LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (BRIDTH00440028) on TOWN HIGHWAY 44, crossing PLYMOUTH BROOK, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-188

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

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By SCOTT A. OLSON and JOSEPH D. AYOTTE

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
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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 28 (BRIDTH00440028) ON TOWN HIGHWAY 44, CROSSING PLYMOUTH BROOK, BRIDGEWATER, VERMONT

***By* Scott A. Olson and Joseph D. Ayotte**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00440028 on town highway 44 crossing Plymouth Brook, 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 11.3-mi^2 drainage area is a predominantly rural basin. In the vicinity of the study site, the left and right banks are pasture.

In the study area, Plymouth Brook has an incised channel with a slope of approximately 0.0054 ft/ft, an average channel top width of 42 ft and an average channel depth of 3 ft. The predominant channel bed material is gravel (D_{50} is 62.3 mm or 0.204 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 9, 1994, indicated that the reach was stable.

The town highway 44 crossing of Plymouth Brook is a 34-ft-long bridge consisting of one 31-foot concrete span (Vermont Agency of Transportation, written communication, August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is 5 degrees.

Type-2 (less than 36 inches) stone fill protects the upstream left and right wingwalls. Type-1 (less than 12 inches) stone fill protects the road approaches. 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.

Plymouth, 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 BRIDTH00440028 ***Stream*** Plymouth Brook

County Windsor ***Road*** TH044 ***District*** 04

Description of Bridge

Bridge length 34 ***ft*** ***Bridge width*** 20 ***ft*** ***Max span length*** 31 ***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*** 11/09/94

Description of stone fill Type-2, in good condition, along the bases of the US wingwalls. Type-1 protection on road approaches.

Abutments are vertical and concrete. The footing is exposed on the left abutment.

Is bridge skewed to flood flow according to N ***survey?*** Y ***Angle*** 10

Opening skew to roadway is 5 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	11/09/94	0	0
Level II	11/09/94	-	-

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 At the bridge site, Plymouth Brook has entered the valley of Broad Brook. Upstream of the site, Plymouth Brook is a steep gradient upland stream.

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

Date of inspection 11/09/94

DS left: wide flood plain

DS right: wide flood plain

US left: bank is at the foot of a moderately steep hillside

US right: wide flood plain

Description of the Channel

Average top width 42 ***ft*** ***Average depth*** 3 ***ft***

Predominant bed material gravel ***Bank material*** silt/clay

Straight, narrow, probably incised channel with relatively wide floodplains compared to the channel.

11/09/94

Vegetative co pasture

DS left: pasture

DS right: pasture

US left: pasture

US right:

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

11/09/94--There is no fluvial erosion evident on either the upstream or downstream banks.

Describe any obstructions in channel and date of observation. 11/09/94--none.

Hydrology

Drainage area 11.3 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
Green Mountain Prov.	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: None. 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 3070 ***ft³/s*** ***Q500*** 3990 ***ft³/s***

The Q100 and Q500 discharges based upon a direct cubic feet per second per square mile of drainage relationship with discharges estimated for nearby (1500 feet) Bridgewater bridge 027 and compared with several different empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887; FEMA, 1980). Bridge 027 discharges had been based upon an area relationship [(13.9/26.9) to the 0.7 power] with bridge 57 on Broad Brook which had flood frequency estimates available in the VTAOT database (VTAOT, written communication, May 1995).

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

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

Datum tie between USGS survey and VTAOT plans Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a chiseled 'X' at the downstream left corner of the bridge deck (elev. 999.45 ft, arbitrary datum). RM2 is a chiseled 'X' at the upstream right corner of the bridge deck (elev. 1000.13 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-51	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	9	1	Road Grade section
APPRO	50	2	Modelled Approach section (Templated from SURVA)
SURVA	71	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 reflects 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 0.037, and overbank "n" values ranged from 0.030 to 0.032.

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 0.0054 ft/ft which was estimated from an analysis of surveyed thalweg points, edge of water points, and the topographic map (U.S. Geological Survey, 1966).

The surveyed approach section (SURVA) was moved along the approach channel slope (0.012 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 999.8 *ft*
Average low steel elevation 996.8 *ft*

100-year discharge 3070 *ft^3/s*
Water-surface elevation in bridge opening 997.1 *ft*
Road overtopping? Y *Discharge over road* 80 *ft^3/s*
Area of flow in bridge opening 278 *ft^2*
Average velocity in bridge opening 10.8 *ft/s*
Maximum WSPRO tube velocity at bridge 12.8 *ft/s*

Water-surface elevation at Approach section with bridge 999.9
Water-surface elevation at Approach section without bridge 994.7
Amount of backwater caused by bridge 5.2 *ft*

500-year discharge 3990 *ft^3/s*
Water-surface elevation in bridge opening 997.1 *ft*
Road overtopping? Y *Discharge over road* 772 *ft^3/s*
Area of flow in bridge opening 278 *ft^2*
Average velocity in bridge opening 11.6 *ft/s*
Maximum WSPRO tube velocity at bridge 13.8 *ft/s*

Water-surface elevation at Approach section with bridge 1000.7
Water-surface elevation at Approach section without bridge 995.4
Amount of backwater caused by bridge 5.3

Incipient overtopping discharge 2857 *ft^3/s*
Water-surface elevation in bridge opening 997.1 *ft*
Area of flow in bridge opening 278 *ft^2*
Average velocity in bridge opening 10.3 *ft/s*
Maximum WSPRO tube velocity at bridge 12.2 *ft/s*

Water-surface elevation at Approach section with bridge 999.5
Water-surface elevation at Approach section without bridge 994.4
Amount of backwater caused by bridge 5.1 *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, 500-year and incipient road-overflow 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, 500-year and incipient road-overflow discharges was computed by use ofthe Chang equation (Richardson and others, 1995, p. 145-146). The results of Laursen's clear-water contraction scour (Richardson and others, 1993, p. 35, equation 18) for the three events were also computed and can be found in appendix F.

Abutment scour for the left abutment 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 at the right abutment was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

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	1.4	2.1	0.9
Depth to armoring	4.9	8.9	3.5
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	15.0	15.8	14.6
Right abutment	9.2	9.3	8.3
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	2.3	2.7	2.1
Right abutment	2.3	2.7	2.1
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

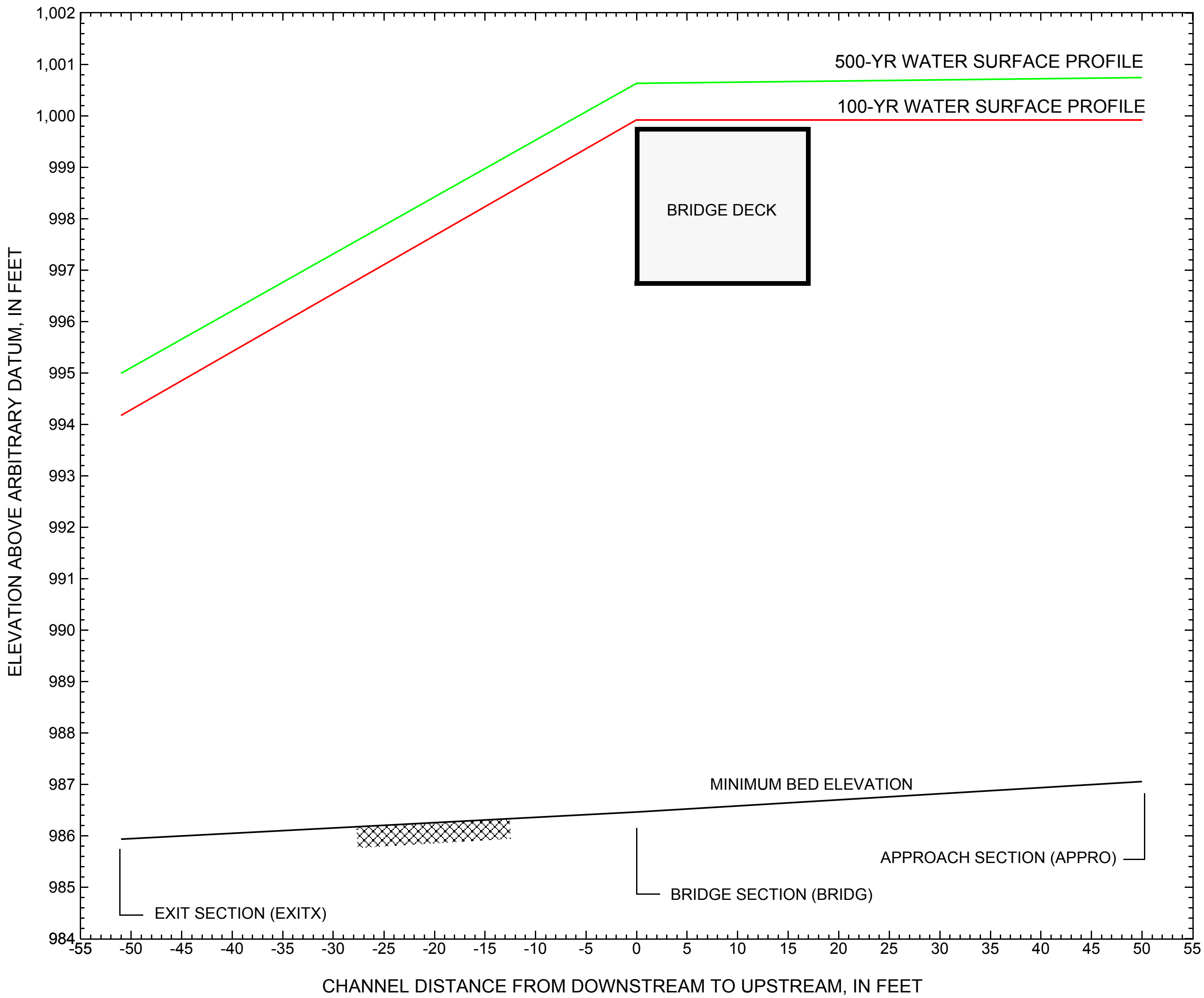

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00440028 on town highway 44, crossing Plymouth Brook, Bridgewater, Vermont.

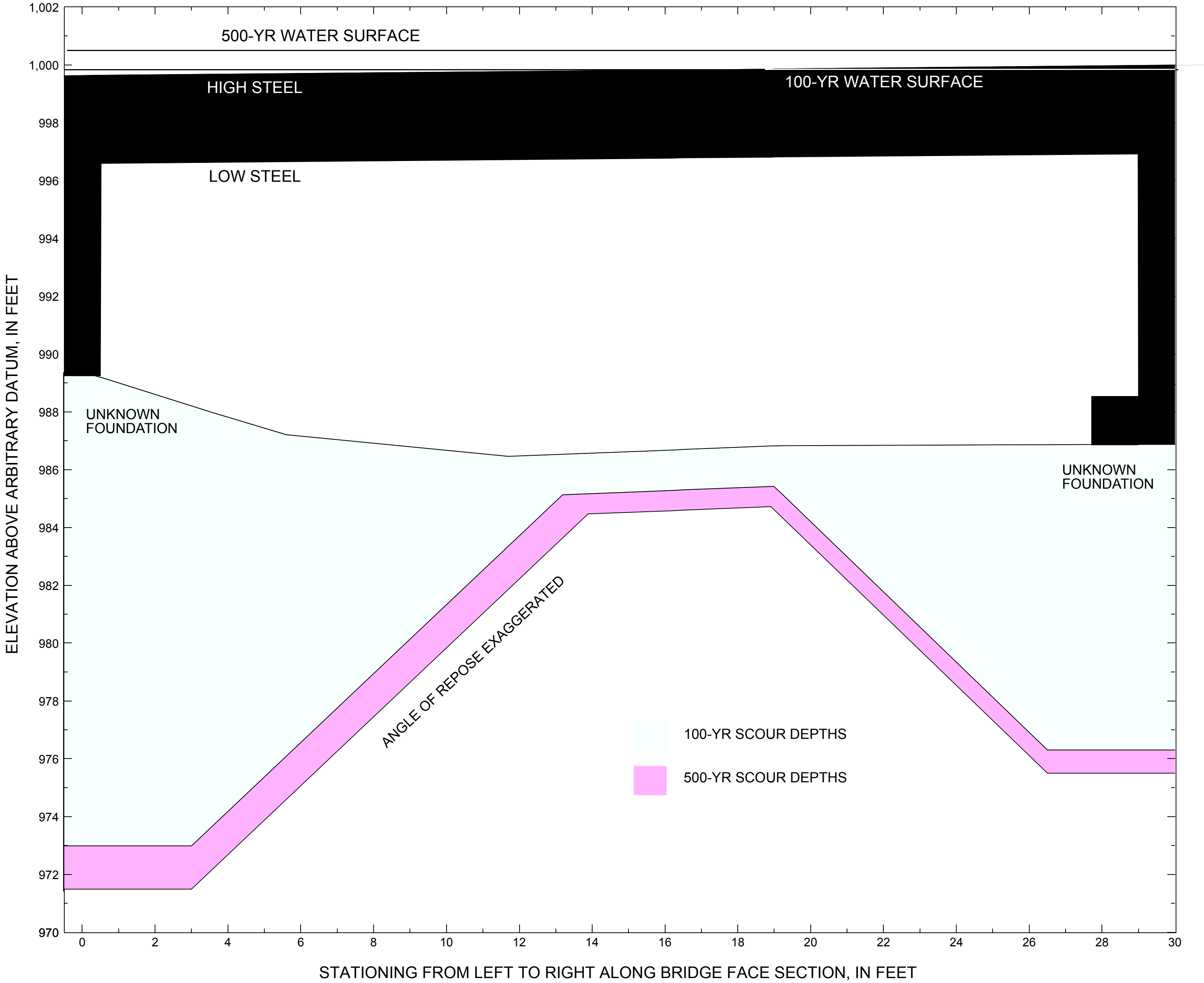

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00440028 on town highway 44, crossing Plymouth Brook, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00440028 on Town Highway 44, crossing Plymouth Brook, 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 3,070 cubic-feet per second											
Left abutment	0.0	--	996.46	--	989.4	1.4	15.0	--	16.4	973.0	--
Right abutment	29.5	--	997.06	--	986.9	1.4	9.2	--	10.6	976.3	--

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 BRIDTH00440028 on Town Highway 44, crossing Plymouth Brook, Bridgewater, Vermont.

[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 3,990 cubic-feet per second											
Left abutment	0.0	--	996.46	--	989.4	2.1	15.8	--	17.9	971.5	--
Right abutment	29.5	--	997.06	--	986.9	2.1	9.3	--	11.4	975.5	--

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

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

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
T2        CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
T3        HYDRAULIC ANALYSIS OF BRID028    SAO
*
J1         * * 0.002
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          3070 3990 2857
WS         994.6 995.3 994.5
SK         0.0054 0.0054 0.0054
*
XS   EXITX    -51
GR          -81.8, 994.85     -7.6, 994.21      0.0, 990.46     12.1, 986.80
GR           19.8, 986.08     25.6, 985.93     34.8, 986.76     41.9, 988.99
GR           47.9, 992.72     72.2, 994.10    104.6, 995.55    195.9, 996.01
GR          354.0, 999.64    484.2,1000.65    543.6,1016.91
N            0.031     0.037    0.032
SA                -7.6      47.9
*
XS   FULLV       0  * * *   0.0054
*
BR   BRIDG   0 996.8 10
GR            0.0, 996.46      0.3, 989.39      3.6, 987.97      5.6, 987.21
GR           11.7, 986.46     19.2, 986.83     27.8, 986.87     27.8, 987.40
GR           27.9, 988.45     29.5, 988.51     29.5, 997.06      0.0, 996.46
N            0.035
CD           4 17.0 5.1 999.5 60.0 5.2
*
XR   RDWAY   9 20.0 2
GR         -127.1,1005.36    -49.4,1000.15      0.0, 999.51     30.5,1000.10
GR          145.7, 999.46    251.2,1001.06    384.1,1004.91    470.7,1010.03
GR          577.0,1019.34
*
XT   SURVA     71
GR          -62.4,1005.41    -49.9, 997.07    -13.7, 993.87     -6.9, 991.30
GR            0.0, 987.71      1.3, 987.37      9.2, 987.30     18.0, 987.38
GR           21.6, 987.78     24.2, 989.04     35.5, 991.10     40.8, 993.67
GR           66.2, 994.81    100.1, 997.28    269.7, 999.67    278.2,1000.69
GR          316.7,1000.69    324.4,1003.68    346.2,1004.38    361.3,1013.93
*
AS   APPRO    50
GT            -0.25
N           0.030        0.037        0.032
SA                 -14.          40.8
*
HP 1 BRIDG    997.06 1 997.06
HP 2 BRIDG    997.06 * * 2991
HP 2 RDWAY    999.92 * * 80
HP 1 APPRO    999.92 1 999.92
HP 2 APPRO    999.92 * * 3070
*
HP 1 BRIDG    997.06 1 997.06
HP 2 BRIDG    997.06 * * 3223
HP 2 RDWAY    1000.63 * * 772
HP 1 APPRO    1000.74 1 1000.74
HP 2 APPRO    1000.74 * * 3990
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
      U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
      CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
      HYDRAULIC ANALYSIS OF BRID028    SAO
         *** RUN DATE & TIME: 09-15-95  13:38
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     278.   28178.     0.    75.                          0.
  997.06          278.   28178.     0.    75.  1.00     0.    30.      0.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

        WSEL     LEW     REW    AREA        K        Q    VEL
      997.06     0.0    29.5   277.6   28178.    2991.  10.77
X STA.        0.0        3.3        5.0        6.5        7.9        9.2
  A(I)            23.7       15.3       13.9       13.1       12.6
  V(I)            6.32       9.76      10.75      11.42      11.88

X STA.        9.2       10.5       11.7       12.9       14.0       15.2
  A(I)            12.4       11.8       11.9       11.8       11.7
  V(I)           12.11      12.72      12.54      12.73      12.77

X STA.       15.2       16.4       17.6       18.8       20.0       21.2
  A(I)            11.8       11.7       11.8       12.2       12.4
  V(I)           12.70      12.74      12.63      12.25      12.08

X STA.       21.2       22.5       23.8       25.2       26.7       29.5
  A(I)            12.4       13.0       13.6       15.2       25.3
  V(I)           12.02      11.47      11.01       9.81       5.91

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.
        WSEL     LEW     REW    AREA        K        Q    VEL
      999.92   -31.6   176.0    36.8     619.      80.   2.17

X STA.      -31.6      -11.8       -6.0       -1.7        2.1        7.6
  A(I)             2.6        1.7        1.6        1.5        1.8
  V(I)            1.56       2.36       2.55       2.73       2.29

X STA.        7.6       98.0      107.7      114.7      120.4      125.0
  A(I)             5.2        2.2        1.9        1.7        1.5
  V(I)            0.77       1.85       2.12       2.34       2.58

X STA.      125.0      129.2      132.9      136.4      139.6      142.6
  A(I)             1.5        1.4        1.4        1.3        1.3
  V(I)            2.67       2.85       2.90       3.01       3.05

X STA.      142.6      145.6      148.6      152.5      157.7      176.0
  A(I)             1.3        1.3        1.5        1.7        2.5
  V(I)            2.99       3.00       2.68       2.41       1.57

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     175.   22739.    41.    42.                       2071.
            2     589.  112180.    55.    57.                      10959.
            3     579.   49425.   233.   233.                       5178.
  999.92         1343.  184343.   328.   332.  1.39   -55.   274.  13097.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
        WSEL     LEW     REW    AREA        K        Q    VEL
      999.92   -54.5   273.9  1343.5  184343.    3070.   2.29

X STA.      -54.5      -30.8      -18.6       -9.0       -3.1        1.0
  A(I)            82.5       64.7       64.2       54.9       48.5
  V(I)            1.86       2.37       2.39       2.80       3.16

X STA.        1.0        4.5        7.8       11.2       14.5       17.8
  A(I)            44.6       42.9       43.3       42.7       42.6
  V(I)            3.44       3.58       3.55       3.60       3.61

X STA.       17.8       21.2       25.3       30.0       35.5       44.7
  A(I)            43.0       47.8       49.0       52.1       66.6
  V(I)            3.57       3.21       3.13       2.95       2.30

X STA.       44.7       57.4       72.8       97.8      145.8      273.9
  A(I)            76.5       83.1       99.2      124.2      171.1
  V(I)            2.01       1.85       1.55       1.24       0.90
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
        CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
        HYDRAULIC ANALYSIS OF BRID028    SAO
           *** RUN DATE & TIME: 09-15-95  13:38
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     278.   28178.     0.    75.                           0.
   997.06          278.   28178.     0.    75.  1.00     0.    30.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       997.06     0.0    29.5   277.6   28178.    3223.  11.61

X STA.         0.0         3.3         5.0         6.5         7.9         9.2
  A(I)            23.7        15.3        13.9        13.1        12.6
  V(I)            6.81       10.52       11.59       12.30       12.80

X STA.         9.2        10.5        11.7        12.9        14.0        15.2
  A(I)            12.4        11.8        11.9        11.8        11.7
  V(I)           13.05       13.71       13.51       13.71       13.76

X STA.        15.2        16.4        17.6        18.8        20.0        21.2
  A(I)            11.8        11.7        11.8        12.2        12.4
  V(I)           13.68       13.73       13.61       13.20       13.01

X STA.        21.2        22.5        23.8        25.2        26.7        29.5
  A(I)            12.4        13.0        13.6        15.2        25.3
  V(I)           12.95       12.36       11.87       10.57        6.36

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       9.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1000.63   -56.6   222.8   209.4    7864.     772.   3.69

X STA.       -56.6       -30.7       -18.1        -8.5         0.2         9.8
  A(I)            13.0        10.1         9.1         9.3         9.8
  V(I)            2.97        3.82        4.26        4.15        3.95

X STA.         9.8        25.0        50.2        66.0        79.2        90.8
  A(I)            11.9        14.7        10.8        10.0         9.7
  V(I)            3.24        2.62        3.56        3.84        3.99

X STA.        90.8       101.1       110.6       119.3       127.6       135.5
  A(I)             9.3         9.0         8.7         8.7         8.6
  V(I)            4.17        4.31        4.45        4.42        4.50

X STA.       135.5       143.2       151.3       161.2       175.4       222.8
  A(I)             8.8         9.1        10.0        11.8        17.1
  V(I)            4.37        4.22        3.86        3.28        2.26

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     209.   29786.    42.    43.                        2657.
             2     634.  126802.    55.    57.                       12237.
             3     784.   73084.   277.   277.                        7492.
  1000.74         1627.  229673.   373.   377.  1.38   -56.   317.  16417.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1000.74   -55.8   317.5  1627.4  229673.    3990.   2.45

X STA.       -55.8       -32.1       -19.8        -9.8        -3.3         1.3
  A(I)            95.5        73.9        72.3        65.3        58.1
  V(I)            2.09        2.70        2.76        3.06        3.43

X STA.         1.3         5.1         8.9        12.6        16.3        20.1
  A(I)            52.2        51.3        50.5        51.6        51.2
  V(I)            3.82        3.89        3.95        3.87        3.89

X STA.        20.1        24.4        29.4        35.4        44.8        57.3
  A(I)            54.7        57.3        62.2        76.0        85.7
  V(I)            3.64        3.48        3.21        2.63        2.33

X STA.        57.3        71.8        93.7       128.3       175.8       317.5
  A(I)            90.5       108.6       124.5       141.2       204.7
  V(I)            2.20        1.84        1.60        1.41        0.97
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
        CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
        HYDRAULIC ANALYSIS OF BRID028    SAO
           *** RUN DATE & TIME: 09-15-95  13:38
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     278.   28178.     0.    75.                          0.
   997.06          278.   28178.     0.    75.  1.00     0.    30.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       997.06     0.0    29.5   277.6   28178.    2857.  10.29

X STA.         0.0        3.3        5.0        6.5        7.9        9.2
  A(I)            23.7       15.3       13.9       13.1       12.6
  V(I)            6.04       9.33      10.27      10.91      11.35

X STA.         9.2       10.5       11.7       12.9       14.0       15.2
  A(I)            12.4       11.8       11.9       11.8       11.7
  V(I)           11.57      12.15      11.97      12.16      12.20

X STA.        15.2       16.4       17.6       18.8       20.0       21.2
  A(I)            11.8       11.7       11.8       12.2       12.4
  V(I)           12.13      12.17      12.07      11.70      11.53

X STA.        21.2       22.5       23.8       25.2       26.7       29.5
  A(I)            12.4       13.0       13.6       15.2       25.3
  V(I)           11.48      10.96      10.52       9.37       5.64

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     157.   19217.    40.    41.                       1774.
             2     564.  104462.    55.    57.                      10278.
             3     475.   35917.   229.   229.                       3878.
   999.47         1197.  159595.   324.   328.  1.43   -54.   270.  10898.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       999.47   -53.9   270.1  1196.7  159595.    2857.   2.39

X STA.       -53.9      -29.8      -17.9       -8.9       -3.2        0.7
  A(I)            76.4       58.7       56.6       50.6       44.7
  V(I)            1.87       2.43       2.52       2.82       3.20

X STA.         0.7        3.9        6.9       10.0       13.1       16.2
  A(I)            38.7       38.1       38.5       38.0       37.9
  V(I)            3.69       3.75       3.71       3.76       3.77

X STA.        16.2       19.3       22.6       26.6       31.2       36.6
  A(I)            38.4       39.7       42.7       44.9       48.2
  V(I)            3.72       3.60       3.34       3.18       2.97

X STA.        36.6       46.6       60.4       79.0      119.3      270.1
  A(I)            63.9       75.7       86.4      111.9      166.8
  V(I)            2.24       1.89       1.65       1.28       0.86

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
        CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
        HYDRAULIC ANALYSIS OF BRID028    SAO
           *** RUN DATE & TIME: 09-15-95  13:38

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

EXITX:XS   ******    -8.     343.  1.33 *****  995.50  992.78   3070.  994.17
      -51. ******    74.   41737.  1.06 ***** *******    0.79    8.95

FULLV:FV      51.    -8.     344.  1.32  0.27  995.78 *******   3070.  994.46
        0.    51.    74.   41926.  1.07  0.00    0.01    0.79    8.91
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.94     994.65     993.86

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   993.96    1013.68    0.50
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 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   993.96    1013.68     993.86

APPRO:AS      50.   -25.     323.  1.53  0.30  996.18  993.86   3070.  994.66
       50.    50.    68.   37327.  1.09  0.10    0.00    0.94    9.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   994.23     997.79     997.91     996.80

 ===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      51.     0.     278.  1.80 *****  998.86  994.11   2991.  997.06
        0. ******    30.   28178.  1.00 ***** *******    0.62   10.77

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   5.  0.479  0.000  996.80 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    30.  0.01  0.11 1000.02    0.00     80.  999.92

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:     23.    46.   -31.    15.   0.4   0.2   2.2   2.2   0.3   2.6
   RT:     57.   118.    15.   176.   0.5   0.2   2.2   2.2   0.3   2.6

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

APPRO:AS      33.   -55.    1342.  0.11  0.06 1000.03  993.86   3070.  999.92
       50.    34.   274.  184087.  1.39  0.37    0.00    0.23    2.29

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -51.    -8.    74.   3070.   41737.     343.    8.95  994.17
   FULLV:FV       0.    -8.    74.   3070.   41926.     344.    8.91  994.46
   BRIDG:BR       0.     0.    30.   2991.   28178.     278.   10.77  997.06
   RDWAY:RG       9.*******    23.     80.******************    2.00  999.92
   APPRO:AS      50.   -55.   274.   3070.  184087.    1342.    2.29  999.92

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    992.78    0.79  985.93 1016.91************  1.33  995.50  994.17
   FULLV:FV  ********    0.79  986.21 1017.19  0.27  0.00  1.32  995.78  994.46
   BRIDG:BR    994.11    0.62  986.46  997.06************  1.80  998.86  997.06
   RDWAY:RG  ****************  999.46 1019.34  0.01******  0.11 1000.02  999.92
   APPRO:AS    993.86    0.23  987.05 1013.68  0.06  0.37  0.11 1000.03  999.92

       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
       CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
       HYDRAULIC ANALYSIS OF BRID028    SAO
          *** RUN DATE & TIME: 09-15-95  13:38
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -82.     451.  1.51 *****  996.50  993.99   3990.  994.99
      -51. ******    92.   54293.  1.24 ***** *******    1.08    8.84

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.04     995.35     994.26

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   994.49    1017.19    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   994.49    1017.19     994.26

 ===140 AT SECID "FULLV":  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =   995.26     995.13    1017.19
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FULLV:FV      51.   -82.     451.  1.51  0.28  996.78  994.26   3990.  995.26
        0.    51.    92.   54252.  1.24  0.00    0.00    1.08    8.85
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.99     995.43     995.15

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   994.76    1013.68    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   994.76    1013.68     995.15

APPRO:AS      50.   -34.     404.  1.75  0.30  997.19  995.15   3990.  995.44
       50.    50.    78.   48623.  1.16  0.12   -0.01    0.99    9.88
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =  1000.46       0.00     995.57     999.46

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   995.34     999.97    1000.06     996.80

 ===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      51.     0.     278.  2.10 *****  999.16  994.46   3223.  997.06
        0. ******    30.   28178.  1.00 ***** *******    0.67   11.61

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   5.  0.491  0.000  996.80 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.    30.  0.01  0.13 1000.86    0.00    772. 1000.63

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    209.    71.   -57.    15.   1.1   0.8   4.3   3.8   1.0   2.9
   RT:    563.   208.    15.   223.   1.2   0.7   4.2   3.7   1.0   2.8

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

APPRO:AS      33.   -56.    1627.  0.13  0.07 1000.87  995.15   3990. 1000.74
       50.    35.   317.  229656.  1.38  0.26    0.00    0.24    2.45

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -51.   -82.    92.   3990.   54293.     451.    8.84  994.99
   FULLV:FV       0.   -82.    92.   3990.   54252.     451.    8.85  995.26
   BRIDG:BR       0.     0.    30.   3223.   28178.     278.   11.61  997.06
   RDWAY:RG       9.*******   209.    772.******************    2.00 1000.63
   APPRO:AS      50.   -56.   317.   3990.  229656.    1627.    2.45 1000.74

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    993.99    1.08  985.93 1016.91************  1.51  996.50  994.99
   FULLV:FV    994.26    1.08  986.21 1017.19  0.28  0.00  1.51  996.78  995.26
   BRIDG:BR    994.46    0.67  986.46  997.06************  2.10  999.16  997.06
   RDWAY:RG  ****************  999.46 1019.34  0.01******  0.13 1000.86 1000.63
   APPRO:AS    995.15    0.24  987.05 1013.68  0.07  0.26  0.13 1000.87 1000.74
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
        CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
        HYDRAULIC ANALYSIS OF BRID028    SAO
           *** RUN DATE & TIME: 09-20-96  11:53
XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******     -6      324  1.27 *****  995.20  992.53    2857  993.92
       -50 ******     69    38870  1.05 ***** *******    0.77    8.83

FULLV:FV       51     -6      325  1.26  0.27  995.48 *******    2857  994.21
         0     51     69    39028  1.05  0.00    0.01    0.77    8.80
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.92     994.39     993.57

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   993.71    1013.68    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   993.71    1013.68     993.57

APPRO:AS       50    -22      301  1.49  0.31  995.90  993.57    2857  994.40
        50     50     63    34185  1.06  0.11    0.00    0.92    9.50
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   993.90     997.30     997.44     996.80

 ===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       51      0      278  1.64 *****  998.70  993.88    2852  997.06
         0 ******     30    28178  1.00 ***** *******    0.59   10.27

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   2.  0.470  0.000  996.80 ****** ****** ******

    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       33    -53     1197  0.13  0.06  999.60  993.57    2857  999.47
        50     34    270   159621  1.43  0.41    0.00    0.26    2.39

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -51.    -7.    69.   2857.   38870.     324.    8.83  993.92
   FULLV:FV       0.    -7.    69.   2857.   39028.     325.    8.80  994.21
   BRIDG:BR       0.     0.    30.   2852.   28178.     278.   10.27  997.06
   RDWAY:RG       9.**************      0.       0.       0.    2.00********
   APPRO:AS      50.   -54.   270.   2857.  159621.    1197.    2.39  999.47

SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    992.53    0.77  985.93 1016.91************  1.27  995.20  993.92
   FULLV:FV  ********    0.77  986.21 1017.19  0.27  0.00  1.26  995.48  994.21
   BRIDG:BR    993.88    0.59  986.46  997.06************  1.64  998.70  997.06
   RDWAY:RG  ****************  999.46 1019.34************  0.13  999.59********
   APPRO:AS    993.57    0.26  987.05 1013.68  0.06  0.41  0.13  999.60  999.47
```
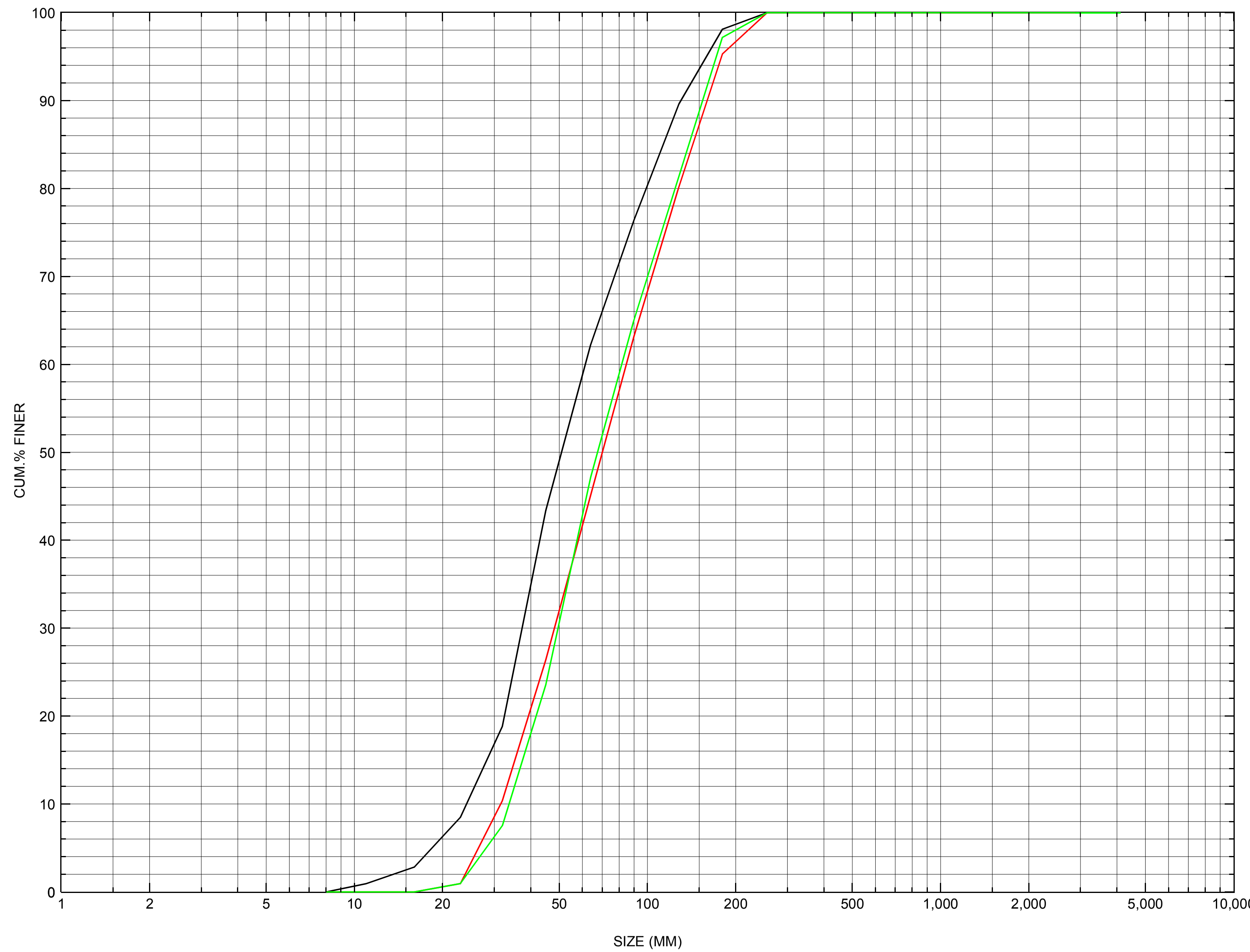

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00440028, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM