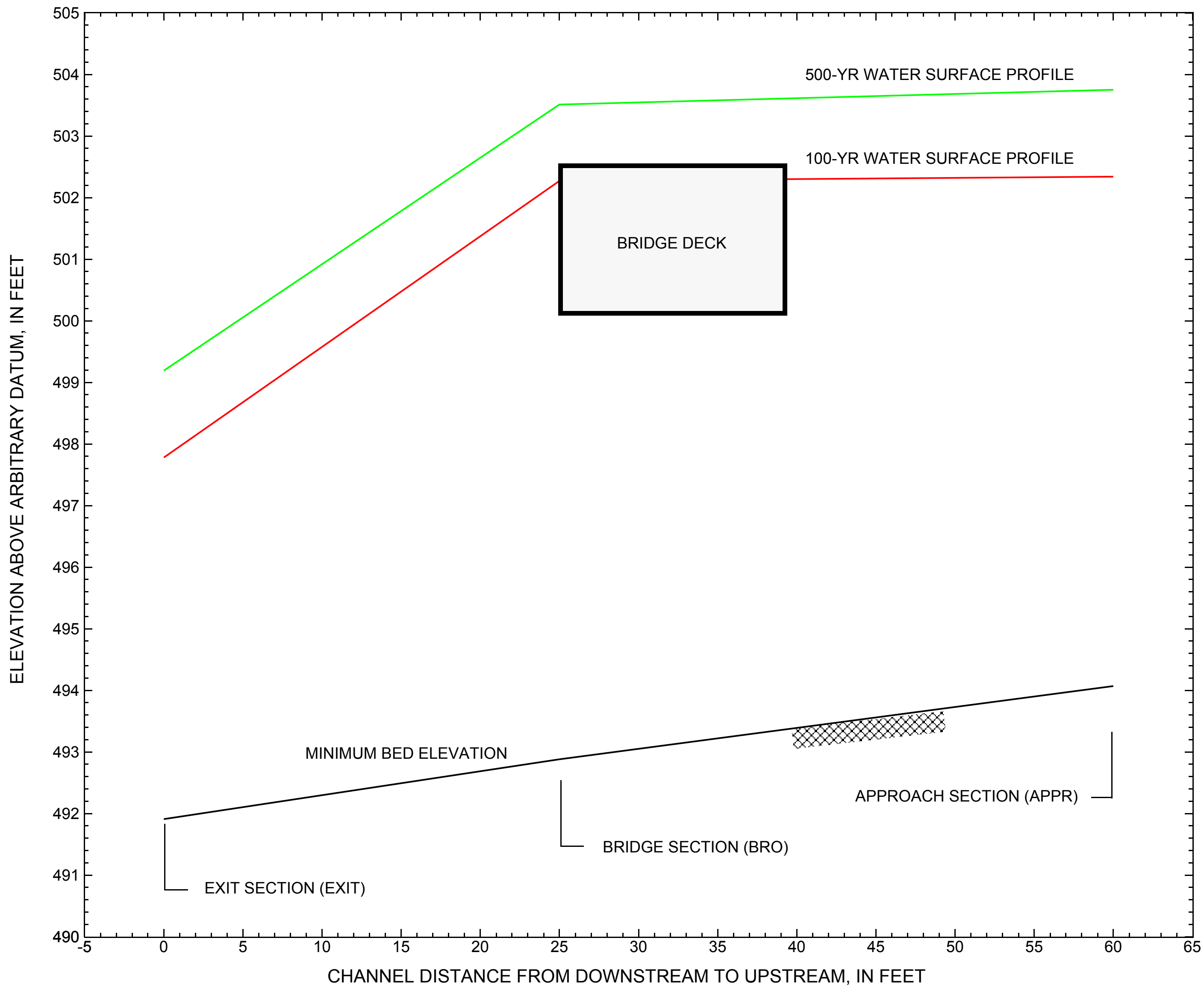

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure WODSTH00180023 on town highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

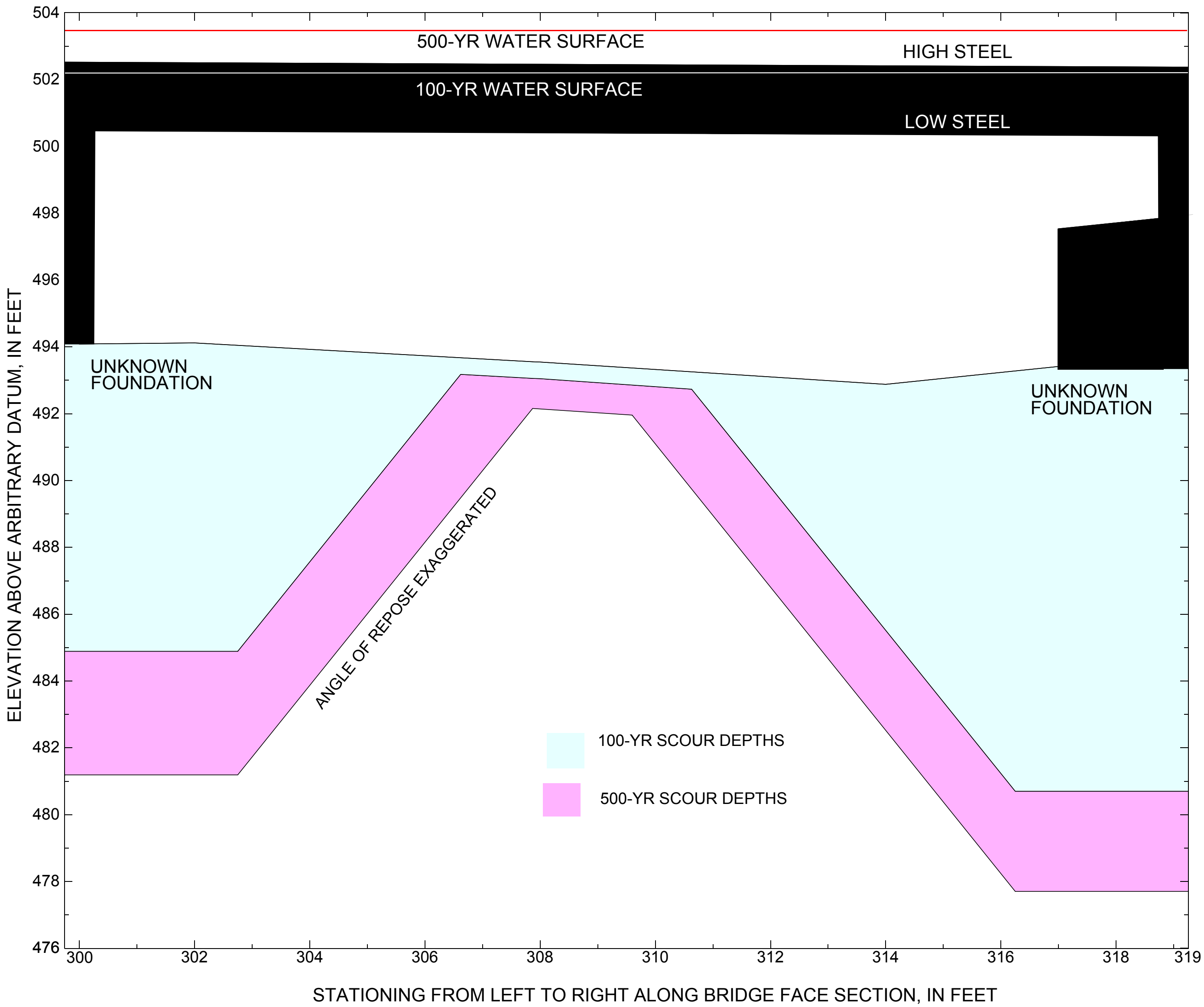

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure WODSTH00180023 on town highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure WODSTH00180023 on Town Highway 18, crossing North Bridgewater Brook, Woodstock, 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 1,090 cubic-feet per second											
Left abutment	300	--	500.57	--	494.1	0.5	8.7	--	9.2	484.9	--
Right abutment	319	--	500.23	--	493.4	0.5	12.2	--	12.7	480.7	--

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 WODSTH00180023 on Town Highway 18, crossing North Bridgewater Brook, Woodstock, 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 1,850 cubic-feet per second											
Left abutment	300	--	500.57	--	494.1	1.4	11.5	--	12.9	481.2	--
Right abutment	319	--	500.23	--	493.4	1.4	14.3	--	15.7	477.7	--

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

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

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U.S. Geological Survey, 1966, Woodstock North, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1             HYDRAULIC ANALYSIS
T2             Woodstock, VT BRIDGE #023
T3             USGS  BOW,NH   03/23/95
*
J1             * * 0.01
J3             6 29 30 28 17 13 23 3 * 5 15 14 7 4 11 12 3
*
Q              1090 1850 895
SK             0.029 0.029 0.029
*
*              slope 0.029 from downstream slope measurement
*
XS   EXIT        0
GR            163., 510.75     173., 509.63     182., 504.17     194., 502.64
GR            202., 503.08     215., 502.51     225., 504.17     234., 504.51
GR            247., 503.65     259., 501.51     265., 501.12     293., 498.70
GR            296., 495.91     300., 493.72     304., 494.70     307., 494.27
GR            308., 493.37     312., 492.68     314., 491.91     315., 492.17
GR            318., 492.55     329., 498.75     333., 498.82
N               0.051        0.060        0.065
SA                    293.         329.
*
*              removed the area right of the "levee" because it was allowing
*              too much conveyance and was only barely overtopped in the
*              500 year event
*
XS   FV        25 * * * 0.030
*
BR   BRO       25 500.23 5
GR            300., 500.57     300., 494.09     302., 494.12     308., 493.55
GR            311., 493.20     314., 492.88     317., 493.42     317., 497.54
GR            318., 497.90     319., 500.23     300., 500.57
N              0.045
CD             1 15
*
XR   RDWAY     32 14 2
GR            198., 505.74     223., 504.81     262., 503.50     300., 502.61
GR            325., 502.30     341., 501.91     367., 501.3
BP            300
*
*              allowing vertical wall at RDWAY station 367 because it is the
*              approximate station of the nearly vertical wall at right end
*              of approach
*
XT   APTEM     90
GR            273., 503.38     283., 502.86     289., 502.21     295., 501.24
GR            300., 498.62     303., 497.46     304., 496.27     308., 496.20
GR            314., 495.79     318., 495.27     321., 495.93     326., 498.82
GR            331., 501.41     335., 500.21     335., 500.56     366., 500.65
GR            367., 500.84     387., 512.70
*
AS   APPR      60
```

```
GT              -1.2
N               0.057    0.050     0.048
SA                    283      335
BP              304
*



HP 1 BRO        500.23 1 500.23
HP 2 BRO        500.23 * * 1033
HP 2 RDWAY      502.27 * * 67
HP 1 APPR       502.34 1 502.34
HP 2 APPR       502.34 * * 1090
*
HP 1 BRO        500.57 1 500.57
HP 2 BRO        500.57 * * 1244
HP 2 RDWAY      503.51 * * 616
HP 1 APPR       503.75 1 503.75
HP 2 APPR       503.75 * * 1850
*
HP 1 BRO        498.03 1 498.03
HP 2 BRO        498.03 * * 895
HP 1 APPR       500.49 1 500.49
HP 2 APPR       500.49 * * 895
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
          HYDRAULIC ANALYSIS
          Woodstock, VT BRIDGE #023
          USGS  BOW,NH   03/23/95
         *** RUN DATE & TIME: 10-05-95  11:39
  CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.
   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     117.    9441.    19.    31.                       1655.
 500.23          117.    9441.    19.    31.  1.00   300.   319.   1655.

  VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.
       WSEL     LEW     REW    AREA        K        Q    VEL
     500.23   300.0   319.0   117.2    9441.    1033.   8.81

X STA.       300.0      301.9      303.1      304.0      304.9      305.6
  A(I)            11.8        6.9        5.8        5.4        5.1
  V(I)            4.37       7.44       8.90       9.62      10.15

X STA.       305.6      306.4      307.1      307.8      308.5      309.2
  A(I)             4.8        4.8        4.5        4.6        4.5
  V(I)           10.70      10.66      11.36      11.19      11.42

X STA.       309.2      309.9      310.5      311.2      311.8      312.5
  A(I)             4.6        4.6        4.5        4.7        4.8
  V(I)           11.35      11.22      11.37      11.07      10.75

X STA.       312.5      313.2      313.9      314.7      315.7      319.0
  A(I)             5.0        5.4        5.8        6.9       12.6
  V(I)           10.42       9.57       8.87       7.52       4.09

  VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      32.
       WSEL     LEW     REW    AREA        K        Q    VEL
     502.27   326.2   367.0    19.9     291.      67.   3.36

X STA.       326.2      339.3      343.5      346.4      348.7      350.7
  A(I)             2.1        1.5        1.3        1.2        1.1
  V(I)            1.60       2.20       2.53       2.79       2.96

X STA.       350.7      352.5      354.0      355.4      356.7      357.9
  A(I)             1.1        1.0        0.9        0.9        0.9
  V(I)            3.18       3.30       3.55       3.69       3.78

X STA.       357.9      359.0      360.0      361.0      361.9      362.7
  A(I)             0.8        0.8        0.8        0.8        0.8
  V(I)            3.98       4.11       4.25       4.42       4.46

X STA.       362.7      363.6      364.4      365.2      365.9      367.0
  A(I)             0.7        0.7        0.7        0.7        1.0
  V(I)            4.63       4.59       4.67       4.54       3.33

  CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1       4.      61.    10.    10.                         15.
           2     247.   19945.    52.    56.                       3062.
           3     100.    5982.    37.    37.                        938.
 502.34          351.   25988.    99.   103.  1.06   273.   372.   3652.

  VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
       WSEL     LEW     REW    AREA        K        Q    VEL
     502.34   273.0   371.6   351.5   25988.    1090.   3.10

X STA.       273.0      298.9      302.7      305.3      307.3      309.2
  A(I)            34.0       20.1       17.5       14.6       14.1
  V(I)            1.60       2.71       3.11       3.72       3.87

X STA.       309.2      311.0      312.7      314.4      316.0      317.5
  A(I)            13.6       13.1       12.6       12.5       12.5
  V(I)            4.01       4.16       4.32       4.35       4.38

X STA.       317.5      319.0      320.7      322.6      325.2      331.0
  A(I)            12.5       12.8       13.8       15.8       21.1
  V(I)            4.34       4.25       3.96       3.46       2.58

X STA.       331.0      339.1      346.1      353.0      360.4      371.6
  A(I)            23.2       20.5       20.4       21.5       25.3
  V(I)            2.35       2.66       2.68       2.54       2.16
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          HYDRAULIC ANALYSIS
          Woodstock, VT BRIDGE #023
          USGS  BOW,NH   03/23/95
         *** RUN DATE & TIME: 10-05-95  11:39
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     120.    7150.     0.    50.                     5430891.
  500.57          120.    7150.     0.    50.  1.00   300.   319.5430891.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.
       WSEL     LEW     REW    AREA        K        Q    VEL
     500.57   300.0   319.0   120.4    7150.    1244.  10.33

X STA.       300.0      301.7      302.7      303.6      304.5      305.3
  A(I)            10.7        6.6        5.9        5.5        5.4
  V(I)            5.84       9.36      10.49      11.22      11.46

X STA.       305.3      306.1      306.8      307.6      308.3      309.0
  A(I)             5.2        5.2        5.0        5.1        5.0
  V(I)           12.01      12.05      12.36      12.21      12.47

X STA.       309.0      309.7      310.5      311.1      311.9      312.6
  A(I)             5.0        5.0        5.0        5.1        5.2
  V(I)           12.49      12.36      12.53      12.23      11.89

X STA.       312.6      313.3      314.1      314.9      315.8      319.0
  A(I)             5.2        5.7        6.0        6.8       11.7
  V(I)           11.86      10.99      10.32       9.08       5.31

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      32.
       WSEL     LEW     REW    AREA        K        Q    VEL
     503.51   261.7   367.0   115.7    3272.     616.   5.33

X STA.       261.7      292.2      301.4      308.5      314.7      320.3
  A(I)            10.9        7.6        6.9        6.4        6.3
  V(I)            2.81       4.07       4.47       4.81       4.92

X STA.       320.3      325.3      329.8      334.1      337.8      341.2
  A(I)             6.0        5.7        5.9        5.5        5.3
  V(I)            5.13       5.41       5.21       5.58       5.79

X STA.       341.2      344.4      347.3      350.1      352.6      355.1
  A(I)             5.1        5.0        4.9        4.8        4.6
  V(I)            6.00       6.12       6.28       6.47       6.66

X STA.       355.1      357.5      359.7      361.9      364.1      367.0
  A(I)             4.7        4.5        4.5        4.7        6.2
  V(I)            6.52       6.84       6.85       6.51       4.93

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      18.     649.    10.    12.                         140.
            2     321.   30742.    52.    56.                        4519.
            3     153.   11620.    39.    40.                        1724.
  503.75          492.   43011.   101.   107.  1.07   273.   374.   5972.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
       WSEL     LEW     REW    AREA        K        Q    VEL

     503.75   273.0   373.9   492.1   43011.    1850.   3.76
X STA.       273.0      293.1      299.8      303.3      305.9      308.1
  A(I)            45.4       30.3       24.9       21.9       19.2
  V(I)            2.04       3.05       3.71       4.23       4.81

X STA.       308.1      310.3      312.4      314.4      316.3      318.1
  A(I)            19.4       18.7       18.1       17.7       18.1
  V(I)            4.76       4.94       5.12       5.24       5.11

X STA.       318.1      320.1      322.2      325.1      330.2      337.4
  A(I)            18.1       19.2       21.6       26.8       30.2
  V(I)            5.12       4.81       4.29       3.45       3.06

X STA.       337.4      343.3      349.5      355.6      361.9      373.9
  A(I)            25.8       26.7       26.7       27.4       35.9
  V(I)            3.58       3.47       3.47       3.38       2.58
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           HYDRAULIC ANALYSIS
          Woodstock, VT BRIDGE #023
          USGS  BOW,NH   03/23/95
         *** RUN DATE & TIME: 10-05-95  11:39
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      77.    5173.    18.    26.                         897.
  498.03           77.    5173.    18.    26.  1.00   300.   318.    897.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRO  ;  SRD =      25.
        WSEL     LEW     REW    AREA        K       Q    VEL
      498.03   300.0   318.1    76.6    5173.     895.  11.68

X STA.       300.0      301.8      302.9      303.9      304.8      305.6
  A(I)            7.2        4.3        3.9        3.6        3.4
  V(I)           6.25      10.42      11.35      12.54      13.15

X STA.       305.6      306.4      307.1      307.8      308.5      309.2
  A(I)            3.3        3.2        3.2        3.1        3.1
  V(I)          13.52      13.90      14.11      14.33      14.53

X STA.       309.2      309.8      310.5      311.1      311.8      312.4
  A(I)            3.1        3.1        3.1        3.1        3.2
  V(I)          14.64      14.40      14.52      14.38      14.03

X STA.       312.4      313.1      313.8      314.5      315.4      318.1
  A(I)            3.3        3.5        3.8        4.5        7.8
  V(I)          13.65      12.97      11.71      10.02       5.75

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            2     157.   10570.    43.    46.                        1708.
            3      35.    1125.    33.    34.                         205.
  500.49          192.   11695.    76.    80.  1.13   292.   368.   1628.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =      60.
        WSEL     LEW     REW    AREA        K       Q    VEL
      500.49   292.2   368.4   192.3   11695.     895.   4.66

X STA.       292.2      301.8      304.2      305.7      307.1      308.5
  A(I)           15.6       10.7        8.4        7.7        7.5
  V(I)           2.86       4.20       5.36       5.81       6.00

X STA.       308.5      309.8      311.0      312.2      313.4      314.5
  A(I)            7.1        7.2        6.7        6.9        6.8
  V(I)           6.31       6.25       6.63       6.51       6.62

X STA.       314.5      315.7      316.8      317.9      319.0      320.3
  A(I)            6.7        6.9        6.9        7.3        7.6
  V(I)           6.65       6.49       6.50       6.15       5.91

X STA.       320.3      321.8      323.9      333.3      349.9      368.4
  A(I)            8.5       10.0       16.8       18.6       18.7
  V(I)           5.27       4.50       2.67       2.41       2.40

          HYDRAULIC ANALYSIS
          Woodstock, VT BRIDGE #023
          USGS  BOW,NH   03/23/95
         *** RUN DATE & TIME: 10-05-95  11:39

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

EXIT :XS   ******   294.     118.  1.32 *****  499.10  497.40   1090.  497.78
        0. ******   327.    6395.  1.00 ***** *******    0.86    9.23

 ===125 FR# EXCEEDS FNTEST AT SECID "FV   ":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     0.87     498.51     498.15

 ===110 WSEL NOT FOUND AT SECID "FV   ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   497.28     511.50    0.50

 ===115 WSEL NOT FOUND AT SECID "FV   ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   497.28     511.50     498.15

FV   :FV      25.   294.     117.  1.34  0.73  499.85  498.15   1090.  498.51
       25.    25.   327.    6334.  1.00  0.01    0.00    0.87    9.29
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
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WSPRO OUTPUT FILE (continued)

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 ===125 FR# EXCEEDS FNTEST AT SECID “APPR “:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.09     499.40     499.14

 ===110 WSEL NOT FOUND AT SECID “APPR “:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   498.01     511.50    0.50

 ===115 WSEL NOT FOUND AT SECID “APPR “:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   498.01     511.50     499.14

APPR :AS      35.   296.     115.  1.41  0.91  500.80  499.14   1090.  499.38
       60.    35.   343.    7188.  1.00  0.03    0.00    1.03    9.52
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   501.44       0.00     498.65     501.30

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                  WS,QBO,QRD =   504.57         0.      1090.

 ===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

BRO  :BR      25.   300.     117.  1.21 *****  501.44  498.46   1033.  500.23
       25. ******   319.    9441.  1.00 ***** *******    0.62    8.82

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.479  0.000  500.23 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      32.    21.  0.04  0.16  502.47    0.01     67.  502.27

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0.    19.   291.   309.   0.3   0.2   2.9   5.0   0.5   2.7
   RT:     67.    41.   326.   367.   1.0   0.5   3.6   3.3   0.7   2.9

===140 AT SECID “APPR “:  END OF CROSS SECTION EXTENDED VERTICALLY.
                           WSEL,YLT,YRT =   502.34      502.2      511.5

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

APPR :AS      20.   273.     352.  0.16  0.09  502.50  499.14   1090.  502.34
       60.    21.   372.   26021.  1.06  0.00    0.01    0.30    3.10

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW   XSTW     AREA     VEL    YMIN    WSEL
   EXIT :XS      0.   294.   327.    33.     118.    9.23  491.91  497.78
   FV   :FV     25.   294.   327.    33.     117.    9.29  492.66  498.51
   BRO  :BR     25.   300.   319.    19.     117.    8.82  492.88  500.23
   RDWAY:RG     32.*******     0.****************    2.00  501.30  502.27
   APPR :AS     60.   273.   372.    99.     352.    3.10  494.07  502.34

 SECOND USER DEFINED TABLE.
    XSID:CODE       Q    CRWS     FR#     EGL  VHD     HF    HO    WSEL
   EXIT :XS     1090.  497.40    0.86  499.10  1.32************  497.78
   FV   :FV     1090.  498.15    0.87  499.85  1.34  0.73  0.01  498.51
   BRO  :BR     1033.  498.46    0.62  501.44  1.21************  500.23
   RDWAY:RG       67.****************  502.47  0.16  0.04******  502.27
   APPR :AS     1090.  499.14    0.30  502.50  0.16  0.09  0.00  502.34

            HYDRAULIC ANALYSIS
            Woodstock, VT BRIDGE #023
            USGS  BOW,NH   03/23/95
           *** RUN DATE & TIME: 10-05-95  11:39

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

EXIT :XS   ******   287.     171.  1.87 *****  501.07  498.95   1850.  499.19
        0. ******   333.   10860.  1.03 ***** *******    1.00   10.83

 ===125 FR# EXCEEDS FNTEST AT SECID “FV   “:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.01     499.91     499.70

 ===110 WSEL NOT FOUND AT SECID “FV   “:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   498.69     511.50    0.50
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WSPRO OUTPUT FILE (continued)

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 ===115 WSEL NOT FOUND AT SECID “FV   “:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   498.69     511.50     499.70

 ===140 AT SECID “FV   “:  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =   499.93     511.50     499.57

FV   :FV      25.   287.     170.  1.89  0.73  501.82  499.70   1850.  499.93
       25.    25.   333.   10806.  1.03  0.01    0.01    1.00   10.87
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            “APPR “     KRATIO =  1.83

APPR :AS      35.   282.     292.  0.66  0.56  502.37 *******   1850.  501.72
       60.    35.   371.   19783.  1.06  0.00    0.00    0.63    6.33
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   504.74       0.00     500.30     501.30

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   499.85     502.93     503.15     500.23

 ===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

BRO  :BR      25.   300.     120.  1.66 *****  502.23  499.10   1244.  500.57
       25. ******   319.    7150.  1.00 ***** *******    0.72   10.33

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.496  0.000  500.23 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      32.    21.  0.04  0.23  503.95    0.01    616.  503.51

           Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    134.    47.   262.   309.   1.0   0.5   4.3   5.2   1.0   2.9
   RT:    483.    58.   309.   367.   2.2   1.5   6.3   5.4   2.0   3.0

===140 AT SECID “APPR “:  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =   503.75      502.2      511.5

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

APPR :AS      20.   273.     492.  0.23  0.18  503.99  500.80   1850.  503.75
       60.    23.   374.   43035.  1.07  0.46    0.01    0.31    3.76

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW   XSTW     AREA     VEL    YMIN    WSEL
   EXIT :XS       0.   287.   333.    46.     171.   10.83  491.91  499.19
   FV   :FV      25.   287.   333.    46.     170.   10.87  492.66  499.93
   BRO  :BR      25.   300.   319.     0.     120.   10.33  492.88  500.57
   RDWAY:RG      32.*******   134.****************    2.00  501.30  503.51
   APPR :AS      60.   273.   374.   101.     492.    3.76  494.07  503.75

 SECOND USER DEFINED TABLE.
    XSID:CODE       Q    CRWS     FR#     EGL  VHD     HF    HO    WSEL
   EXIT :XS     1850.  498.95    1.00  501.07  1.87************  499.19
   FV   :FV     1850.  499.70    1.00  501.82  1.89  0.73  0.01  499.93
   BRO  :BR     1244.  499.10    0.72  502.23  1.66************  500.57
   RDWAY:RG      616.****************  503.95  0.23  0.04******  503.51
   APPR :AS     1850.  500.80    0.31  503.99  0.23  0.18  0.46  503.75

            HYDRAULIC ANALYSIS
            Woodstock, VT BRIDGE #023
            USGS  BOW,NH   03/23/95
           *** RUN DATE & TIME: 10-05-95  11:39

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

EXIT :XS   ******   294.     103.  1.17 *****  498.49  496.96    895.  497.32
        0. ******   326.    5252.  1.00 ***** *******    0.85    8.68

 ===125 FR# EXCEEDS FNTEST AT SECID “FV   “:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80     0.86     498.05     497.71
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 ===110 WSEL NOT FOUND AT SECID “FV   “:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   496.82     511.50    0.50

 ===115 WSEL NOT FOUND AT SECID “FV   “:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   496.82     511.50     497.71

FV   :FV      25.   295.     102.  1.19  0.73  499.24  497.71    895.  498.05
       25.    25.   326.    5199.  1.00  0.01    0.00    0.86    8.74
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPR “:  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.90     498.90     498.66

 ===110 WSEL NOT FOUND AT SECID “APPR “:  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   497.55     511.50    0.50

 ===115 WSEL NOT FOUND AT SECID “APPR “:  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   497.55     511.50     498.66

APPR :AS      35.   297.      98.  1.28  0.90  500.18  498.66    895.  498.90
       60.    35.   328.    6008.  1.00  0.05    0.00    0.90    9.09
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID “BRO  “     Q,CRWS =     895.     498.03

            <<<<<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

BRO  :BR      25.   300.      77.  2.12 *****  500.15  498.03    895.  498.03
       25.    25.   318.    5171.  1.00 ***** *******    1.00   11.69

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  500.23 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q   WSEL
   RDWAY:RG      32.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR :AS      20.   292.     192.  0.38  0.27  500.87  498.66    895.  500.49
       60.    20.   368.   11685.  1.13  0.45    0.01    0.55    4.66

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.423  0.152    9873.   305.   323.   500.36

                       <<<<<END OF BRIDGE COMPUTATIONS>>>>>
   FIRST USER DEFINED TABLE.
     XSID:CODE    SRD    LEW    REW   XSTW     AREA     VEL    YMIN    WSEL
    EXIT :XS       0.   294.   326.    32.     103.    8.68  491.91  497.32
    FV   :FV      25.   295.   326.    32.     102.    8.74  492.66  498.05
    BRO  :BR      25.   300.   318.    18.      77.   11.69  492.88  498.03
    RDWAY:RG      32.******************************    2.00  501.30********
    APPR :AS      60.   292.   368.    76.     192.    4.66  494.07  500.49

  SECOND USER DEFINED TABLE.
     XSID:CODE       Q    CRWS     FR#     EGL  VHD     HF     HO    WSEL
    EXIT :XS      895.  496.96    0.85  498.49  1.17************  497.32
    FV   :FV      895.  497.71    0.86  499.24  1.19  0.73  0.01  498.05
    BRO  :BR      895.  498.03    1.00  500.15  2.12************  498.03
    RDWAY:RG        0.**************************************************
    APPR :AS      895.  498.66    0.55  500.87  0.38  0.27  0.45  500.49
```
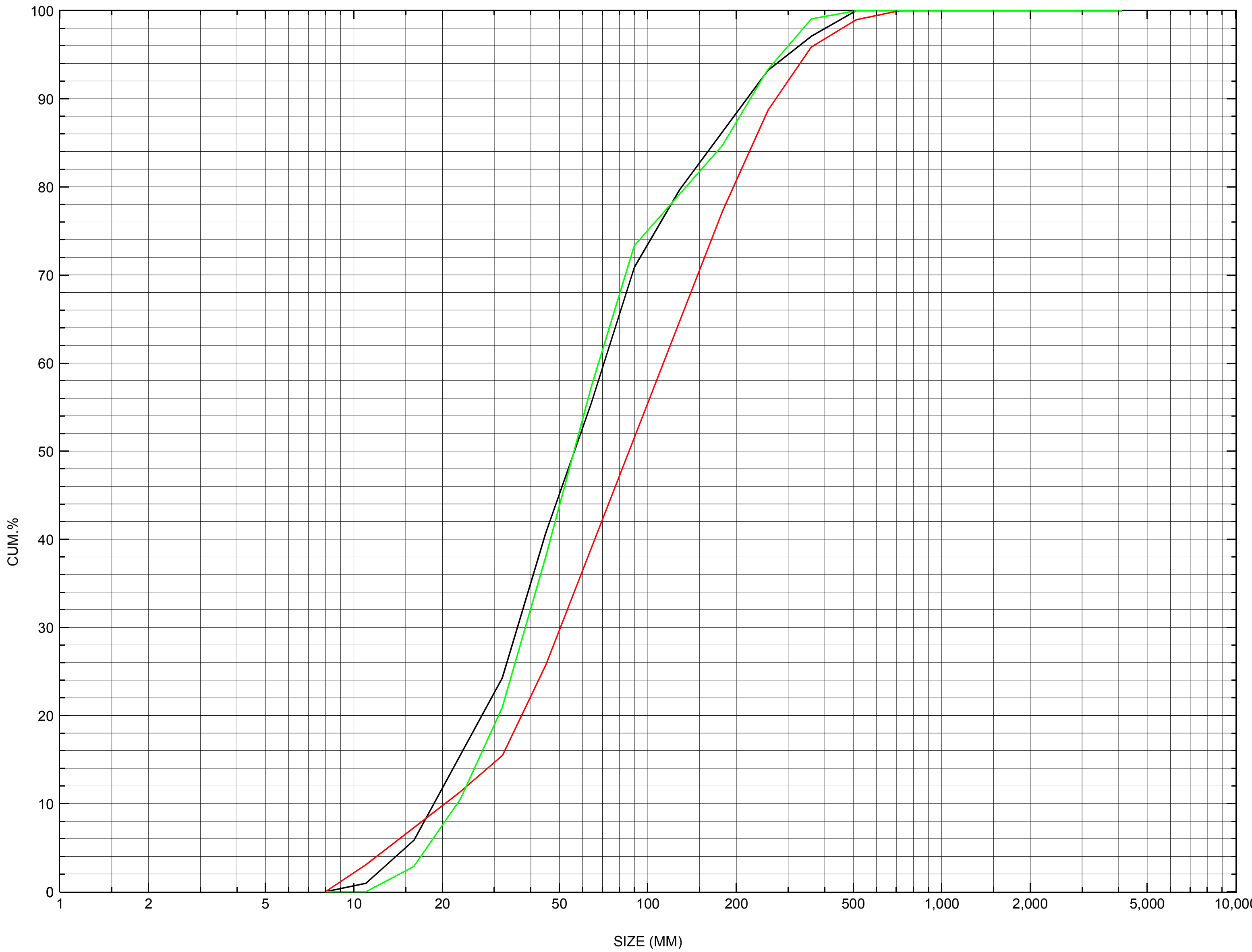

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure WODSTH00180023, in Woodstock, Vermont.

APPENDIX D:

HISTORICAL DATA FORM