LEVEL II SCOUR ANALYSIS FOR BRIDGE 30 (BRIDTH00330030) on TOWN HIGHWAY 33, crossing DAILEY HOLLOW BRANCH, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-304

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

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By SCOTT A. OLSON and DONALD L. SONG

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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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Denver, CO 80225

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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 30 (BRIDTH00330030) ON TOWN HIGHWAY 33, CROSSING DAILEY HOLLOW BRANCH, BRIDGEWATER, VERMONT

By Scott A. Olson and Donald L. Song

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00330030 on town highway 33 crossing Dailey Hollow Branch, Bridgewater, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Bridgewater. The 7.51-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is forest.

In the study area, Dailey Hollow Branch has an incised, sinuous channel with a slope of approximately 0.013 ft/ft, an average channel top width of 45 ft and an average channel depth of 5 ft. The channel bed material ranges from sand to boulder with a median grain size (D_{50}) of 60.7 mm (0.199 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 1, 1994, indicated that the reach was stable.

The town highway 33 crossing of Dailey Hollow Branch is a 31-ft-long, one-lane bridge consisting of one 25-foot steel-beam span with a timber deck (Vermont Agency of Transportation, written communication, August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is 0 degrees. Type-2 stone-fill (less than 36 inches diameter) protection was found at all four wingwalls. 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). Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.5 to 3.1 ft. The worst-case contraction scour occurred at the incipient-roadway-overtopping discharge, which is between the 100- and 500-year discharge. Abutment scour ranged from 6.9 to 14.6 ft. with the worst-case scenario also occurring at the incipient-roadway-overtopping discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1993, p. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

Delectable Mountain, VT. Quadrangle, 1:24,000, 1966
Plymouth, 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 BRIDTH00330030 ***Stream*** Dailey Hollow Branch

County Windsor ***Road*** TH0033 ***District*** 4

Description of Bridge

Bridge length 31 ***ft*** ***Bridge width*** 15.2 ***ft*** ***Max span length*** 25 ***ft***

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

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

Stone fill on abutment? no ***Date of inspection*** 11/1/94

Description of stone fill Type-2 stone-fill at all wingwalls. Only stone-fill on upstream left and downstream right wingwall was noted as being in good condition.

Brief description of piers/abutments Abutments are vertical and concrete. The top of the footing of the left abutment is exposed.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 20

Mild bend with left abutment being impacted at about 20 degrees to the face of the abutment.

11/1/94

Debris accumulation on bridge at time of Level I or Level II site visit:

	Date of inspection	***Percent of channel blocked horizontally***	***Percent of channel blocked vertically***
Level I	11/1/94	0	0
Level II	0	0	0

Potential for debris Moderate, since the stream is in a forested valley.

Describe any features near or at the bridge that may affect flow (include observation date) November 1, 1994--None.

Description of the Geomorphic Setting

General topography The bridge crosses a high gradient incised upland stream with terraces in a moderate relief valley.

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

Date of inspection 11/1/94

DS left: High narrow terrace to valley wall.

DS right: High narrow terrace to valley wall.

US left: High narrow terrace to valley wall.

US right: Steep valley wall with gravel road parallel to channel.

Description of the Channel

Average top width 45 ***ft*** ***Average depth*** 5 ***ft***

Predominant bed material gravel/cobble/boulder ***Bank material*** cobble/boulder

Straight, incised stream.

11/1/94

Vegetative co Forest with gravel road parallel to channel bank.

DS left: Forest.

DS right: Forest.

US left: Forest with gravel road parallel to channel bank.

US right: Y

Do banks appear stable? 11/1/94 ***If not, describe location and type of instability and date of observation.***

November 1, 1994--

None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 7.51 ***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.

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 1,900 ***ft³/s*** ***Q500*** 2,500 ***ft³/s***

The 100-year discharge is from the VTAOT database (VTAOT, written communication, May 1995). The 500-year discharge was selected from a range determined by several empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887; 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 Subtract 1 ft from USGS survey datum to obtain VTAOT plan's datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of the upstream end of the right abutment (elev. 499.62 ft, arbitrary survey datum). RM2 is a chiseled X on top of the downstream end of the left abutment (elev. 499.46 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT1	-43	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	7.6	1	Road Grade section
APPRO	50	2	Modelled Approach section (Templated from APTEM)
APTEM	69	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 0.055 to 0.060, and overbank "n" values ranged from 0.035 to 0.100.

Normal depth at the exit section (EXIT1) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the User's manual for WSPRO (Shearman, 1990). The slope used was 0.013 ft/ft which was determined from an analysis of surveyed thalweg and water surface points downstream of the bridge and the topographic map (U.S. Geological Survey, 1966).

The surveyed approach section (APTEM) was moved along the approach channel slope (0.010 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

For the 100-year and incipient overtopping discharge, WSPRO assumes critical depth at the bridge section. Supercritical models were developed for these discharges. Analyzing both the supercritical and subcritical profiles for each discharge, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satifactory solutions.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.3 *ft*
Average low steel elevation 497.6 *ft*

100-year discharge 1,900 *ft³/s*
Water-surface elevation in bridge opening 492.9 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 138 *ft²*
Average velocity in bridge opening 13.8 *ft/s*
Maximum WSPRO tube velocity at bridge 17.0 *ft/s*

Water-surface elevation at Approach section with bridge 496.7
Water-surface elevation at Approach section without bridge 493.9
Amount of backwater caused by bridge 2.8 *ft*

500-year discharge 2,500 *ft³/s*
Water-surface elevation in bridge opening 497.6 *ft*
Road overtopping? Y *Discharge over road* 185 *ft³/s*
Area of flow in bridge opening 246 *ft²*
Average velocity in bridge opening 9.5 *ft/s*
Maximum WSPRO tube velocity at bridge 11.5 *ft/s*

Water-surface elevation at Approach section with bridge 499.6
Water-surface elevation at Approach section without bridge 494.5
Amount of backwater caused by bridge 5.1

Incipient overtopping discharge 2,310 *ft³/s*
Water-surface elevation in bridge opening 493.7 *ft*
Area of flow in bridge opening 157 *ft²*
Average velocity in bridge opening 14.7 *ft/s*
Maximum WSPRO tube velocity at bridge 18.4 *ft/s*

Water-surface elevation at Approach section with bridge 497.9
Water-surface elevation at Approach section without bridge 494.3
Amount of backwater caused by bridge 3.6 *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.

Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the 100-year and incipient overtopping discharges. Contraction scour was computed by use of Chang pressure-flow scour equation (Richardson and others, 1995, p. 145-146) for the 500-year discharge, where orifice flow occurred at the bridge. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). The results of Laursen's clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the 500-year discharge was also computed and can be found in appendix F. For contraction scour computations using the Laursen's equation, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

The incipient overtopping discharge resulted in the worst case contraction scour results. This discharge also resulted in worst case total scour. Also, the 100-year scour depths were greater than the 500-year scour depths. Thus, figure 8 only shows the 100-year scour depths.

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	2.4	0.5	3.1
Depth to armoring	2.6	2.4	3.9
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	13.8	14.5	14.6
Right abutment	6.9	7.1	7.4
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:			
Left abutment	2.5	1.7	2.8
Right abutment	2.5	1.7	2.8
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

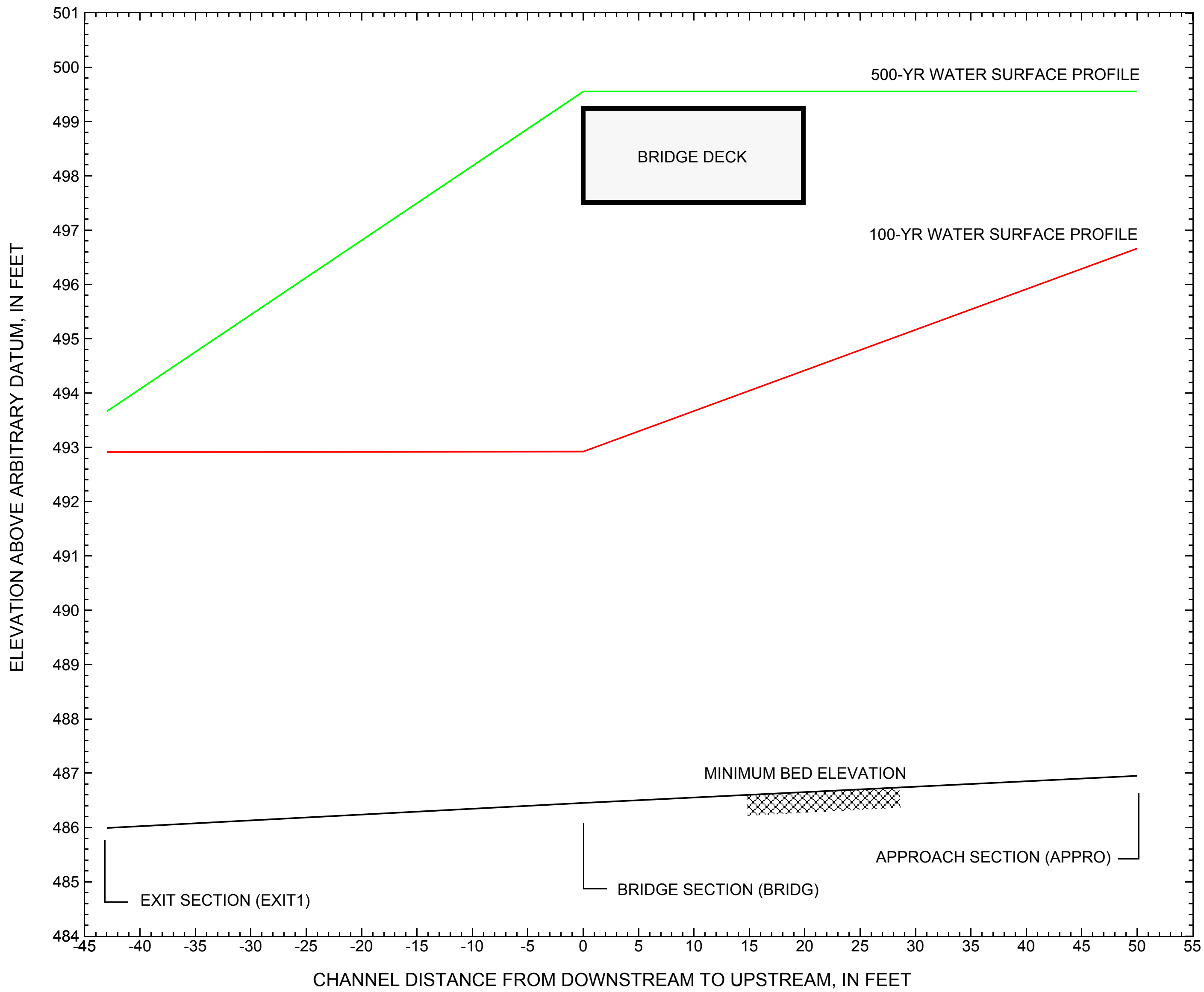

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00330030 on town highway 33, crossing Dailey Hollow Branch, Bridgewater, Vermont.

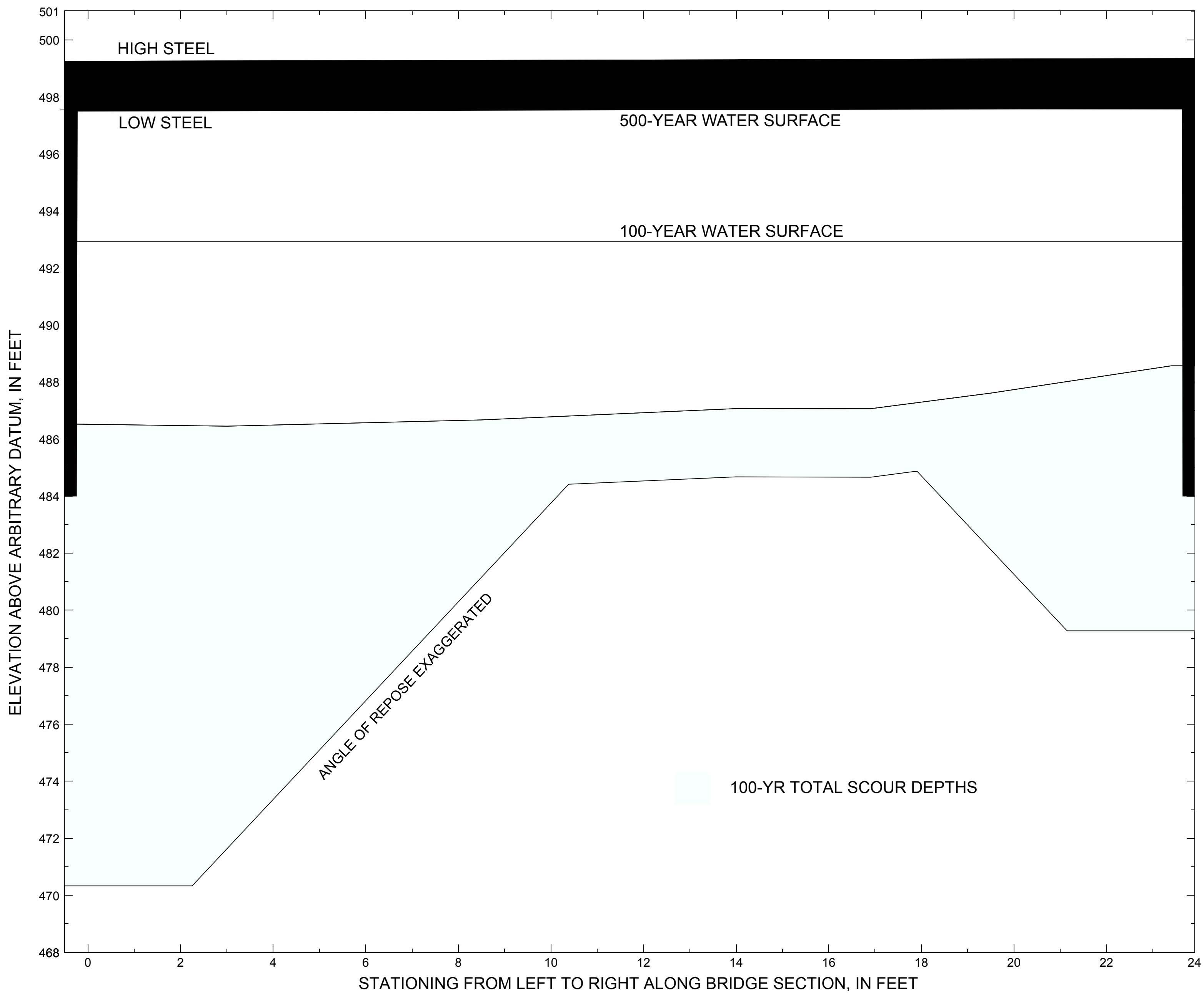

Figure 8. Scour elevations for the 100-year discharge at structure BRIDTH00330030 on town highway 33, crossing Dailey Hollow Branch, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00330030 on Town Highway 33, crossing Dailey Hollow Branch, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 1,900 cubic-feet per second											
Left abutment	0.0	496.6	497.5	484	486.5	2.4	13.8	--	16.2	470.3	-14
Right abutment	23.4	496.9	497.6	484	488.6	2.4	6.9	--	9.3	479.3	-5

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 BRIDTH00330030 on Town Highway 33, crossing Dailey Hollow Branch, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 2,500 cubic-feet per second											
Left abutment	0.0	496.6	497.5	484	486.5	0.5	14.5	--	15.0	471.5	-13
Right abutment	23.4	496.9	497.6	484	488.6	0.5	7.1	--	7.6	481.0	-3

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 brid030.wsp
T2        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
T3        HYDRAULIC ANALYSIS OF BRID030        SAO
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          1900 2500 2310
SK         0.013 0.013 0.013
*
XS   EXIT1    -43
GR          -67.1, 508.33    -47.3, 497.18    -28.3, 496.64    -12.4, 495.22
GR            0.0, 486.85      2.5, 486.28      9.7, 485.99     15.3, 486.14
GR           19.5, 486.77     26.9, 487.76     32.3, 490.60     43.8, 492.38
GR           57.0, 492.35    119.5, 492.22    119.5, 508
N            0.037        0.060        0.100
SA                 -12.4        32.3
*
XS   FULLV      0  * * *   0.013
*
BR   BRIDG   0 497.6
GR            0.0, 497.50      0.0, 486.53      1.6, 486.48      3.0, 486.45
GR            8.5, 486.67     14.0, 487.07     16.9, 487.06     19.5, 487.61
GR           23.4, 488.57     23.4, 497.61      0.0, 497.50
N            0.055
CD           1 27.8 * * 45 7.8
*
XR   RDWAY   7.6 15.2 2
GR          -61.5, 503.64    -44.5, 498.73    -23.4, 498.73      0.0, 499.21
GR           30.8, 499.38     55.6, 499.36     79.6, 499.59    116.9, 502.64
*
XT   APTEM     69
GR          -68.8, 508.65    -34.4, 497.66    -16.7, 497.01     -6.0, 490.87
GR            5.2, 488.14      7.8, 487.81     12.5, 487.14     18.9, 487.57
GR           19.7, 488.15     20.5, 488.38     26.5, 495.56     40.7, 498.79
GR           49.4, 499.19     65.6, 499.32     73.2, 499.95     82.8, 503.46
GR          100.6, 508.31
*
AS   APPRO     50
GT          -0.19
N           0.040        0.055        0.035
SA                 -10.7        46.7
*
HP 1 BRIDG    492.92 1 492.92
HP 2 BRIDG    492.92 * * 1900
HP 1 APPRO    496.66 1 496.66
HP 2 APPRO    496.66 * * 1900
*
HP 1 BRIDG    497.61 1 497.61
HP 2 BRIDG    497.61 * * 2329
HP 2 RDWAY    499.55 * * 185
HP 1 APPRO    499.55 1 499.55
HP 2 APPRO    499.55 * * 2500
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     138.    9439.    23.    34.                        1899.
   492.92          138.    9439.    23.    34.  1.00     0.    23.   1899.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       492.92     0.0    23.4   137.9    9439.    1900.  13.78
X STA.         0.0         2.1         3.3         4.4         5.4         6.3
  A(I)            13.7         7.8         6.9         6.4         6.0
  V(I)            6.93       12.23       13.83       14.96       15.73

X STA.         6.3         7.3         8.2         9.1        10.0        10.9
  A(I)             5.9         5.7         5.6         5.7         5.6
  V(I)           16.17       16.59       16.96       16.74       16.93

X STA.        10.9        11.9        12.8        13.8        14.8        15.8
  A(I)             5.6         5.7         5.7         5.8         6.0
  V(I)           16.86       16.53       16.79       16.38       15.79

X STA.        15.8        16.8        18.0        19.2        20.7        23.4
  A(I)             6.1         6.5         7.0         7.7        12.5
  V(I)           15.61       14.64       13.65       12.26        7.57

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       9.     443.     6.     7.                          68.
             2     279.   24519.    43.    48.                        4037.
   496.66          288.   24962.    49.    54.  1.02   -16.    32.   3950.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       496.66   -16.4    32.2   288.3   24962.    1900.   6.59
X STA.       -16.4        -7.7        -4.9        -2.7        -0.8         0.9
  A(I)            22.0        16.1        14.0        13.4        12.7
  V(I)            4.33        5.90        6.78        7.08        7.47

X STA.         0.9         2.5         3.9         5.3         6.6         7.9
  A(I)            12.3        12.1        11.8        11.5        11.7
  V(I)            7.73        7.85        8.09        8.24        8.09

X STA.         7.9         9.2        10.4        11.7        12.9        14.2
  A(I)            11.5        11.7        11.6        12.0        12.5
  V(I)            8.29        8.13        8.17        7.91        7.59

X STA.        14.2        15.5        17.0        18.6        20.7        32.2
  A(I)            12.8        14.1        14.8        18.5        31.2
  V(I)            7.44        6.73        6.40        5.14        3.05
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     246.   15898.     0.    67.                           0.
  497.61           246.   15898.     0.    67.  1.00     0.    23.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       497.61     0.0    23.4   246.4   15898.    2329.   9.45
X STA.         0.0        2.1        3.4        4.5        5.5        6.5
  A(I)            23.3       13.8       12.3       11.4       10.8
  V(I)            5.01       8.42       9.50      10.24      10.74

X STA.         6.5        7.5        8.4        9.4       10.3       11.3
  A(I)            10.6       10.3       10.4       10.2       10.1
  V(I)           11.01      11.26      11.22      11.42      11.49

X STA.        11.3       12.2       13.2       14.2       15.2       16.2
  A(I)            10.3       10.2       10.3       10.6       10.8
  V(I)           11.31      11.38      11.32      10.97      10.82

X STA.        16.2       17.2       18.3       19.6       21.0       23.4
  A(I)            10.8       11.4       12.5       13.8       22.6
  V(I)           10.80      10.19       9.35       8.47       5.16

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.55   -47.3    75.4    46.2    1054.     185.   4.00
X STA.       -47.3      -43.4      -41.4      -39.6      -37.7      -35.9
  A(I)             2.1        1.6        1.5        1.5        1.5
  V(I)            4.46       5.77       6.13       6.06       6.10

X STA.       -35.9      -34.1      -32.2      -30.4      -28.5      -26.7
  A(I)             1.5        1.5        1.5        1.5        1.5
  V(I)            6.18       6.15       6.10       6.17       6.17

X STA.       -26.7      -24.9      -23.1      -21.1      -19.0      -16.7
  A(I)             1.5        1.5        1.5        1.6        1.7
  V(I)            6.16       6.16       6.08       5.85       5.57

X STA.       -16.7      -14.0       -9.5       -0.5       16.4       75.4
  A(I)             1.8        2.6        4.0        5.0        9.4
  V(I)            5.27       3.53       2.32       1.86       0.99

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      76.    5102.    30.    31.                         685.
             2     424.   41187.    57.    62.                        6541.
             3      11.     261.    24.    24.                          40.
  499.55           511.   46550.   112.   118.  1.06   -41.    71.   6010.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.55   -40.9    70.7   510.7   46550.    2500.   4.90
X STA.       -40.9      -19.7      -11.4       -7.8       -5.1       -3.0
  A(I)            41.4       30.2       25.0       22.6       20.3
  V(I)            3.02       4.14       4.99       5.54       6.15

X STA.        -3.0       -1.0        0.9        2.7        4.4        6.0
  A(I)            19.6       19.4       19.3       18.7       18.8
  V(I)            6.36       6.45       6.49       6.67       6.66

X STA.         6.0        7.6        9.2       10.8       12.4       14.1
  A(I)            18.9       19.2       19.8       20.4       21.1
  V(I)            6.63       6.51       6.31       6.12       5.91

X STA.        14.1       16.0       17.9       20.3       24.4       70.7
  A(I)            22.7       24.1       27.9       38.2       63.0
  V(I)            5.50       5.19       4.48       3.27       1.98
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     157.   11369.    23.    36.                        2309.
   493.74          157.   11369.    23.    36.  1.00     0.    23.   2309.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       493.74     0.0    23.4   157.1   11369.    2310.  14.71
X STA.         0.0         2.2         3.4         4.5         5.5         6.5
  A(I)            15.9         9.1         7.8         7.4         6.8
  V(I)            7.24       12.75       14.90       15.69       17.00

X STA.         6.5         7.4         8.3         9.2        10.1        11.0
  A(I)             6.6         6.5         6.5         6.3         6.3
  V(I)           17.46       17.90       17.87       18.25       18.43

X STA.        11.0        12.0        12.9        13.9        14.9        15.8
  A(I)             6.4         6.3         6.5         6.5         6.6
  V(I)           18.19       18.37       17.71       17.64       17.41

X STA.        15.8        16.9        18.0        19.2        20.7        23.4
  A(I)             7.0         7.1         7.9         9.1        14.6
  V(I)           16.45       16.23       14.66       12.69        7.92

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      31.    1309.    25.    26.                         197.
             2     337.   31148.    48.    53.                        5042.
   497.93          368.   32456.    74.    80.  1.06   -36.    38.   4529.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       497.93   -35.8    37.8   368.1   32456.    2310.   6.27
X STA.       -35.8        -9.8        -6.5        -4.2        -2.2        -0.4
  A(I)            35.6        20.0        17.0        15.8        15.4
  V(I)            3.25        5.79        6.81        7.29        7.52

X STA.        -0.4         1.3         2.9         4.4         5.8         7.2
  A(I)            14.8        14.4        14.5        13.9        14.1
  V(I)            7.80        8.05        7.96        8.33        8.17

X STA.         7.2         8.6         9.9        11.3        12.6        14.1
  A(I)            14.2        14.5        14.4        14.9        15.6
  V(I)            8.13        7.98        8.02        7.75        7.41

X STA.        14.1        15.6        17.2        19.1        21.6        37.8
  A(I)            16.3        17.7        19.7        24.4        41.1
  V(I)            7.07        6.53        5.86        4.74        2.81
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12

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

EXIT1:XS   ******    -9.     282.  1.02 *****  493.93  491.59   1900.  492.91
      -43. ******   120.   16648.  1.44 ***** *******    0.96    6.73

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.95     493.49     492.15

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   492.41     508.89    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   492.41     508.89     492.15

FULLV:FV      43.    -9.     284.  1.01  0.56  494.50  492.15   1900.  493.49
        0.    43.   120.   16746.  1.45  0.00    0.01    0.95    6.68
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.88     493.92     493.51

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   492.99     508.46    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   492.99     508.46     493.51

APPRO:AS      50.   -12.     175.  1.84  0.86  495.77  493.51   1900.  493.92
       50.    50.    25.   12604.  1.00  0.42    0.00    0.88   10.88
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"     Q,CRWS =    1900.      492.92

            <<<<<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      43.     0.     138.  2.95 *****  495.87  492.92   1900.  492.92
        0.    43.    23.    9445.  1.00 ***** *******    1.00   13.77

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.60 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.        <<<<<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      22.   -16.     288.  0.69  0.35  497.34  493.51   1900.  496.66
       50.    23.    32.   24941.  1.02  1.12    0.01    0.48    6.59

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.367  0.090   22648.    -1.    22.   496.45

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT1:XS     -43.    -9.   120.   1900.   16648.     282.    6.73  492.91
   FULLV:FV       0.    -9.   120.   1900.   16746.     284.    6.68  493.49
   BRIDG:BR       0.     0.    23.   1900.    9445.     138.   13.77  492.92
   RDWAY:RG       8.**************      0.*****************    2.00********
   APPRO:AS      50.   -16.    32.   1900.   24941.     288.    6.59  496.66

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -1.    22.   22648.

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX     HF     HO   VHD      EGL    WSEL
   EXIT1:XS    491.59    0.96  485.99  508.33************  1.02  493.93  492.91
   FULLV:FV    492.15    0.95  486.55  508.89  0.56  0.00  1.01  494.50  493.49
   BRIDG:BR    492.92    1.00  486.45  497.61************  2.95  495.87  492.92
   RDWAY:RG  ****************  498.73  503.64**********************************
   APPRO:AS    493.51    0.48  486.95  508.46  0.35  1.12  0.69  497.34  496.66
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WSPRO OUTPUT FILE (continued)

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12

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

EXIT1:XS   ******   -10.     379.  1.09 *****  494.76  493.12   2500.  493.66
      -43. ******   120.   21909.  1.61 ***** *******    0.86    6.60

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.86     494.24     493.68

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   493.16     508.89    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   493.16     508.89     493.68

FULLV:FV      43.   -10.     381.  1.08  0.56  495.32  493.68   2500.  494.24
        0.    43.   120.   22050.  1.62  0.00    0.01    0.86    6.55
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.02     494.42     494.46

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   493.74     508.46    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   493.74     508.46     494.46

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  0.67

APPRO:AS      50.   -13.     195.  2.58  0.95  497.04  494.46   2500.  494.46
       50.    50.    26.   14867.  1.01  0.75    0.01    1.01   12.84
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   494.11     498.20     498.51     497.60

 ===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      43.     0.     246.  1.39 *****  499.00  493.78   2329.  497.61
        0. ******    23.   15898.  1.00 ***** *******    0.51    9.45

     TYPE PPCD FLOW       C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.432 ******  497.60 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.    35.  0.10  0.40  499.85    0.01    185.  499.55

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    144.    58.   -47.    11.   0.8   0.6   4.1   4.0   0.9   2.9
   RT:     42.    44.    11.    56.   0.3   0.2   2.8   4.7   0.5   2.7

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

APPRO:AS      22.   -41.     511.  0.40  0.18  499.95  494.46   2500.  499.55
       50.    23.    71.   46568.  1.06  1.16    0.01    0.42    4.89

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT1:XS     -43.   -10.   120.   2500.   21909.     379.    6.60  493.66
   FULLV:FV       0.   -10.   120.   2500.   22050.     381.    6.55  494.24
   BRIDG:BR       0.     0.    23.   2329.   15898.     246.    9.45  497.61
   RDWAY:RG       8.*******   144.    185.*********       0.    2.00  499.55
   APPRO:AS      50.   -41.    71.   2500.   46568.     511.    4.89  499.55

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT1:XS    493.12    0.86  485.99  508.33************  1.09  494.76  493.66
   FULLV:FV    493.68    0.86  486.55  508.89  0.56  0.00  1.08  495.32  494.24
   BRIDG:BR    493.78    0.51  486.45  497.61************  1.39  499.00  497.61
   RDWAY:RG  ****************  498.73  503.64  0.10******  0.40  499.85  499.55
   APPRO:AS    494.46    0.42  486.95  508.46  0.18  1.16  0.40  499.95  499.55
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid030.wsp
        CREATED ON 21-SEP-95 FOR BRIDGE BRIDTH00330030 USING FILE brid030.dca
        HYDRAULIC ANALYSIS OF BRID030        SAO
           *** RUN DATE & TIME: 04-15-96  11:12

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

EXIT1:XS   ******   -10.     351.  1.07 *****  494.51  492.85   2310.  493.44
      -43. ******   120.   20253.  1.58 ***** *******    0.89    6.59

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.88     494.02     493.41

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   492.94     508.89    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   492.94     508.89     493.41

FULLV:FV      43.   -10.     355.  1.05  0.55  495.08  493.41   2310.  494.03
        0.    43.   120.   20477.  1.59  0.00    0.02    0.87    6.52
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.97     494.29     494.15

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   493.53     508.46    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   493.53     508.46     494.15

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "APPRO"     KRATIO =  0.69

APPRO:AS      50.   -12.     189.  2.34  0.92  496.64  494.15   2310.  494.30
       50.    50.    26.   14197.  1.00  0.64    0.00    0.97   12.23
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                 SECID "BRIDG"     Q,CRWS =    2310.      493.74

            <<<<<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      43.     0.     157.  3.37 *****  497.10  493.74   2310.  493.74
        0.    43.    23.   11363.  1.00 ***** *******    1.00   14.71

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.60 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.        <<<<<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      22.   -36.     368.  0.65  0.33  498.58  494.15   2310.  497.93
       50.    23.    38.   32442.  1.06  1.15    0.01    0.51    6.28

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.383  0.118   28557.    -1.    22.   497.75

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   EXIT1:XS     -43.   -10.   120.   2310.   20253.     351.    6.59  493.44
   FULLV:FV       0.   -10.   120.   2310.   20477.     355.    6.52  494.03
   BRIDG:BR       0.     0.    23.   2310.   11363.     157.   14.71  493.74
   RDWAY:RG       8.**************      0.******************    2.00********
   APPRO:AS      50.   -36.    38.   2310.   32442.     368.    6.28  497.93
    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -1.    22.   28557.

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT1:XS    492.85    0.89  485.99  508.33************  1.07  494.51  493.44
   FULLV:FV    493.41    0.87  486.55  508.89  0.55  0.00  1.05  495.08  494.03
   BRIDG:BR    493.74    1.00  486.45  497.61************  3.37  497.10  493.74
   RDWAY:RG  ****************  498.73  503.64**********************************
   APPRO:AS    494.15    0.51  486.95  508.46  0.33  1.15  0.65  498.58  497.93
```
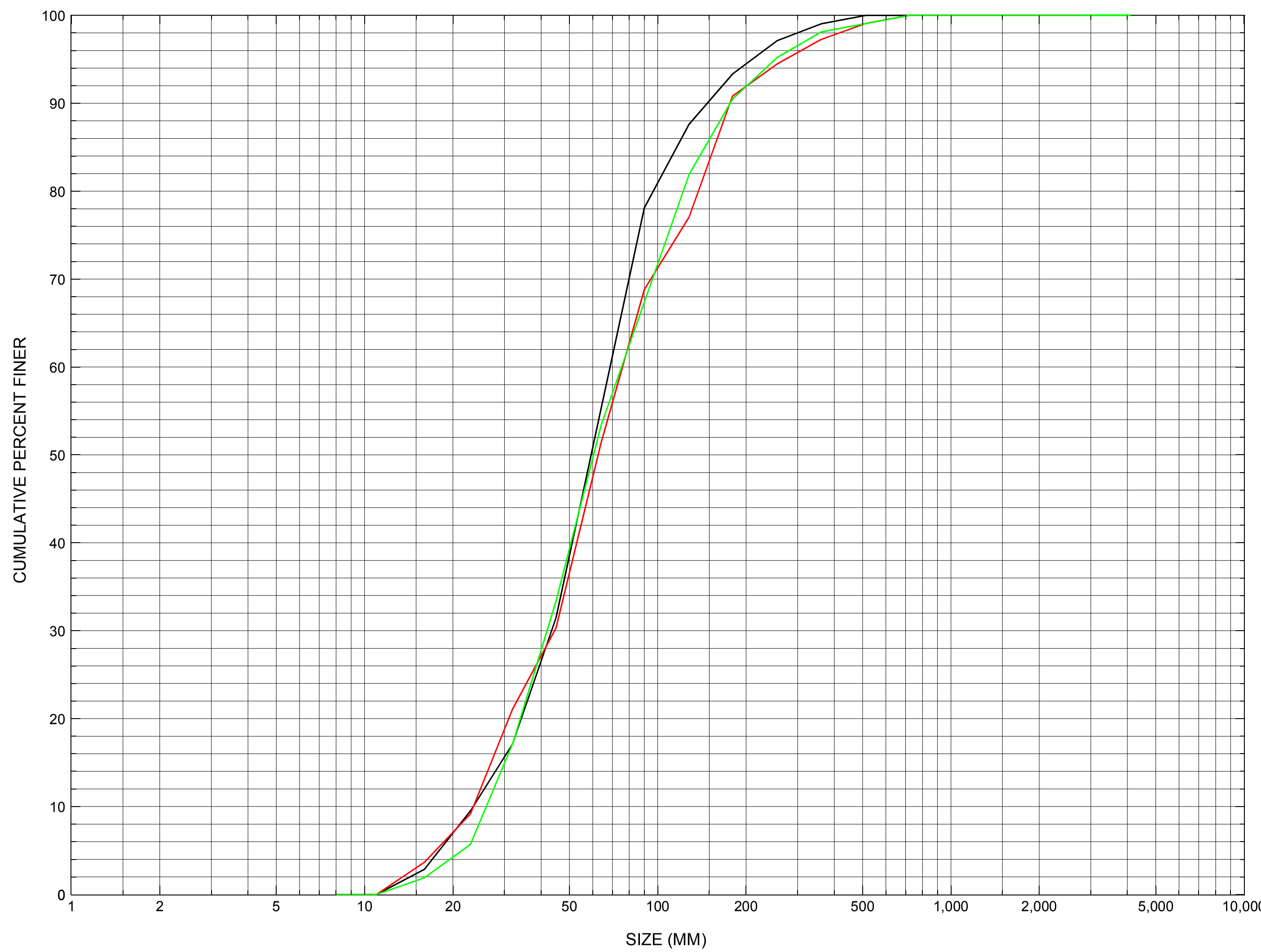

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00330030, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM