LEVEL II SCOUR ANALYSIS FOR BRIDGE 49 (BRIDTH00530049) on TOWN HIGHWAY 53, crossing the NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-407

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

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By MICHAEL A. IVANOFF and SCOTT A. OLSON

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Pembroke, New Hampshire

U.S. DEPARTMENT OF THE INTERIOR
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CONTENTS

FIGURES

TABLES

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 49 (BRIDTH00530049) ON TOWN HIGHWAY 53, CROSSING THE NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

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

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00530049 on town highway 53 crossing the North Branch of 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). Results of a Level I scour investigation also are included in Appendix E of this report. A Level I investigation 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 26.6-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the immediate banks have woody vegetation coverage with grass on the overbanks.

In the study area, the North Branch Ottauquechee River has a sinuous channel with a slope of approximately 0.0075 ft/ft, an average channel top width of 66 ft and an average channel depth of 6 ft. The predominant channel bed material is cobble and gravel (D_{50} is 68.4 mm or 0.224 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 27, 1994, indicated that the reach was stable.

The town highway 53 crossing of the North Branch of the Ottauquechee River is a 51-ft-long, one-lane bridge consisting of one 49-foot steel-beam span (Vermont Agency of Transportation, written communication, August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is not skewed to the opening and the opening-skew-to-roadway is zero degrees.

The scour protection measures in place at the site are type-1 stone fill (less than 12 inches diameter) along the upstream left wingwall and type-2 stone fill (less than 36 inches diameter) along the upstream right wingwall. 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 aggradation or degradation; 2) contraction scour (due to reduction in flow area caused by 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 scour depths for contraction and local scour and a summary of the results follows.

Contraction scour for all modelled flows was 0 feet. Abutment scour ranged from 2.3 to 12.0 feet and the worst-case abutment scour also occurred 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. 47). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photo inspected 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 BRIDTH00530049 *Stream* North Branch Ottauquechee River

County Windsor *Road* TH 53 *District* 04

Description of Bridge

Bridge length 51 *ft* *Bridge width* 14 *ft* *Max span length* 49 *ft*

Alignment of bridge to road (on curve or straight) Right approach is curved

Abutment type Vertical *Embankment type* Sloping

Stone fill on abutment? No *Date of inspection* 10/27/94

Description of stone fill Type-1, along the upstream left wingwall. Type-2, along the upstream right wingwall.

Brief description of piers/abutments Abutments and wingwalls are concrete.

Is bridge skewed to flood flow according to Yes *survey?* No *Angle* --

There is a mild channel bend in the upstream reach.

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	10/27/94	0	0
Level II	10/27/94	--	--

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) 10/27/94 -- None

Description of the Geomorphic Setting

General topography The channel is a high gradient upland stream with a flat to slightly irregular 370 feet wide flood plain and steep valley walls on both sides.

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

Date of inspection 10/27/94

DS left: Moderately sloped channel bank to a narrow flood plain

DS right: Moderately sloped channel bank to a narrow flood plain

US left: Moderately sloped channel bank to a narrow flood plain

US right: Moderately sloped channel bank to a narrow flood plain

Description of the Channel

Average top width 66 ft

Average depth 6 ft

Predominant bed material Gravel / Cobbles

Bank material Gravel

Slightly sinuous but stable with alluvial channel boundaries and a narrow flood plain.

10/27/94

Vegetative co Trees on immediate bank with tall grasses and a paved road on overbank.

DS left: Trees on immediate bank with grass on overbank.

DS right: Trees on immediate bank with tall grasses and a paved road on overbank.

US left: Trees on immediate bank with grass and a gravel roadway on overbank.

US right:

Do banks appear stable? Yes

If not, describe location and type of instability and date of observation.

10/27/94 -- There is a slight impact upon the upstream left bank causing moderate fluvial erosion.

Describe any obstructions in channel and date of observation.

10/27/94 -- None

Hydrology

Drainage area 26.6 ***mi^2***

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 ***mi^2***

Is there a lake/p No

Calculated Discharges

Q100 4,800 ***ft^3/s*** ***Q500*** 6,500 ***ft^3/s***

The 100- and 500-year discharges were extrapolated from data available from the VTAOT database (VTAOT, written communication, May 4, 1995). The discharges were selected when compared with discharges computed from various empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887).

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 None

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of the US end of the right abutment (elev. 499.65 ft, arbitrary survey datum). RM2 is a chiseled X on top of the DS end of the left abutment (elev. 499.67 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-67	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	8	1	Road Grade section
APPRO	69	1	Approach section

[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 and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.040 to 0.046, and overbank "n" values were 0.035.

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 0.0075 ft/ft which was determined from downstream thalweg points.

The surveyed approach section (APPRO) was one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

The incipient overtopping discharge was determined to be 2,502 ft^3/s.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.8 *ft*
Average low steel elevation 497.2 *ft*

100-year discharge 4,800 *ft^3/s*
Water-surface elevation in bridge opening 497.2 *ft*
Road overtopping? Y *Discharge over road* 1,560 *ft^3/s*
Area of flow in bridge opening 413 *ft^2*
Average velocity in bridge opening 7.9 *ft/s*
Maximum WSPRO tube velocity at bridge 8.9 *ft/s*

Water-surface elevation at Approach section with bridge 498.5
Water-surface elevation at Approach section without bridge 497.6
Amount of backwater caused by bridge 0.9 *ft*

500-year discharge 6,500 *ft^3/s*
Water-surface elevation in bridge opening 497.2 *ft*
Road overtopping? Y *Discharge over road* 2,569 *ft^3/s*
Area of flow in bridge opening 413 *ft^2*
Average velocity in bridge opening 9.5 *ft/s*
Maximum WSPRO tube velocity at bridge 10.7 *ft/s*

Water-surface elevation at Approach section with bridge 499.4
Water-surface elevation at Approach section without bridge 498.4
Amount of backwater caused by bridge 1.0

Incipient overtopping discharge 2,502 *ft^3/s*
Water-surface elevation in bridge opening 494.5 *ft*
Area of flow in bridge opening 286 *ft^2*
Average velocity in bridge opening 8.7 *ft/s*
Maximum WSPRO tube velocity at bridge 10.0 *ft/s*

Water-surface elevation at Approach section with bridge 495.4
Water-surface elevation at Approach section without bridge 495.4
Amount of backwater caused by bridge 0.0 *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 Chang pressure-flow scour equation (Richardson and others, 1995, p. 145-146) for the 100-year and 500-year discharges. For the 100-year and 500-year discharges, there was orifice flow at the bridge. Contraction scour at bridges with orifice flow is best estimated by use of 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) were also computed and can be found in appendix F. Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the incipient road-overflow discharge. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour at all modelled discharges 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. Variables for the HIRE 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 Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.0	0.0	0.0
Depth to armoring	0.7	2.1	1.9
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	6.8	7.2	4.0
Right abutment	10.3	12.0	2.3
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	1.2	1.7	1.5
Right abutment	1.2	1.7	1.5
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

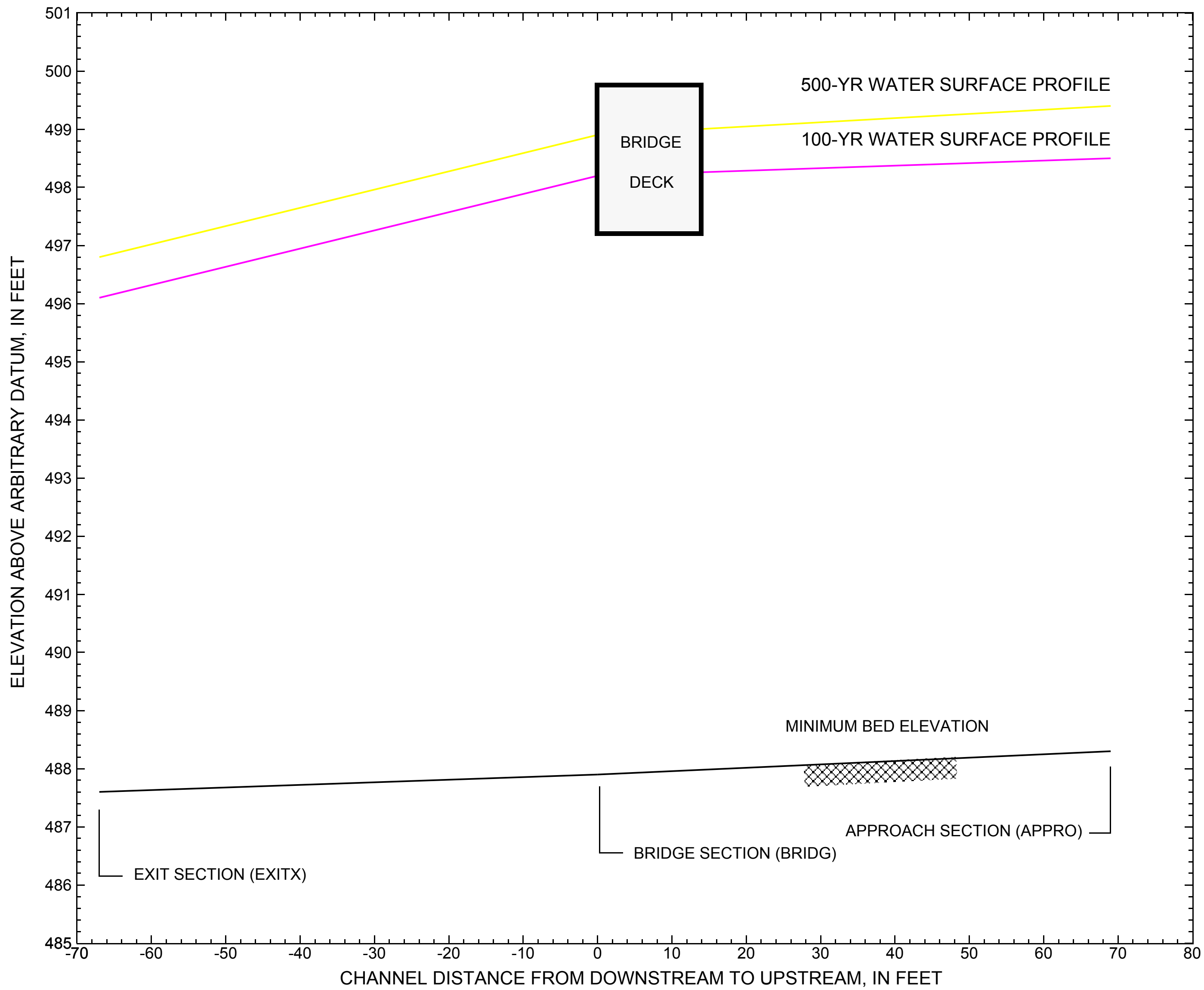

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00530049 on town highway 53, crossing Ottauquechee River, Bridgewater, Vermont.

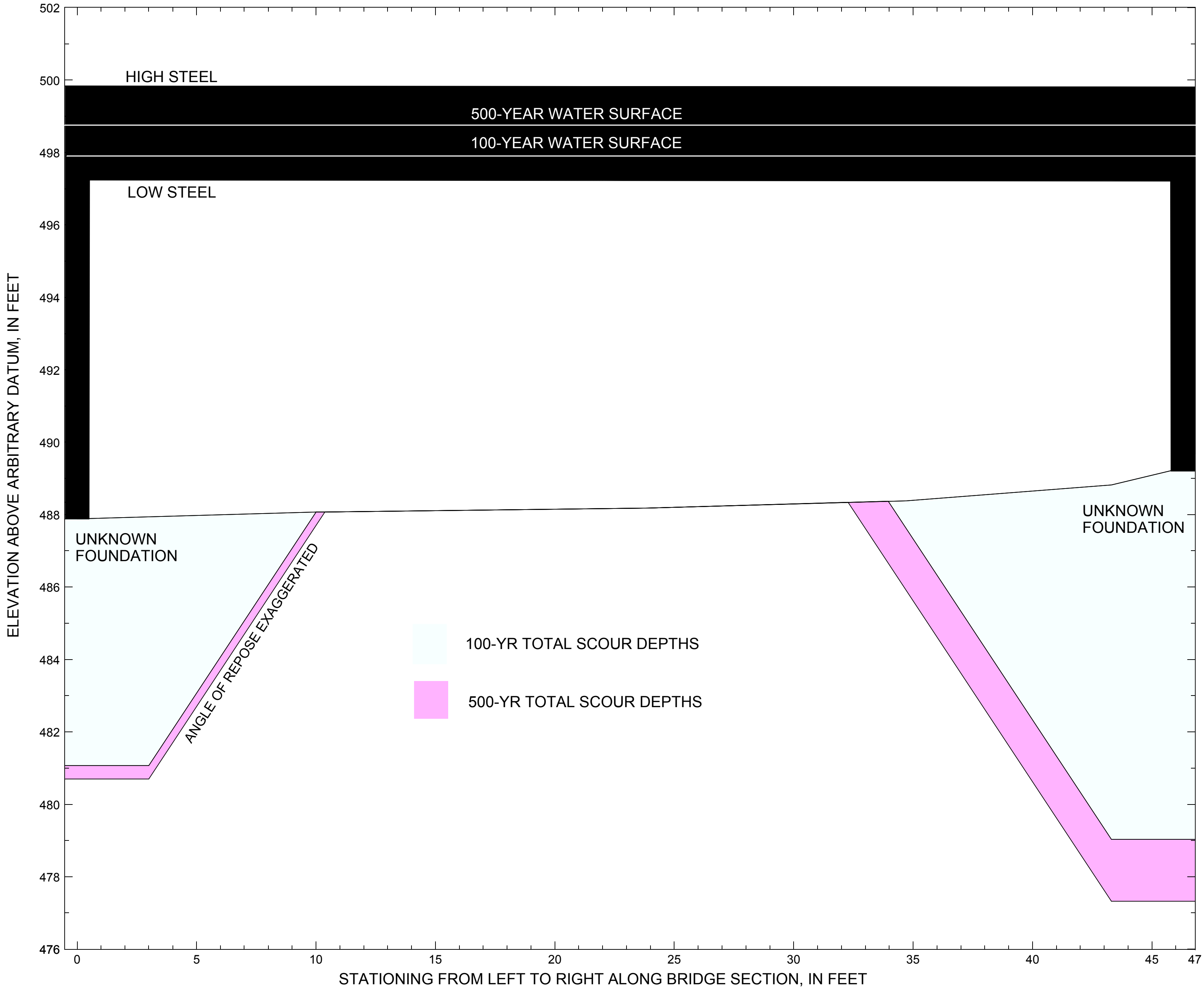

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00530049 on town highway 53, crossing Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00530049 on Town Highway 53, crossing Ottauquechee River, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 4,800 cubic-feet per second											
Left abutment	0.0	--	497.2	--	487.9	0.0	6.8	--	6.8	481.1	--
Right abutment	46.3	--	497.2	--	489.3	0.0	10.3	--	10.3	479.0	--

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 BRIDTH00530049 on Town Highway 53, crossing Ottauquechee River, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 6,500 cubic-feet per second											
Left abutment	0.0	--	497.2	--	487.9	0.0	7.2	--	7.2	480.7	--
Right abutment	46.3	--	497.2	--	489.3	0.0	12.0	--	12.0	477.3	--

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, Photo inspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid049.wsp
T2        CREATED ON 20-APR-95 FOR BRIDGE BRIDTH00530049 USING FILE brid049.dca
T3        N. Branch Ottauquechee River, TH 53, Town of Bridgewater
*
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          4800 6500 2502
SK         0.0075 0.0075 0.0075
*
XS   EXITX    -67
GR         -127.3, 503.03   -107.4, 495.06    -84.3, 495.26    -62.6, 493.34
GR          -50.8, 495.85    -13.4, 495.27      0.0, 488.30      6.1, 487.66
GR           13.6, 487.59     22.5, 487.60     33.2, 487.72     35.8, 488.33
GR           50.1, 493.71     91.0, 495.37    188.5, 498.30    247.9, 512.48
N            0.035        0.046        0.035
SA                 -13.         50.1
*
XS   FULLV    0 * * * 0.0075
*
BR   BRIDG    0 497.2
GR            0.0, 497.23     0.0, 487.88      5.3, 488.00
GR           14.3, 488.13     23.9, 488.18     34.7, 488.38     43.3, 488.82
GR           46.3, 489.29     46.3, 497.17     0.0, 497.23
N            0.040
CD           1 23.1 * * 45.0 7.1
*
XR   RDWAY    8 14.0 2
GR          -98.4, 503.32    -78.9, 494.99    -57.0, 495.77      0.0, 499.84
GR           46.8, 499.81    129.5, 494.85    162.4, 499.45    231.1, 499.19
GR          281.3, 512.41
*
AS   APPRO   69
GR          -76.8, 506.89    -57.9, 495.10    -36.2, 496.62    -13.6, 496.33
GR           -9.5, 494.12      0.0, 489.11      4.4, 488.30     12.9, 488.50
GR           21.6, 488.41     30.5, 488.36     39.7, 488.94     44.5, 490.24
GR           57.7, 495.61    114.1, 494.98    153.7, 495.10    188.1, 500.82
GR          264.6, 506.08    286.5, 514.39
N           0.035        0.046        0.035
SA                  -9.         57.7
*
HP 1 BRIDG    497.23 1 497.23
HP 2 BRIDG    497.23 * * 3254
HP 2 RDWAY    498.15 * * 1555
HP 1 APPRO    498.54 1 498.54
HP 2 APPRO    498.54 * * 4800
*
HP 1 BRIDG    497.23 1 497.23
HP 2 BRIDG    497.23 * * 3923
HP 2 RDWAY    498.90 * * 2569
HP 1 APPRO    499.36 1 499.36
HP 2 APPRO    499.36 * * 6500
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid049.wsp
        CREATED ON 20-APR-95 FOR BRIDGE BRIDTH00530049 USING FILE brid049.dca
        N. Branch Ottauquechee River, TH 53, Town of Bridgewater
           *** RUN DATE & TIME: 08-31-95  12:04
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     413.   37168.     0.   110.                           0.
   497.23          413.   37168.     0.   110.  1.00     0.    46.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       497.23     0.0    46.3   412.9   37168.    3254.   7.88

X STA.         0.0         3.5         5.8         8.0        10.1        12.2
  A(I)             32.6        21.2        20.3        19.1        18.9
  V(I)             4.98        7.68        8.00        8.51        8.59

X STA.        12.2        14.3        16.3        18.3        20.4        22.4
  A(I)             19.0        18.6        18.3        18.7        18.6
  V(I)             8.57        8.76        8.91        8.72        8.73

X STA.        22.4        24.5        26.6        28.7        30.8        33.0
  A(I)             18.7        18.7        18.8        18.6        19.3
  V(I)             8.68        8.71        8.65        8.76        8.43

X STA.        33.0        35.2        37.4        39.8        42.4        46.3
  A(I)             19.3        19.9        20.4        21.8        32.0
  V(I)             8.45        8.17        7.97        7.47        5.08

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.15   -86.3   153.1   241.7   14661.    1555.   6.43

X STA.       -86.3       -78.5       -75.5       -72.5       -69.4       -66.1
  A(I)             13.0         9.1         8.9         8.9         9.1
  V(I)             5.99        8.50        8.70        8.69        8.52

X STA.       -66.1       -62.4       -58.5       -53.7       -47.1        99.6
  A(I)              9.8         9.9        11.0        12.6        38.5
  V(I)             7.92        7.86        7.05        6.19        2.02

X STA.        99.6       107.4       112.8       117.1       120.8       124.0
  A(I)             13.6        11.4        10.4         9.9         9.3
  V(I)             5.71        6.80        7.45        7.82        8.32

X STA.       124.0       127.0       129.9       133.2       137.6       153.1
  A(I)              9.2         9.2         9.9        11.0        16.7
  V(I)             8.45        8.46        7.85        7.04        4.64

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      69.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     130.    9716.    54.    56.                        1143.
             2     579.   77336.    67.    69.                        9684.
             3     357.   32007.   117.   117.                        3546.
   498.54         1067.  119060.   238.   242.  1.14   -63.   174.  12009.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      69.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.54   -63.4   174.4  1066.5  119060.    4800.   4.50

X STA.       -63.4       -30.2        -4.8         1.0         5.1         9.1
  A(I)             79.3        75.0        48.6        41.4        40.7
  V(I)             3.03        3.20        4.94        5.80        5.90

X STA.         9.1        13.1        17.1        21.0        25.0        28.9
  A(I)             40.5        39.7        40.1        39.8        39.9
  V(I)             5.92        6.05        5.98        6.03        6.02

X STA.        28.9        32.9        37.1        41.7        48.1        66.2
  A(I)             41.0        41.3        43.9        51.3        72.0
  V(I)             5.85        5.81        5.46        4.67        3.33

X STA.        66.2        87.1       105.7       123.0       141.4       174.4
  A(I)             65.7        62.5        61.0        64.7        78.0
  V(I)             3.65        3.84        3.94        3.71        3.08
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    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     413.   37168.     0.   110.                          0.
   497.23          413.   37168.     0.   110.  1.00     0.    46.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       497.23     0.0    46.3   412.9   37168.    3923.   9.50

X STA.         0.0        3.5        5.8        8.0       10.1       12.2
  A(I)            32.6       21.2       20.3       19.1       18.9
  V(I)            6.01       9.26       9.65      10.26      10.36

X STA.        12.2       14.3       16.3       18.3       20.4       22.4
  A(I)            19.0       18.6       18.3       18.7       18.6
  V(I)           10.33      10.56      10.74      10.51      10.52

X STA.        22.4       24.5       26.6       28.7       30.8       33.0
  A(I)            18.7       18.7       18.8       18.6       19.3
  V(I)           10.46      10.50      10.43      10.56      10.16

X STA.        33.0       35.2       37.4       39.8       42.4       46.3
  A(I)            19.3       19.9       20.4       21.8       32.0
  V(I)           10.19       9.85       9.61       9.01       6.13

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.90   -88.1   158.5   359.0   24906.    2569.   7.16

X STA.       -88.1      -78.6      -75.0      -71.4      -67.7      -63.8
  A(I)            19.1       13.6       13.5       13.1       13.6
  V(I)            6.73       9.42       9.50       9.84       9.41

X STA.       -63.8      -59.5      -54.7      -48.7      -39.9       94.7
  A(I)            14.0       15.0       16.5       19.6       57.6
  V(I)            9.16       8.56       7.80       6.55       2.23

X STA.        94.7      103.3      109.7      114.8      119.2      123.1
  A(I)            19.3       16.9       15.4       14.5       13.8
  V(I)            6.67       7.60       8.34       8.84       9.32

X STA.       123.1      126.7      130.2      134.1      139.5      158.5
  A(I)            13.7       13.8       14.5       16.4       25.1
  V(I)            9.38       9.33       8.88       7.81       5.12

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      69.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     175.   15673.    56.    58.                       1765.
             2     634.   89888.    67.    69.                      11088.
             3     455.   46574.   122.   122.                       4992.
   499.36         1264.  152135.   244.   249.  1.10   -65.   179.  15575.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      69.

         WSEL     LEW     REW    AREA        K        Q    VEL
       499.36   -64.7   179.3  1264.1  152135.    6500.   5.14

X STA.       -64.7      -37.9      -10.0       -0.8        4.1        8.5
  A(I)            85.8       84.3       68.3       51.9       48.0
  V(I)            3.79       3.86       4.76       6.27       6.77

X STA.         8.5       13.0       17.4       21.9       26.3       30.7
  A(I)            49.2       48.2       48.8       48.3       48.5
  V(I)            6.60       6.75       6.66       6.72       6.71

X STA.        30.7       35.2       40.1       46.1       60.0       78.8
  A(I)            49.1       50.8       56.8       80.0       72.9
  V(I)            6.62       6.40       5.72       4.06       4.46

X STA.        78.8       96.2      112.1      128.0      144.5      179.3
  A(I)            71.0       67.8       69.6       70.9       93.9
  V(I)            4.58       4.79       4.67       4.58       3.46
```

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	286.	30903.	46.	58.				4043.
494.47		286.	30903.	46.	58.	1.00	0.	46.	4043.

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

WSEL	LEW	REW	AREA	K	Q	VEL
494.47	0.0	46.3	286.5	30903.	2502.	8.73

X STA.	0.0	3.7	6.1	8.2	10.3	12.3
A(I)	24.0	15.6	13.9	13.4	12.9	
V(I)	5.21	8.02	8.99	9.32	9.71	
X STA.	12.3	14.4	16.4	18.4	20.4	22.3
A(I)	12.9	12.6	12.7	12.5	12.5	
V(I)	9.70	9.92	9.86	9.99	10.01	
X STA.	22.3	24.3	26.3	28.3	30.4	32.5
A(I)	12.5	12.5	12.5	12.9	13.0	
V(I)	9.99	10.03	9.97	9.70	9.64	
X STA.	32.5	34.7	36.9	39.4	42.0	46.3
A(I)	13.3	13.4	14.6	15.1	23.7	
V(I)	9.42	9.33	8.59	8.28	5.29	

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 69.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	3.	58.	7.	8.				10.
	2	368.	36509.	66.	69.				4923.
	3	20.	352.	76.	76.				59.
495.37		391.	36919.	149.	152.	1.09	-58.	155.	3432.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 69.

WSEL	LEW	REW	AREA	K	Q	VEL
495.37	-58.3	155.3	390.6	36919.	2502.	6.41

X STA.	-58.3	-1.5	1.7	4.3	6.7	9.0
A(I)	28.9	19.8	17.7	16.7	16.1	
V(I)	4.32	6.32	7.06	7.48	7.76	
X STA.	9.0	11.4	13.7	16.1	18.4	20.7
A(I)	16.5	16.1	16.3	16.1	16.2	
V(I)	7.56	7.77	7.70	7.76	7.73	
X STA.	20.7	23.1	25.4	27.7	30.2	32.6
A(I)	16.2	16.2	16.4	17.0	16.7	
V(I)	7.74	7.73	7.62	7.36	7.49	
X STA.	32.6	35.2	38.0	41.1	45.2	155.3
A(I)	17.6	18.7	19.8	22.5	49.0	
V(I)	7.11	6.67	6.33	5.55	2.55	

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

EXITX:XS   ******  -110.     594.  1.32 *****  497.38  495.99   4800.  496.06
      -67. ******   114.   55416.  1.30 ***** *******    1.00    8.09

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.00     496.56     496.49

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   495.56     512.98    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   495.56     512.98     496.49

FULLV:FV      67.  -110.     605.  1.27  0.49  497.88  496.49   4800.  496.61
        0.    67.   116.   56546.  1.30  0.00    0.01    0.97    7.94
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  1.53

APPRO:AS      69.   -62.     847.  0.60  0.32  498.20 *******   4800.  497.60
       69.    69.   169.   86656.  1.20  0.00    0.00    0.57    5.67
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   499.00       0.00     495.37     494.85

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   496.48     497.78     497.98     497.20

 ===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      67.     0.     413.  0.97 *****  498.20  493.64   3254.  497.23
        0. ******    46.   37168.  1.00 ***** *******    0.47    7.88

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.402  0.000  497.20 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG        8.    55.  0.09  0.36  498.81    0.00   1555.  498.15

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    742.    63.   -86.   -24.   3.2   1.8   7.3   6.6   2.4   3.1
   RT:    812.    79.    74.   153.   3.3   1.7   6.7   6.3   2.3   2.9

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

APPRO:AS      46.   -63.    1067.  0.36  0.19  498.90  496.24   4800.  498.54
       69.    52.   174.  119171.  1.14  0.14    0.00    0.40    4.50

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -67.  -110.   114.   4800.   55416.     594.    8.09  496.06
   FULLV:FV       0.  -110.   116.   4800.   56546.     605.    7.94  496.61
   BRIDG:BR       0.     0.    46.   3254.   37168.     413.    7.88  497.23
   RDWAY:RG       8.*******   742.   1555.*****************     2.00  498.15
   APPRO:AS      69.   -63.   174.   4800.  119171.    1067.    4.50  498.54

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    495.99    1.00  487.59  512.48************  1.32  497.38  496.06
   FULLV:FV    496.49    0.97  488.09  512.98  0.49  0.00  1.27  497.88  496.61
   BRIDG:BR    493.64    0.47  487.88  497.23************  0.97  498.20  497.23
   RDWAY:RG  ***************  494.85  512.41  0.09******  0.36  498.81  498.15
   APPRO:AS    496.24    0.40  488.30  514.39  0.19  0.14  0.36  498.90  498.54
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WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******  -112.     776.  1.41 *****  498.23  496.78   6500.  496.82
      -67. ******   139.   75049.  1.29 ***** *******    0.95    8.38

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.95     497.32     497.28

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   496.32     512.98    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   496.32     512.98     497.28

FULLV:FV      67.  -112.     784.  1.37  0.50  498.73  497.28   6500.  497.36
        0.    67.   141.   76080.  1.29  0.00    0.01    0.94    8.29
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  1.47

APPRO:AS      69.   -63.    1021.  0.73  0.34  499.07 *******   6500.  498.35
       69.    69.   173.  111955.  1.15  0.00    0.00    0.58    6.37
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   497.36     497.20

            <<<<<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      67.     0.     413.  1.40 *****  498.63  494.35   3923.  497.23
        0. ******    46.   37168.  1.00 ***** *******    0.56    9.50

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  497.20 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q   WSEL
   RDWAY:RG       8.    55.  0.10  0.45  499.71    0.00   2569.  498.90

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   1202.    75.   -88.   -13.   3.9   2.2   8.0   7.3   3.0   3.1
   RT:   1367.    96.    62.   158.   4.0   2.0   7.5   7.0   2.8   3.0

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

APPRO:AS      46.   -65.    1263.  0.45  0.26  499.81  497.12   6500.  499.36
       69.    53.   179.  151988.  1.10  0.14    0.00    0.42    5.15

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -67.  -112.   139.   6500.   75049.     776.    8.38  496.82
   FULLV:FV       0.  -112.   141.   6500.   76080.     784.    8.29  497.36
   BRIDG:BR       0.     0.    46.   3923.   37168.     413.    9.50  497.23
   RDWAY:RG       8.******* 1202.   2569.*****************    2.00  498.90
   APPRO:AS      69.   -65.   179.   6500.  151988.    1263.    5.15  499.36

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    496.78    0.95  487.59  512.48************  1.41  498.23  496.82
   FULLV:FV    497.28    0.94  488.09  512.98  0.50  0.00  1.37  498.73  497.36
   BRIDG:BR    494.35    0.56  487.88  497.23************  1.40  498.63  497.23
   RDWAY:RG  ****************  494.85  512.41  0.10******  0.45  499.71  498.90
   APPRO:AS    497.12    0.42  488.30  514.39  0.26  0.14  0.45  499.81  499.36
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 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -72.     318.  1.00 *****  495.17  492.70   2502.  494.18
      -67. ******    62.   28869.  1.04 ***** *******    0.74    7.87

FULLV:FV      67.   -72.     318.  1.00  0.50  495.67 *******   2502.  494.68
        0.    67.    62.   28846.  1.04  0.00    0.00    0.74    7.88
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      69.   -58.     393.  0.69  0.40  496.08 *******   2502.  495.39
       69.    69.   155.   37121.  1.10  0.00    0.00    0.73    6.36
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   495.37       0.00     494.47     494.85

 ===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      67.     0.     286.  1.19  0.47  495.65  492.77   2502.  494.47
        0.    67.    46.   30874.  1.00  0.01   -0.01    0.62    8.74

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   4.  1.000 ******  497.20 ****** ****** ******

    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      46.   -58.     390.  0.70  0.27  496.06  493.13   2502.  495.37
       69.    49.   155.   36870.  1.09  0.15    0.02    0.73    6.42

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.783  0.035   35383.    -2.    45. ********

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -67.   -72.    62.   2502.   28869.     318.    7.87  494.18
   FULLV:FV       0.   -72.    62.   2502.   28846.     318.    7.88  494.68
   BRIDG:BR       0.     0.    46.   2502.   30874.     286.    8.74  494.47
   RDWAY:RG       8.**************      0.       0.       0.    2.00********
   APPRO:AS      69.   -58.   155.   2502.   36870.     390.    6.42  495.37

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -2.    45.   35383.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    492.70    0.74  487.59  512.48************  1.00  495.17  494.18
   FULLV:FV  ********    0.74  488.09  512.98  0.50  0.00  1.00  495.67  494.68
   BRIDG:BR    492.77    0.62  487.88  497.23  0.47  0.01  1.19  495.65  494.47
   RDWAY:RG ***************  494.85  512.41  0.26******  0.70  495.79********
   APPRO:AS    493.13    0.73  488.30  514.39  0.27  0.15  0.70  496.06  495.37
```
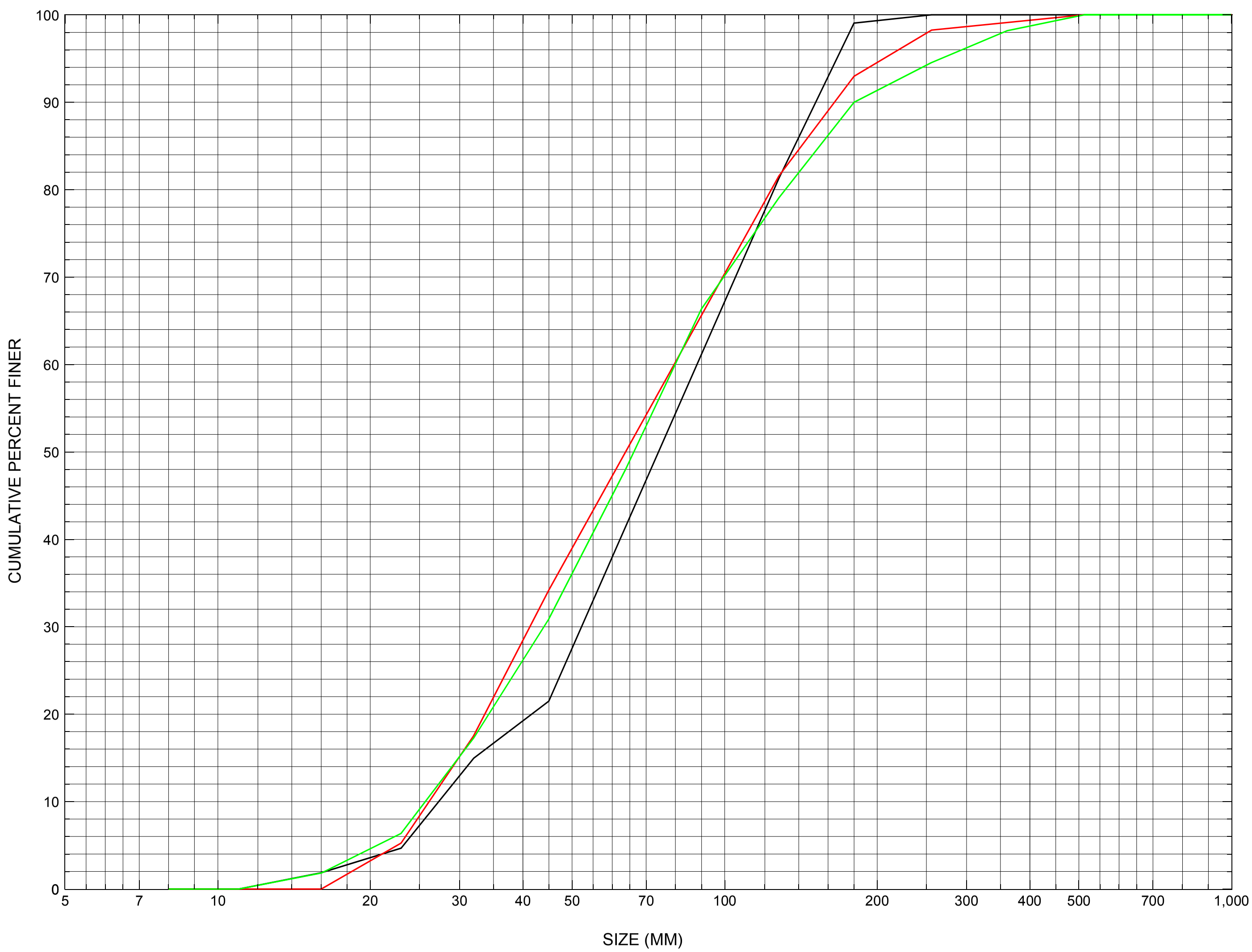

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00530049, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM