LEVEL II SCOUR ANALYSIS FOR BRIDGE 51 (BRIDTH00460051) on TOWN HIGHWAY 46, crossing OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-242

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
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FEDERAL HIGHWAY ADMINISTRATION

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By SCOTT A. OLSON and MICHAEL A. IVANOFF

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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 51 (BRIDTH00460051) ON TOWN HIGHWAY 46, CROSSING OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

***By* Scott A. Olson and Michael A. Ivanoff**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00460051 on town highway 46 crossing the Ottauquechee River, Bridgewater, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic division of central Vermont in the town of Bridgewater. The 103-mi^2 drainage area is a predominantly rural basin. In the vicinity of the study site, the immediate left and right banks are covered by trees and brush with residences beyond.

In the study area, the Ottauquechee River has a straight channel with a slope of approximately 0.008 ft/ft, an average channel top width of 150 ft and an average channel depth of 6 ft. The predominant channel bed materials are gravel and cobble with a median grain size (D_{50}) of 81.8 mm (0.268 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 24, 1994, indicated that the reach was stable.

The town highway 46 crossing of the Ottauquechee River is a 135-ft-long, two-lane bridge consisting of two 66-ft steel-beam spans, supported by vertical, concrete abutments with upstream wingwalls and one concrete pier (Vermont Agency of Transportation, written commun., August 24, 1994). Type-2 stone fill (less than 36 inches diameter) has been placed along the left abutment and both upstream wingwalls. The upstream side of both road embankments are also protected by type-2 stone fill. Abutments of a previous bridge still exist at the downstream side of the present structure's abutments. The channel is skewed 10 degrees to the bridge face; the opening-skew-to-roadway is 0 degrees.

There are remains of a breached dam 160 feet upstream of the bridge which deflect flow toward the left bank. Additional details describing conditions at the site are included in the Level II Summary, Appendix D, and Appendix 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 2.6 to 5.4 ft. The worst-case contraction scour occurred at the incipient overtopping discharge, which was between the 100- and 500-year discharges. Pier scour ranged from 9.9 to 10.9 ft with the worst-case scenario also occurring at the incipient roadway overtopping discharge. Abutment scour ranged from 25.3 to 33.6 ft. with the worst-case occurring at the 500-year 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.

Woodstock South, 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 BRIDTH00460051 **Stream** Ottauquechee River

County Windsor **Road** TH046 **District** 04

Description of Bridge

Bridge length 135 ***ft*** ***Bridge width*** 25.4 ***ft*** ***Max span length*** 66 ***ft***

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

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

Stone fill on abutment? yes, left ***Date of inspection*** 10/24/94

Description of stone fill Type-2 stone fill along the left abutment, upstream wingwalls, and upstream road embankments.

Brief description of piers/abutments Abutments, wingwalls, and the pier are concrete. On the downstream side of the abutments are the abutments of a previous structure.

Y 10

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

The skew is due to the flow being deflected by the breached dam.

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	10/24/94	0	0
Level II	10/24/94	-	-

Potential for debris Low, although there is some debris caught on the remains of the breached dam.

Describe any features near or at the bridge that may affect flow (include observation date) October 24, 1994. Remains of a breached dam 160 feet upstream of the bridge deflect flow toward the left bank.

Description of the Geomorphic Setting

General topography At the study site, the channel is incised with narrow floodplains in a moderate relief valley.

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

Date of inspection 10/24/94

DS left: Narrow flood plain.

DS right: Steep high bank to a mildly sloping overbank.

US left: Steep high bank to a mildly sloping overbank.

US right: Steep high bank to a mildly sloping overbank.

Description of the Channel

Average top width 150 ***ft***

Average depth 6 ***ft***

Predominant bed material cobble and gravel

Bank material cobble

Straight, incised channel with a narrow floodplain.

10/24/94

Vegetative co Trees and brush; residential on far overbank.

DS left: Moderate tree cover on immediate bank; residential on overbank.

DS right: Moderate tree cover on immediate bank; residential on overbank.

US left: Moderate tree cover.

US right:

Do banks appear stable? Y ***If not, describe location and type of instability and date of observation.*** October 24, 1994

October 24, 1994.

Describe any obstructions in channel and date of observation. Remains of a breached dam 160 feet upstream of the bridge deflect flow toward the left bank.

Hydrology

Drainage area 103 ***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.

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 18,900 ***ft³/s*** ***Q500*** 30,900 ***ft³/s***

The 100- and 500-year discharges were taken from the Flood Insurance Study for the Town of Bridgewater (Federal Emergency Management Agency, 1980).

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

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

Datum tie between USGS survey and VTAOT plans Add 401 ft to USGS survey datum to get VTAOT datum within one foot. This is also NAVD88.

Description of reference marks used to determine USGS datum. RM1 is the center of a bronze disk in the top of the downstream end of the right abutment stamped BMN55 (elev. 100.87 feet, arbitrary survey datum). RM2 is a chiseled square on the top of the upstream end of the left abutment (elev. 101.42 feet, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-113	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	13	1	Road Grade section
APPRO	150	2	Modelled Approach section (Templated from SURVA)
APTEM	136	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 0.037 to 0.040, and overbank "n" values ranged from 0.075 to 0.085.

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 0.008 ft/ft which was determined by an analysis of surveyed thalweg and water-surface points downstream of the bridge.

The surveyed approach section (SURVA) was moved along the approach channel slope (0.006 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 100.8 *ft*
Average low steel elevation 97.4 *ft*

100-year discharge 18,900 *ft*^{3}*/s*
Water-surface elevation in bridge opening 91.9 *ft*
Road overtopping? N *Discharge over road* -- *ft*^{3}*/s*
Area of flow in bridge opening 1,300 *ft*^{2}
Average velocity in bridge opening 14.5 *ft/s*
Maximum WSPRO tube velocity at bridge 16.2 *ft/s*

Water-surface elevation at Approach section with bridge 95.1
Water-surface elevation at Approach section without bridge 95.0
Amount of backwater caused by bridge 0.1 *ft*

500-year discharge 30,900 *ft*^{3}*/s*
Water-surface elevation in bridge opening 97.4 *ft*
Road overtopping? Y *Discharge over road* 4,950 *ft*^{3}*/s*
Area of flow in bridge opening 4,530 *ft*^{2}
Average velocity in bridge opening 13.7 *ft/s*
Maximum WSPRO tube velocity at bridge 15.1 *ft/s*

Water-surface elevation at Approach section with bridge 102.2
Water-surface elevation at Approach section without bridge 98.8
Amount of backwater caused by bridge 3.4

Incipient overtopping discharge 24,800 *ft*^{3}*/s*
Water-surface elevation in bridge opening 92.6 *ft*
Area of flow in bridge opening 1,390 *ft*^{2}
Average velocity in bridge opening 17.9 *ft/s*
Maximum WSPRO tube velocity at bridge 19.8 *ft/s*

Water-surface elevation at Approach section with bridge 97.7
Water-surface elevation at Approach section without bridge 97.0
Amount of backwater caused by bridge 0.7 *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 500-year discharge 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 500-year discharge was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the 100-year and incipient road-overflow discharge. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour. The results of Laursen's clear-water contraction scour for the 500-year event were also computed and can be found in appendix F. The large depth to armoring values indicate that armoring of the channel bed will not limit the amount of contraction scour.

Abutment scour was computed by the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Parameters 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.

Pier scour was computed by the Colorado State University (CSU) pier scour equation (Richardson and others, 1993, p. 39, equation 21).

The incipient overtopping model resulted in worst case contraction, abutment, and pier scour. Scour depths for the incipient overtopping model are in the Scour Summary under "other".

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	2.6	3.6	5.4
Depth to armoring	20.7	9.3	N/A
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	28.8	29.0	30.8
Right abutment	25.3	33.6	30.9
Pier scour			
Pier 1	9.9	10.1	10.9
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:			
Left abutment	4.1	3.7	4.7
Right abutment	4.1	3.7	4.7
Piers:			
Pier 1	3.1	2.7	4.7
Pier 2	--	--	--
	--	--	--

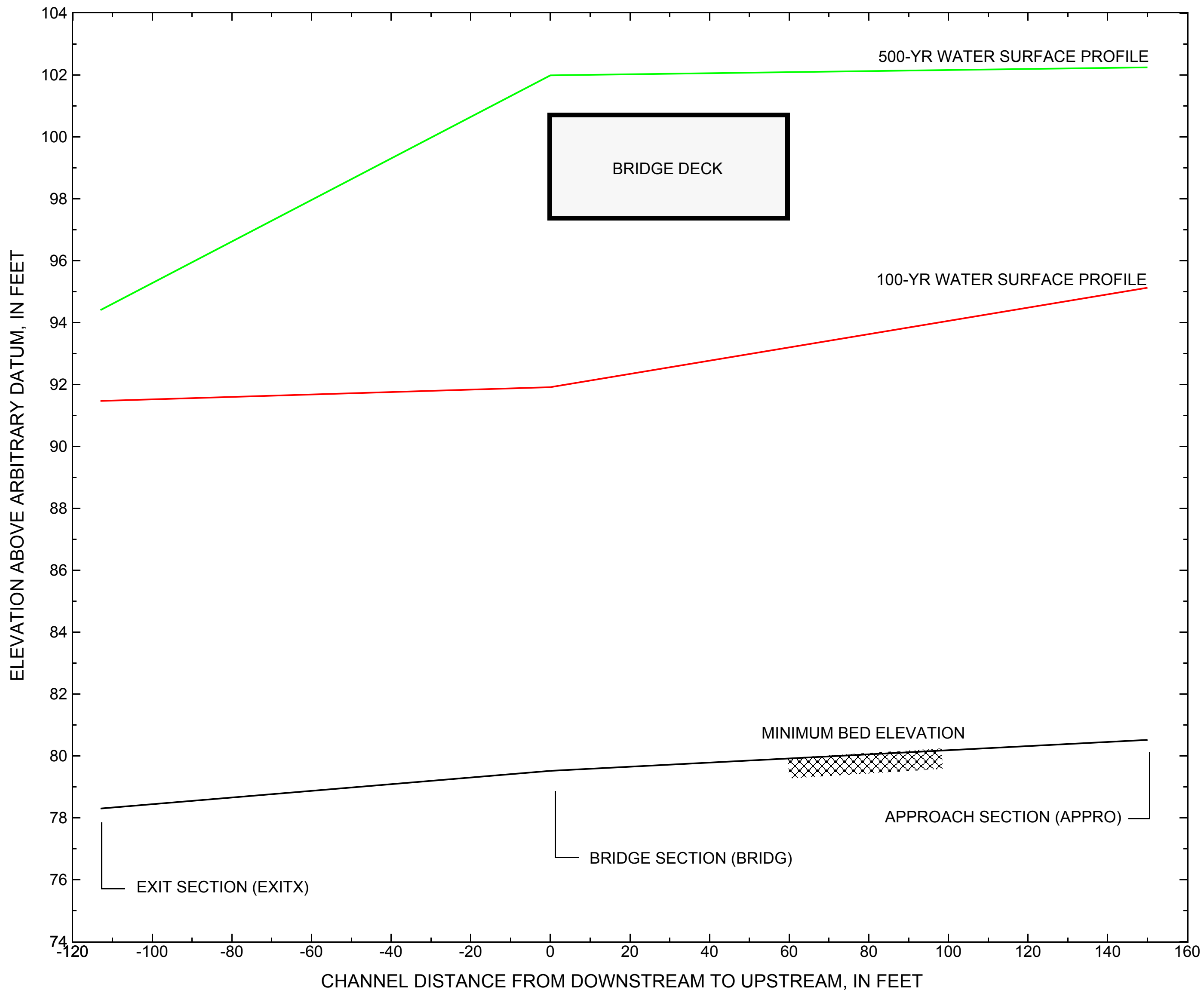

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00460051 on town highway 46, crossing Ottauquechee River, Bridgewater, Vermont.

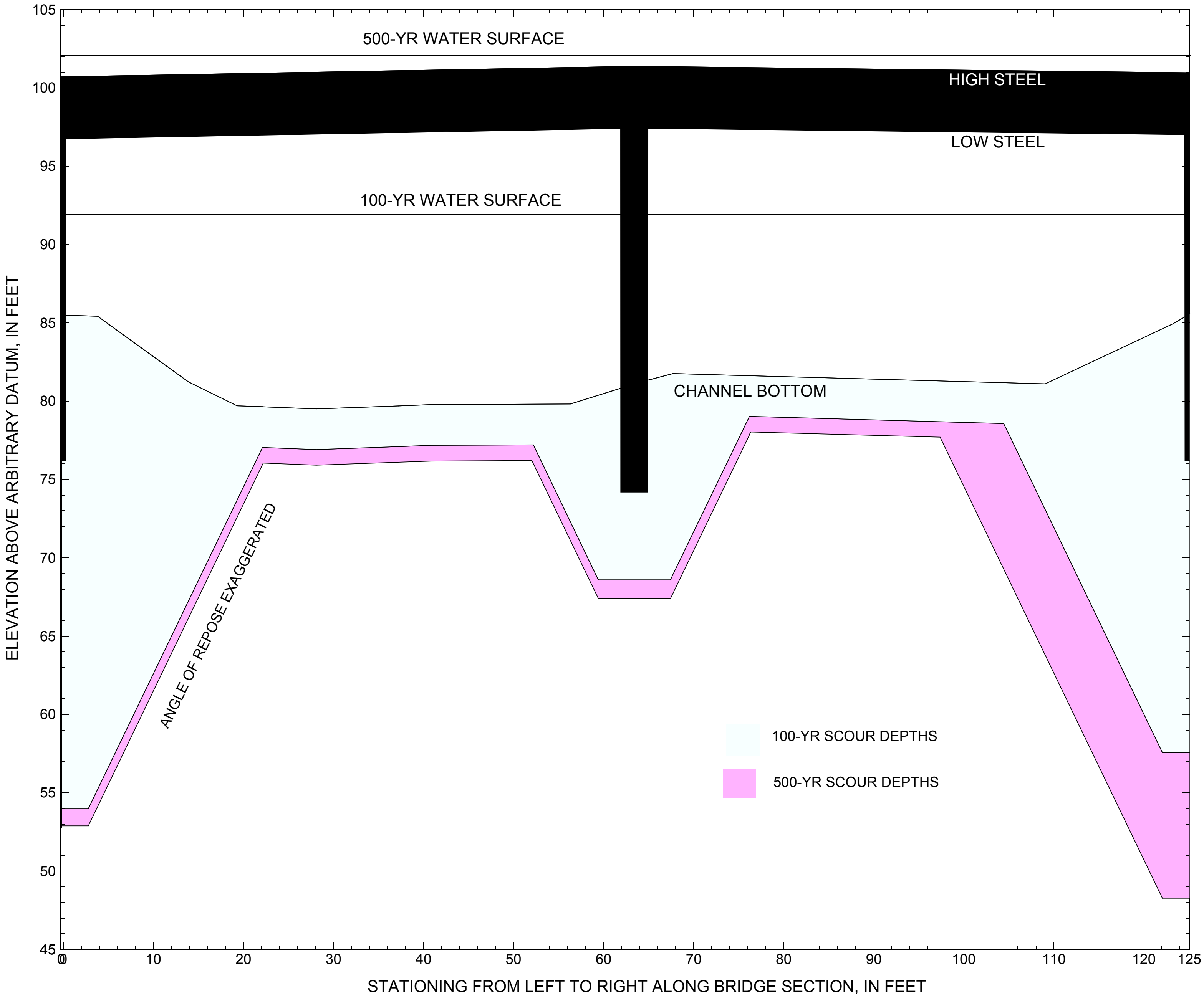

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00460051 on town highway 46, crossing Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00460051 on Town Highway 46, crossing Ottauquechee River, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 18,900 cubic-feet per second											
Left abutment	0.0	497.55	96.73	76	85.5	2.6	28.9	--	31.5	54.0	-22
Pier	63.4	497.90	97.43	74	81.1	2.6	--	9.9	12.5	68.6	-5
Right abutment	124.8	497.81	97.05	76	85.5	2.6	25.3	--	27.9	57.6	-18

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 BRIDTH00460051 on Town Highway 46, crossing Ottauquechee River, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 30,900 cubic-feet per second											
Left abutment	0.0	497.55	96.73	76	85.5	3.6	29.0	--	32.6	52.9	-23
Pier	63.4	497.90	97.43	74	81.1	3.6	--	10.1	13.7	67.4	-7
Right abutment	124.8	497.81	97.05	76	85.5	3.6	33.6	--	37.2	48.3	-28

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, Woodstock South, 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 brid051.wsp
T2        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
T3        HYDRAULIC ANALYSIS OF BRID051    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         18900 30900 24816
SK        0.008 0.008 0.008
*
XS   EXITX   -113
GR         -198.7, 102.72   -111.7,  92.70    -76.7,  92.24    -56.2,  92.09
GR          -31.5,  84.94    -18.0,  86.11      0.0,  84.96     12.1,  80.58
GR           16.1,  80.21     27.1,  79.24     41.7,  79.01     55.0,  78.29
GR           81.5,  80.19     96.3,  85.05    112.1,  93.13    184.8,  99.44
GR          246.5, 102.39
N            0.085      0.040       0.070
SA                 -56.2        112.1
*
XS   FULLV   0 * * * 0.0083
*
BR   BRIDG   0 97.42 10
GR            0.0,  96.73      0.0,  85.49      3.8,  85.42     13.9,  81.23
GR           19.3,  79.71     28.1,  79.51     40.8,  79.78     56.3,  79.82
GR           63.4,  81.10     67.7,  81.77    109.0,  81.11    123.2,  84.94
GR          124.8,  85.47    124.8,  97.05     65.0,  97.43      0.0,  96.73
N            0.037
CD            4 58.0 2.3 100.7 55 15.8
PW           80.8,3
*
XR   RDWAY    13 25.4 1
GR         -120.0, 105.00   -120.0, 97.51     -95.9,  97.51    -64.9,  98.95
GR            0.0, 100.70     36.6, 101.18     72.0, 101.38    130.4, 100.97
GR          157.0, 100.17    184.8,  99.44    213.7, 101.54    246.5, 102.39
BP            0
*
*           BRAIL
*           -51.6,  99.33    -51.4, 101.46      0.0, 102.85    129.8, 103.11
*           160.5, 101.38    161.2,  99.11
*
XT   APTEM    136
GR         -110.4, 106.89    -70.0, 101.87    -30.3,  94.83    -27.7,  93.78
GR          -18.5,  86.76     -8.4,  84.83      0.0,  81.98      9.7,  81.34
GR           29.3,  80.95     44.6,  80.42     62.8,  80.97     81.6,  80.93
GR           95.1,  81.87    119.3,  83.75    142.2,  82.46    172.8,  88.55
GR          200.3,  92.65    210.6,  98.05    231.4,  98.01    246.5, 102.39
*
AS   APPRO    150
GT            0.09
N                 0.040     0.075
SA                     210.6
BP            0
*
HP 1 BRIDG    91.91 1 91.91
HP 2 BRIDG    92.37 * * 18900
HP 1 APPRO    95.12 1 95.12
HP 2 APPRO    95.12 * * 18900
*
HP 1 BRIDG    97.43 1 97.43
HP 2 BRIDG    98.02 * * 25919
HP 2 RDWAY    101.98 * * 4947
HP 1 APPRO    102.24 1 102.24
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
        HYDRAULIC ANALYSIS OF BRID051    SAO
           *** RUN DATE & TIME: 08-30-95  15:27
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW     REW     QCR
             1    1300.  234048.   123.   138.                        24000.
    91.91         1300.  234048.   123.   138.  1.00     0.   125.  24000.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
        92.37     0.0   124.8  1356.8  250139.   18900.  13.93

X STA.         0.0        12.9        19.3        24.4        29.3        34.1
  A(I)           105.4        73.5        64.5        61.4        60.9
  V(I)            8.97       12.86       14.64       15.39       15.53

X STA.        34.1        38.9        43.7        48.4        53.2        58.1
  A(I)            59.6        59.5        58.4        59.8        59.4
  V(I)           15.86       15.89       16.17       15.81       15.90

X STA.        58.1        63.4        69.5        75.6        81.7        87.8
  A(I)            61.7        64.6        64.9        64.7        64.6
  V(I)           15.30       14.63       14.56       14.60       14.64

X STA.        87.8        93.8        99.8       106.0       112.5       124.8
  A(I)            64.7        65.7        67.8        71.4       104.3
  V(I)           14.60       14.39       13.93       13.23        9.06

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW     REW     QCR
             1    2555.  459103.   236.   241.                        47681.
    95.12         2555.  459103.   236.   241.  1.00   -31.   205.  47681.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
        WSEL     LEW     REW    AREA        K        Q    VEL
        95.12   -31.4   204.8  2555.1  459103.   18900.   7.40

X STA.       -31.4        -4.0         6.0        14.8        22.9        30.8
  A(I)           187.4       128.6       121.0       111.4       111.1
  V(I)            5.04        7.35        7.81        8.48        8.50

X STA.        30.8        38.5        46.0        53.5        61.1        68.9
  A(I)           110.6       108.6       108.7       107.8       110.0
  V(I)            8.55        8.70        8.69        8.76        8.59

X STA.        68.9        76.9        84.8        93.1       102.2       112.4
  A(I)           111.8       111.5       113.0       118.0       124.4
  V(I)            8.45        8.47        8.36        8.01        7.59

X STA.       112.4       123.5       134.8       145.6       160.2       204.8
  A(I)           127.4       134.1       132.9       152.6       224.2
  V(I)            7.42        7.05        7.11        6.19        4.21
```

```
     U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
     CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
     HYDRAULIC ANALYSIS OF BRID051    SAO
        *** RUN DATE & TIME: 08-30-95  15:27
 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#    AREA       K   TOPW   WETP  ALPH    LEW    REW     QCR
          1    1945.  291846.    0.   270.                          0.
 97.43         1945.  291846.    0.   270.  1.00     0.   125.      0.

 VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL     LEW     REW    AREA        K        Q    VEL
     98.02     0.0   124.8  1945.1  291846.   25919.  13.32

X STA.        0.0       11.7       18.2       23.7       29.1       34.2
  A(I)           143.1      102.9       93.6       91.8       88.6
  V(I)            9.05      12.59      13.84      14.11      14.63

X STA.       34.2       39.4       44.5       49.6       54.6       59.7
  A(I)            88.9       87.0       87.9       85.7       87.6
  V(I)           14.58      14.89      14.74      15.12      14.79

X STA.       59.7       65.3       71.3       77.2       83.2       89.2
  A(I)            91.1       92.6       90.7       94.1       93.4
  V(I)           14.23      14.00      14.29      13.77      13.88

X STA.       89.2       95.0      101.2      107.3      113.9      124.8
  A(I)            90.6       96.6       96.6      100.3      141.9
  V(I)           14.31      13.42      13.41      12.91       9.13

 VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      13.
      WSEL     LEW     REW    AREA        K        Q    VEL
    101.98  -120.0   230.7   618.5   23463.    4947.   8.00

X STA.     -120.0     -112.4     -106.7     -101.0      -95.3      -89.5
  A(I)            33.8       25.7       25.5       25.3       25.3
  V(I)            7.32       9.61       9.71       9.79       9.78

X STA.      -89.5      -82.7      -75.1      -65.7      -55.1      -48.3
  A(I)            27.1       28.2       30.8       30.7       18.1
  V(I)            9.14       8.78       8.02       8.05      13.66

X STA.      -48.3      -40.5      -31.1      -18.9       -1.2       30.0
  A(I)            19.4       21.2       23.8       27.4       34.1
  V(I)           12.76      11.67      10.38       9.02       7.26

X STA.       30.0       94.9      144.7      166.5      182.7      230.7
  A(I)            45.9       48.9       38.4       36.9       52.0
  V(I)            5.39       5.06       6.45       6.70       4.76

 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
  WSEL  SA#    AREA       K   TOPW   WETP  ALPH    LEW    REW     QCR
          1    4413. 1011342.  283.   289.                      98902.
          2     115.    5004.   35.    36.                       1185.
102.24         4528. 1016346.  318.   325.  1.04   -72.   246.  95191.

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
      WSEL     LEW     REW    AREA        K        Q    VEL
    102.24   -72.3   245.7  4527.9 1016346.   30900.   6.82

X STA.      -72.3      -10.2        3.8       15.0       25.0       34.5
  A(I)           415.6      264.5      231.8      210.6      202.0
  V(I)            3.72       5.84       6.67       7.34       7.65

X STA.       34.5       43.6       52.4       61.4       70.3       79.1
  A(I)           195.2      192.2      191.3      187.6      187.7
  V(I)            7.92       8.04       8.08       8.24       8.23

X STA.       79.1       87.9       97.3      107.1      117.6      128.4
  A(I)           185.2      191.4      194.2      199.5      200.9
  V(I)            8.34       8.07       7.96       7.74       7.69

X STA.      128.4      138.7      149.4      162.4      180.6      245.7
  A(I)           196.5      205.3      220.8      254.3      401.3
  V(I)            7.86       7.53       7.00       6.07       3.85
```

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
        HYDRAULIC ANALYSIS OF BRID051    SAO
           *** RUN DATE & TIME: 08-30-95  15:27
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1    1388.  259028.   123.   139.                        26456.
    92.62         1388.  259028.   123.   139.  1.00     0.   125.  26456.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        93.21     0.0   124.8  1460.1  280395.   24816.  17.00

X STA.         0.0       12.8       19.2       24.4       29.3       34.2
  A(I)           114.3       79.3       69.5       66.1       65.5
  V(I)           10.86      15.65      17.85      18.77      18.94

X STA.        34.2       39.0       43.8       48.7       53.5       58.4
  A(I)            64.2       64.1       64.5       62.7       64.2
  V(I)           19.34      19.36      19.24      19.79      19.32

X STA.        58.4       63.7       69.8       75.8       81.8       87.8
  A(I)            66.0       69.6       67.8       69.1       68.9
  V(I)           18.79      17.84      18.29      17.95      18.00

X STA.        87.8       93.9       99.9      106.0      112.6      124.8
  A(I)            71.0       70.4       72.6       76.5      113.8
  V(I)           17.48      17.64      17.08      16.23      10.90

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1    3195.  631030.   256.   262.                        64061.
    97.72         3195.  631030.   256.   262.  1.00   -46.   210.  64061.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     150.
         WSEL     LEW     REW    AREA        K        Q    VEL
        97.72   -46.1   209.8  3194.9  631030.   24816.   7.77

X STA.       -46.1       -5.0        6.3       15.7       24.7       33.1
  A(I)           263.1      174.3      153.6      148.6      139.4
  V(I)            4.72       7.12       8.08       8.35       8.90

X STA.        33.1       41.3       49.2       57.1       65.2       73.4
  A(I)           138.7      135.4      134.6      135.9      135.5
  V(I)            8.95       9.16       9.22       9.13       9.16

X STA.        73.4       81.5       89.8       98.7      108.3      119.0
  A(I)           135.3      137.3      141.1      144.3      153.2
  V(I)            9.17       9.04       8.79       8.60       8.10

X STA.       119.0      129.8      140.3      151.9      168.2      209.8
  A(I)           153.1      154.4      167.4      189.4      260.6
  V(I)            8.11       8.04       7.41       6.55       4.76
```

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
        HYDRAULIC ANALYSIS OF BRID051    SAO
           *** RUN DATE & TIME: 08-30-95  15:27

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

EXITX:XS   ******   -54.    1385.  2.90 *****   94.36   90.33  18900.   91.46
     -113. ******   109.  211186.  1.00 ***** *******    0.83   13.65

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.83      92.38      91.27

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    90.96     103.66    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    90.96     103.66      91.27

FULLV:FV     113.   -54.    1378.  2.93  0.91   95.29   91.27  18900.   92.36
        0.   113.   109.  209710.  1.00  0.01    0.00    0.83   13.71
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  2.15

APPRO:AS     150.   -31.    2522.  0.87  0.57   95.85 *******  18900.   94.98
      150.   150.   205.  450607.  1.00  0.00    0.00    0.40    7.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

            <<<<<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     113.     0.    1300.  3.29  0.82   95.20   90.52  18900.   91.91
        0.   113.   125.  233877.  1.00  0.01   -0.01    0.79   14.54

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4.   0.   1.  1.000  0.026   97.42 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      13.        <<<<<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      92.   -31.    2555.  0.85  0.32   95.97   89.45  18900.   95.12
      150.    97.   205.  459179.  1.00  0.46    0.01    0.40    7.40

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.469  0.234  351208.    11.   135.    94.91

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS    -113.   -54.   109.  18900.  211186.    1385.   13.65   91.46
   FULLV:FV       0.   -54.   109.  18900.  209710.    1378.   13.71   92.36
   BRIDG:BR       0.     0.   125.  18900.  233877.    1300.   14.54   91.91
   RDWAY:RG      13.**************       0.******************    1.00********
   APPRO:AS     150.   -31.   205.  18900.  459179.    2555.    7.40   95.12

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS     90.33    0.83   78.29  102.72************  2.90    94.36   91.46
   FULLV:FV     91.27    0.83   79.23  103.66  0.91  0.01  2.93    95.29   92.36
   BRIDG:BR     90.52    0.79   79.51   97.43  0.82  0.01  3.29    95.20   91.91
   RDWAY:RG  ****************   97.51  105.00*********************************
   APPRO:AS     89.45    0.40   80.51  106.98  0.32  0.46  0.85    95.97   95.12
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
        HYDRAULIC ANALYSIS OF BRID051    SAO
           *** RUN DATE & TIME: 08-30-95  15:27

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

EXITX:XS   ******  -126.    2010.  4.10 *****   98.50   93.66  30900.   94.40
     -113. ******   127.  345371.  1.12 ***** *******    1.02   15.37

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    1.02      95.29      94.60

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =    93.90     103.66    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =    93.90     103.66      94.60

FULLV:FV     113.  -126.    2001.  4.13  0.91   99.43   94.60  30900.   95.30
        0.   113.   126.  343496.  1.11  0.01    0.01    1.02   15.44
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "APPRO"     KRATIO =  2.08

APPRO:AS     150.    -52.    3490.  1.23  0.58  100.03 *******  30900.   98.80
      150.   150.   234.  713435.  1.01  0.00    0.01    0.45    8.85
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   100.42       0.00      94.08      97.51

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =    93.78      99.52      99.90      97.42

 ===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     113.     0.    1895.  2.91 *****  100.34   92.68  25919.   97.43
        0. ******   125.  291846.  1.00 ***** *******    0.62   13.68

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4.   0.   5.  0.475  0.026   97.42 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      13.   125.  0.12  0.75  102.87    0.00    4947.  101.98

              Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   3357.   179.  -120.    59.   4.5   2.3   8.7   8.0   3.2   3.2
   RT:   1590.   172.    59.   231.   2.5   1.2   6.7   7.9   2.1   3.1

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

APPRO:AS      92.    -72.    4527.  0.75  0.27  102.99   92.15  30900.  102.24
      150.    99.   246. 1016103.  1.04  0.59    0.00    0.32    6.83

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS    -113.  -126.   127.  30900.  345371.    2010.   15.37   94.40
   FULLV:FV       0.  -126.   126.  30900.  343496.    2001.   15.44   95.30
   BRIDG:BR       0.     0.   125.  25919.  291846.    1895.   13.68   97.43
   RDWAY:RG      13.*******  3357.   4947.******************    1.00  101.98
   APPRO:AS     150.   -72.   246.  30900. 1016103.    4527.    6.83  102.24

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS     93.66    1.02   78.29  102.72************  4.10   98.50   94.40
   FULLV:FV     94.60    1.02   79.23  103.66  0.91  0.01  4.13   99.43   95.30
   BRIDG:BR     92.68    0.62   79.51   97.43************  2.91  100.34   97.43
   RDWAY:RG  ****************   97.51  105.00  0.12******  0.75  102.87  101.98
   APPRO:AS     92.15    0.32   80.51  106.98  0.27  0.59  0.75  102.99  102.24
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WSPRO OUTPUT FILE (continued)

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid051.wsp
        CREATED ON 30-AUG-95 FOR BRIDGE BRIDTH00460051 USING FILE brid051.dca
        HYDRAULIC ANALYSIS OF BRID051     SAO
           *** RUN DATE & TIME: 08-30-95  15:27

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

 EXITX:XS   ******  -115.    1690.  3.50 *****   96.56   91.98  24816.   93.06
      -113. ******   112.  277196.  1.04 ***** *******    0.97   14.68

  ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.97      93.96      92.92

  ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    92.56     103.66    0.50

  ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    92.56     103.66      92.92

 FULLV:FV     113.  -115.    1686.  3.51  0.91   97.49   92.92  24816.   93.98
         0.   113.   112.  276327.  1.04  0.01    0.02    0.97   14.72
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  2.10

 APPRO:AS     150.    -42.    3015.  1.05  0.58   98.06 *******  24816.   97.01
       150.   150.   208.  581338.  1.00  0.00    0.00    0.42    8.23
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =    97.72       0.00      92.62      97.51

  ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

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

 BRIDG:BR     113.     0.    1387.  5.10  0.97   97.71   92.34  24816.   92.62
         0.   113.   125.  258854.  1.02  0.17   -0.02    0.95   17.89

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        4.   0.   4.  0.988  0.026   97.42 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD      EGL     ERR       Q   WSEL
    RDWAY:RG      13.        <<<<<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      92.    -46.    3196.  0.94  0.37   98.66   90.85  24816.   97.72
       150.    98.   210.  631241.  1.00  0.59    0.02    0.39    7.77

        M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
       0.502  0.254  469923.    14.   139. ********

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

   FIRST USER DEFINED TABLE.
     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS    -113.  -115.   112.  24816.  277196.    1690.   14.68   93.06
    FULLV:FV       0.  -115.   112.  24816.  276327.    1686.   14.72   93.98
    BRIDG:BR       0.     0.   125.  24816.  258854.    1387.   17.89   92.62
    RDWAY:RG      13.**************       0.       0.       0.    1.00********
    APPRO:AS     150.   -46.   210.  24816.  631241.    3196.    7.77   97.72

  SECOND USER DEFINED TABLE.
     XSID:CODE     CRWS      FR#     YMIN    YMAX    HF    HO   VHD      EGL     WSEL
    EXITX:XS      91.98     0.97    78.29  102.72************  3.50    96.56    93.06
    FULLV:FV      92.92     0.97    79.23  103.66  0.91  0.01  3.51    97.49    93.98
    BRIDG:BR      92.34     0.95    79.51   97.43  0.97  0.17  5.10    97.71    92.62
    RDWAY:RG   ****************    97.51  105.00  0.19******  0.94    98.45********
    APPRO:AS      90.85     0.39    80.51  106.98  0.37  0.59  0.94    98.66    97.72
```
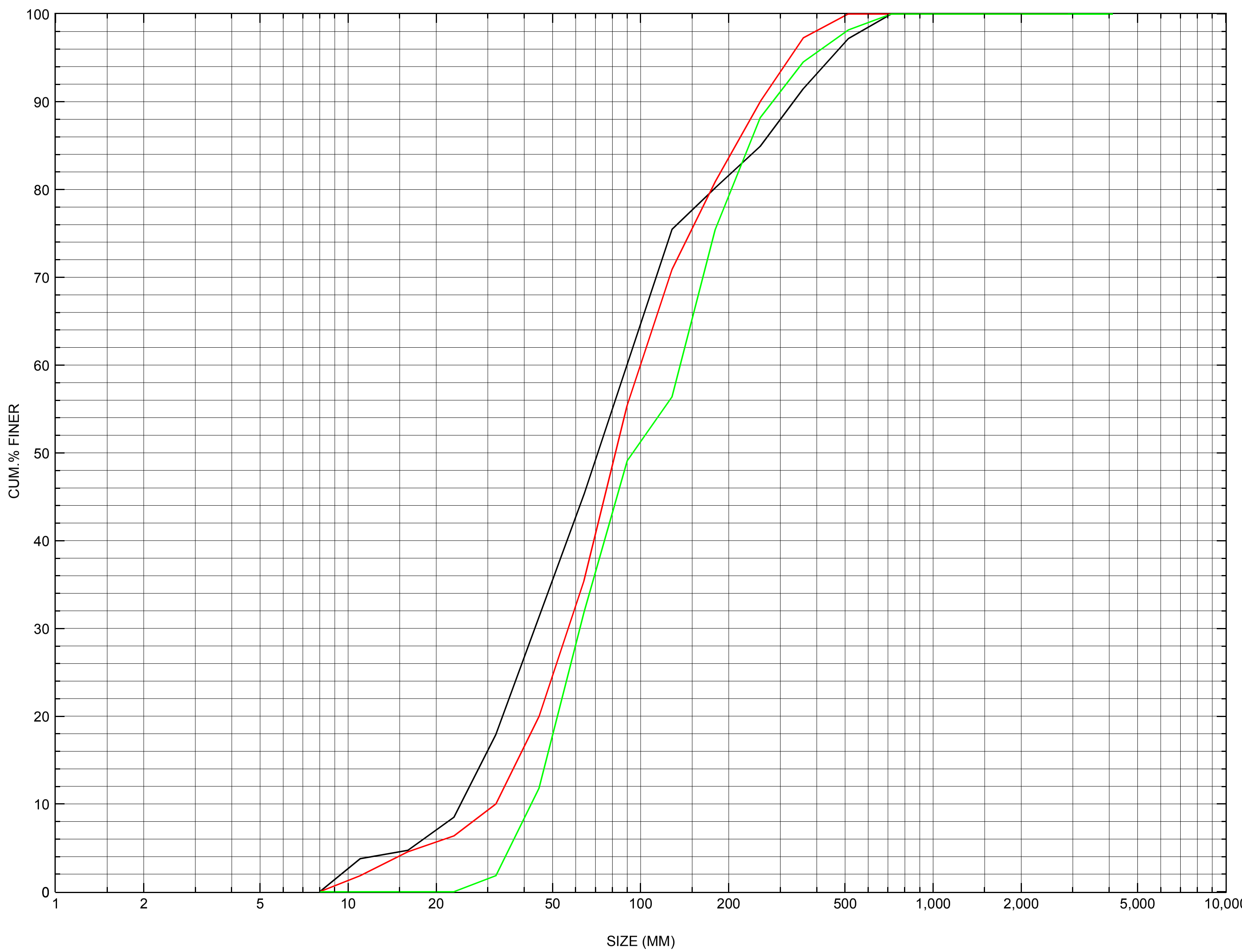

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00460051, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM