LEVEL II SCOUR ANALYSIS FOR BRIDGE 26 (BRIDTH00340026) on TOWN HIGHWAY 34, crossing OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-157

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

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By ERICK M. BOEHMLER

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

BF	bank full	LWW	left wingwall
cfs	cubic feet per second	MC	main channel
D_{50}	median diameter of bed material	RAB	right abutment
DS	downstream	RABUT	face of right abutment
elev.	elevation	RB	right bank
f/p	flood plain	ROB	right overbank
ft^2	square feet	RWW	right wingwall
ft/ft	feet per foot	TH	town highway
JCT	junction	UB	under bridge
LAB	left abutment	US	upstream
LABUT	face of left abutment	USGS	United States Geological Survey
LB	left bank	VTAOT	Vermont Agency of Transportation
LOB	left overbank	WSPRO	water-surface profile model

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 26 (BRIDTH00340026) ON TOWN HIGHWAY 34, CROSSING OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

***By* Erick M. Boehmler**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00340026 on town highway 34 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 were 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 38.0-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have dense woody vegetation coverage except for the upstream right bank, which is grass covered.

In the study area, the Ottauquechee River has an incised, sinuous channel with a slope of approximately 0.01 ft/ft, an average channel top width of 62.5 ft and an average channel depth of 4.5 ft. The predominant channel bed material is cobble (D_{50} is 97.3 mm or 0.319 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 8, 1994, indicated that the reach was stable.

The town highway 34 crossing of the Ottauquechee River is a 69-ft-long, two-lane bridge consisting of one 63-foot clear-span steel-pony truss-type superstructure (Vermont Agency of Transportation, written commun., August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 40 degrees to the opening while the opening-skew-to-roadway is 45 degrees.

A scour hole 4.5 ft deeper than the mean thalweg depth was observed along the upstream left wingwall during the Level I assessment. The only scour protection measure at the site was type-1 stone fill (less than 12 inches diameter) at the upstream end of the upstream left wingwall. Additional details describing conditions at the site are included in the Level II Summary and Appendices D
and E.

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). These guidelines provide scour equations, which assume an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

NORTH

Figure 1. Location of study area on USGS 1:24,000 scale map.

Figure 2. Location of study area on Vermont Agency of Transportation town highway map.

LEVEL II SUMMARY

Structure Number BRIDTH00340026 ***Stream*** Ottauquechee River

County Windsor ***Road*** TH034 ***District*** 04

Description of Bridge

Bridge length 69 ***ft*** ***Bridge width*** 21.1 ***ft*** ***Max span length*** 63 ***ft***

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

Abutment type Vertical ***Embankment type*** Sloping

Stone fill on abutment? No ***Date of inspection*** 11/08/94

Description of stone fill Type-1, around the upstream end of the upstream left wingwall in good condition.

Abutments and wingwalls are concrete. There is a three to four foot deep scour hole in front of the upstream left wingwall.

Y 40

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

There is a mild channel bend in the upstream reach. The scour hole has developed in the location where the bend impacts the upstream left wingwall.

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	11/08/94	0	0
Level II	11/08/94	--	--

Potential for debris Moderate. There is some debris caught on boulders and trees leaning over the channel upstream.

Describe any features near or at the bridge that may affect flow (include observation date) A large pile of boulders on the upstream left bank set up an eddy current at the upstream left wingwall resulting in a significant scour hole as of 11/08/94.

Description of the Geomorphic Setting

General topography The channel is located within a 280 foot-wide, flat to slightly irregular flood plain with steep valley walls on both sides.

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

Date of inspection 11/08/95

DS left: Steep channel bank to a narrow terrace

DS right: Narrow flood plain

US left: Steep valley wall

US right: Moderately sloped overbank

Description of the Channel

Average top width 62.5 ***ft***

Average depth 4.5 ***ft***

Predominant bed material Gravel / Cobbles

Bank material Gravel/Cobbles

Sinuous but stable with semi-alluvial to non-alluvial channel boundaries and a narrow flood plain.

11/08/95

Vegetative co

Trees and brush

DS left: Trees and brush

DS right: Trees

US left: Short grass and brush with a few trees.

US right: Y

Do banks appear stable? -

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

The assessment of 11/8/95 noted flow conditions up to bank-full level are influenced by a pile of boulders on the left bank side of the channel upstream. In addition, some debris is caught on boulders in the channel upstream.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 38.0 ***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***: There are a couple houses and a motor lodge on the upstream right overbank area

Is there a USGS gage on the stream of interest? Yes

USGS gage description Ottauquechee River near W. Bridgewater

USGS gage number 01150900

Gage drainage area 23.4 ***mi²***

Is there a lake/ No

Calculated Discharges

Q100 8,030 ***ft³/s*** ***Q500*** 11,600 ***ft³/s***

The 100- and 500-year discharges are based on a drainage area relationship [(38.0/41.9)exp 0.7] with bridge number 48 in Bridgewater. Bridge number 48 crosses the Ottauquechee River downstream of this site and has flood frequency estimates available from the VTAOT database. The drainage area above bridge number 48 is 41.9 square miles.

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 DS end of the left abutment (elev. 507.54 ft, arbitrary datum). RM2 is a chiseled X on top of the US end of the right abutment (elev. 507.57ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
EXITX	-64	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	20.8	1	Road Grade section
APPRO	82	2	Modelled Approach section (Templated from SURVA)
SURVA	132	1	Approach section as surveyed (Used as a template)

[1] For location of cross-sections see plan-view plot 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). 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 0.040 to 0.060, and overbank "n" values ranged from 0.040 to 0.095.

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 0.0095 ft/ft which was estimated from the topographic map (U.S. Geological Survey, 1966).

The surveyed approach section (SURVA) was moved along the approach channel slope (0.014 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.

The modeled 100- and 500-year discharges overtop the roadway embankments but not the bridge deck. The truss structure was assumed to collect debris, effectively blocking flow from passing over the deck.

Bridge Hydraulics Summary

Average bridge embankment elevation 510.4 *ft*
Average low steel elevation 507.7 *ft*

100-year discharge 8,030 *ft³/s*
Water-surface elevation in bridge opening 507.7 *ft*
Road overtopping? Y *Discharge over road* 1,890 *ft³/s*
Area of flow in bridge opening 466 *ft²*
Average velocity in bridge opening 13.2 *ft/s*
Maximum WSPRO tube velocity at bridge 15.6 *ft/s*

Water-surface elevation at Approach section with bridge 512.8
Water-surface elevation at Approach section without bridge 509.5
Amount of backwater caused by bridge 3.3 *ft*

500-year discharge 11,600 *ft³/s*
Water-surface elevation in bridge opening 507.7 *ft*
Road overtopping? Y *Discharge over road* 5,490 *ft³/s*
Area of flow in bridge opening 466 *ft²*
Average velocity in bridge opening 13.1 *ft/s*
Maximum WSPRO tube velocity at bridge 15.6 *ft/s*

Water-surface elevation at Approach section with bridge 514.7
Water-surface elevation at Approach section without bridge 511.3
Amount of backwater caused by bridge 3.4

Incipient overtopping discharge 4,850 *ft³/s*
Water-surface elevation in bridge opening 505.1 *ft*
Area of flow in bridge opening 359 *ft²*
Average velocity in bridge opening 13.5 *ft/s*
Maximum WSPRO tube velocity at bridge 16.8 *ft/s*

Water-surface elevation at Approach section with bridge 508.1
Water-surface elevation at Approach section without bridge 507.1
Amount of backwater caused by bridge 1.0 *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.

The 100-year and 500-year discharges resulted in submerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Therefore, contraction scour for the 100-year and 500-year discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). 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 discharges. 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. The 500-year model resulted in the worst case contraction and total scour.

Abutment scour for the left abutment at all modelled discharges and the right abutment at the incipient overtopping discharge was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). 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.

Scour at the right abutment for the 100- and 500-year 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 abutment scour equation are the same as the Froehlich abutment scour equation.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	2.7 2.9	1.2	9.3
Depth to armoring	9.1	16.3	--
Left overbank	--	--	--
Right overbank	--	--	24.8
Local scour:			
Abutment scour			
Left abutment	25.4	23.6	7.3
Right abutment	7.6	12.7	--
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	4.5

Rock Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	4.5	3.5	4.5
Right abutment	4.5	3.5	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	

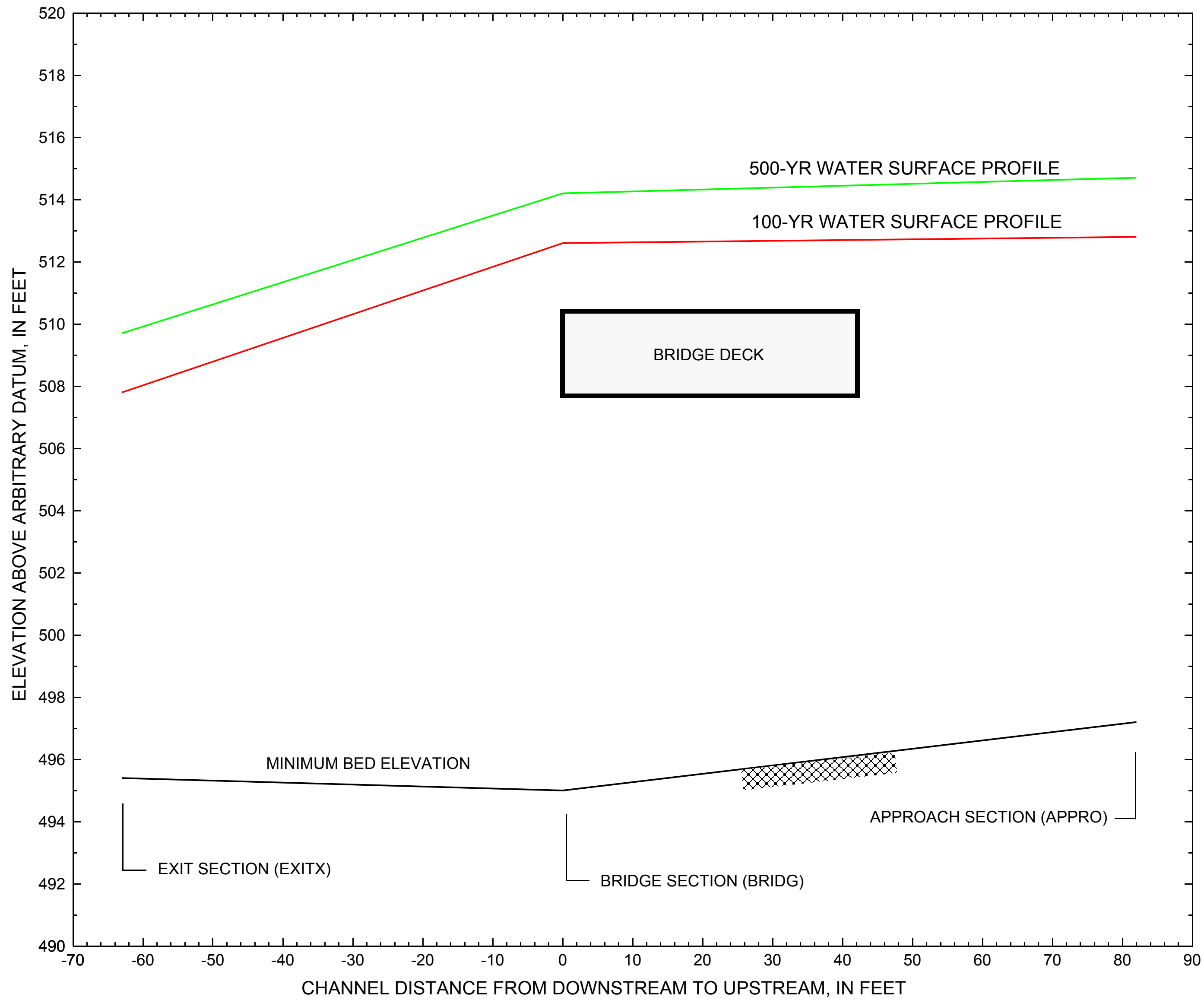

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00340026 on town highway 34, crossing Ottauquechee River, Bridgewater, Vermont.

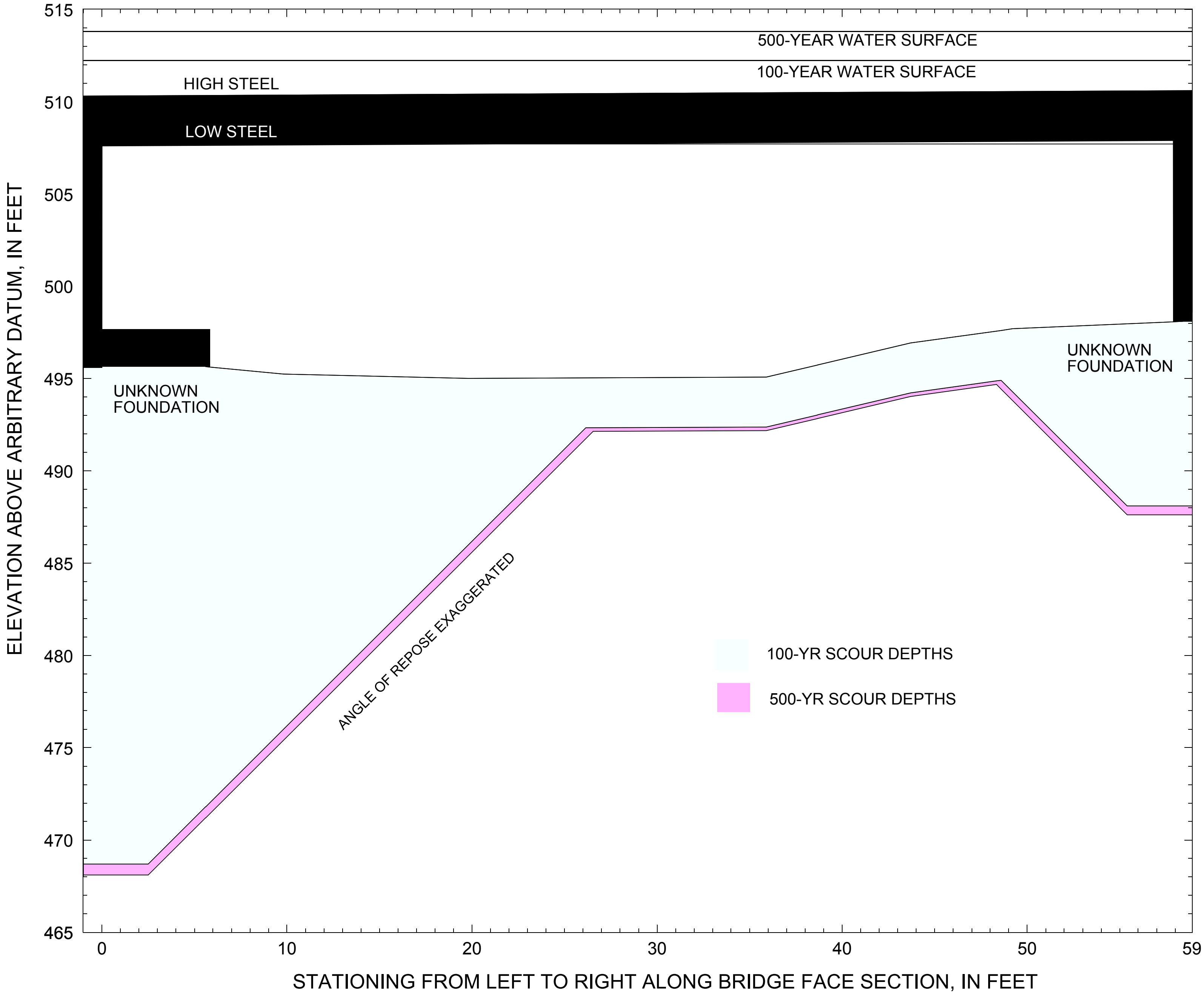

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00340026 on town highway 34, crossing Ottauquechee River, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00340026 on Town Highway 34, 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 8,030 cubic-feet per second											
Left abutment	0	--	507.71	--	495.6	2.7	24.8	--	27.5	468.1	--
Right abutment	57.9	--	507.62	--	498.1	2.7	7.3	--	10.0	488.1	--

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 BRIDTH00340026 on Town Highway 34, 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 11,600 cubic-feet per second											
Left abutment	0	--	507.71	--	495.6	2.9	25.4	--	28.3	467.3	--
Right abutment	57.9	--	507.62	--	498.1	2.9	7.6	--	10.5	487.6	--

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

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

U.S. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

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 brid0026.wsp
T2        CREATED ON 24-APR-95 FOR BRIDGE BRIDTH00340026 USING FILE brid0026.dca
T3        Ottauquechee River, Town Highway 34, 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          8030 11600 4853
SK         0.0095 0.0095 0.0095
*
XS   EXITX   -64
GR          -89.5, 522.44    -77.3, 512.94    -64.6, 511.49    -59.6, 512.17
GR          -32.4, 511.01    -20.6, 500.65     -5.2, 498.47      0.0, 497.42
GR            2.5, 496.23      7.2, 495.44     13.6, 495.39     20.2, 495.92
GR           26.0, 497.48     39.0, 501.48     52.2, 502.36     63.8, 504.56
GR          113.4, 506.55    186.7, 508.39    247.0, 510.48    322.8, 527.45
N           0.055        0.055        0.095
SA                 -32.         52.2
*
XS   FULLV   0
*
BR   BRIDG   0 507.7 45
GR            0.0, 507.71      1.1, 497.48      5.6, 497.11      5.6, 495.65
GR            9.8, 495.25     19.8, 495.01     35.9, 495.08     43.7, 496.93
GR           49.2, 497.70     56.6, 498.07     57.9, 507.62      0.0, 507.71
N            0.040
CD           4 41.5 2.1 508 52.5 8.6
*
XR   RDWAY    20.8 22 1
GR          -78.6, 523.19    -69.8, 511.92    -61.1, 511.18    -55.2, 511.67
GR          -48.2, 511.37     -5.0, 510.17     -5.0, 514.60      2.5, 514.50
GR            3.9, 515.71     52.8, 516.09     54.2, 514.86     60.7, 514.91
GR           60.7, 510.65    111.4, 510.57    147.1, 511.16    228.1, 512.83
GR          373.5, 521.12
BP            0
*
*
XT   SURVA    132
GR          -25.8, 516.12    -3.2, 501.03    -0.5, 499.48     4.1, 498.61
GR           18.3, 498.03    28.9, 497.90    40.0, 499.26    54.4, 499.73
GR           62.5, 502.09   100.9, 510.59   156.7, 511.29   248.0, 514.30
GR          323.3, 518.84
*
AS   APPRO    82
GT           -0.72
N           .060  .040
SA          100.9
BP           17
*
HP 1 BRIDG    507.71 1 507.71
HP 2 BRIDG    507.71 * * 6138
HP 2 RDWAY    512.63 * * 1893
HP 1 APPRO    512.80 1 512.80
HP 2 APPRO    512.80 * * 8030
*
HP 1 BRIDG    507.71 1 507.71
HP 2 BRIDG    507.71 * * 6114
HP 2 RDWAY    514.24 * * 5489
HP 1 APPRO    514.66 1 514.66
HP 2 APPRO    514.66 * * 11600
*
HP 1 BRIDG    505.06 1 505.06
```

```
HP 2 BRIDG    505.06 * * 4853
HP 1 APPRO    508.08 1 508.08
HP 2 APPRO    508.08 * * 4853
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid0026.wsp
        CREATED ON 24-APR-95 FOR BRIDGE BRIDTH00340026 USING FILE brid0026.dca
        Ottauquechee River, Town Highway 34, Town of Bridgewater
           *** RUN DATE & TIME: 11-01-95  13:12

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      466     47759      0    102                            0
   507.71           466     47759      0    102  1.00      0     58        0

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       507.71     0.0    57.9   465.7   47759.    6138.  13.18

X STA.         0.0         6.0        8.9       11.6       14.0       16.4
  A(I)             40.6       25.4       22.9       21.5       21.1
  V(I)             7.56      12.09      13.38      14.30      14.55

X STA.        16.4        18.6       20.8       23.1       25.3       27.5
  A(I)             20.2       19.8       20.0       19.7       19.7
  V(I)            15.22      15.46      15.35      15.55      15.56

X STA.        27.5        29.7       31.9       34.1       36.4       38.9
  A(I)             19.7       19.6       19.9       20.1       21.4
  V(I)            15.60      15.62      15.45      15.29      14.32

X STA.        38.9        41.5       44.5       47.7       51.5       57.9
  A(I)             21.5       23.0       23.8       26.4       39.4
  V(I)            14.29      13.33      12.90      11.64       7.78

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      21.
         WSEL     LEW     REW    AREA        K        Q    VEL
       512.63   -70.4   218.4   322.7    8077.    1893.   5.87

X STA.       -70.4       -57.7      -45.7      -37.3      -30.7      -25.2
  A(I)             14.1       13.6       12.2       10.9        9.9
  V(I)             6.72       6.94       7.76       8.67       9.59

X STA.       -25.2       -20.3      -16.0      -11.9       -8.2       65.0
  A(I)              9.7        9.1        8.9        8.7       16.2
  V(I)             9.75      10.43      10.61      10.86       5.83

X STA.        65.0        73.5       81.9       90.5       99.2      107.9
  A(I)             16.9       17.0       17.3       17.7       17.9
  V(I)             5.60       5.57       5.46       5.36       5.30

X STA.       107.9       116.8      127.6      140.6      158.5      218.4
  A(I)             18.1       20.2       21.9       25.3       37.0
  V(I)             5.23       4.68       4.32       3.74       2.56

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1     1346    159974    123    128                        25275
             2      219     11987    123    123                         1660
   512.80          1565    171962    246    252  1.11    -21    224    21285

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
         WSEL     LEW     REW    AREA        K        Q    VEL
       512.80   -21.9   224.3  1565.0  171962.    8030.   5.13

X STA.       -21.9        -3.1        2.5        7.1       11.4       15.4
  A(I)            118.3       77.9       67.6       65.5       61.4
  V(I)             3.39       5.16       5.94       6.13       6.53

X STA.        15.4        19.4       23.2       27.0       30.8       34.8
  A(I)             60.8       59.9       59.1       58.6       60.7
  V(I)             6.61       6.70       6.79       6.85       6.61

X STA.        34.8        38.9       43.4       47.8       52.6       57.7
  A(I)             60.8       62.9       63.2       65.8       68.7
  V(I)             6.61       6.39       6.36       6.11       5.84

X STA.        57.7        63.9       71.9       84.2      119.2      224.3
  A(I)             74.7       81.6       98.7      131.0      167.9
  V(I)             5.37       4.92       4.07       3.06       2.39
```

WSPRO OUTPUT FILE (continued)

```
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      466     47759      0    102                            0
    507.71           466     47759      0    102  1.00      0     58        0

     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
          WSEL     LEW     REW    AREA         K        Q    VEL
        507.71     0.0    57.9   465.7   47759.    6114.  13.13

X STA.         0.0        6.0        8.9       11.6       14.0       16.4
  A(I)            40.6       25.4       22.9       21.5       21.1
  V(I)            7.53      12.05      13.33      14.24      14.50

X STA.        16.4       18.6       20.8       23.1       25.3       27.5
  A(I)            20.2       19.8       20.0       19.7       19.7
  V(I)           15.16      15.40      15.29      15.49      15.50

X STA.        27.5       29.7       31.9       34.1       36.4       38.9
  A(I)            19.7       19.6       19.9       20.1       21.4
  V(I)           15.54      15.56      15.39      15.23      14.27

X STA.        38.9       41.5       44.5       47.7       51.5       57.9
  A(I)            21.5       23.0       23.8       26.4       39.4
  V(I)           14.24      13.28      12.85      11.60       7.75

     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      21.
          WSEL     LEW     REW    AREA         K        Q    VEL
        514.24   -71.6   252.8   714.9   26605.    5489.   7.68

X STA.       -71.6      -60.2      -50.8      -42.5      -34.9      -28.3
  A(I)            28.2       25.8       24.2       23.6       22.0
  V(I)            9.74      10.65      11.36      11.64      12.46

X STA.       -28.3      -22.2      -16.5      -11.1       63.6       74.3
  A(I)            21.4       20.8       20.7       34.9       38.5
  V(I)           12.80      13.22      13.26       7.86       7.13

X STA.        74.3       84.6       95.0      105.4      115.8      127.2
  A(I)            37.4       37.6       38.2       37.9       39.8
  V(I)            7.33       7.30       7.18       7.24       6.90

X STA.       127.2      140.0      154.4      171.9      195.6      252.8
  A(I)            42.4       44.2       48.2       55.1       74.1
  V(I)            6.47       6.21       5.69       4.98       3.71

     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1     1577    204776    126    132                        31698
              2      493     38136    165    165                         4842
    514.66          2070    242912    291    297  1.10    -24    266    29880

     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
          WSEL     LEW     REW    AREA         K        Q    VEL
        514.66   -24.7   265.9  2070.0  242912.   11600.   5.60

X STA.       -24.7       -3.2        3.0        8.4       13.2       18.0
  A(I)           154.8       97.7       89.6       82.4       82.2
  V(I)            3.75       5.93       6.47       7.04       7.06

X STA.        18.0       22.5       26.9       31.4       36.0       40.9
  A(I)            77.9       78.0       78.0       77.9       80.1
  V(I)            7.44       7.44       7.44       7.45       7.24

X STA.        40.9       46.0       51.1       56.7       63.1       71.1
  A(I)            81.7       80.8       86.0       89.9       98.3
  V(I)            7.10       7.18       6.74       6.45       5.90

X STA.        71.1       82.4      104.1      132.9      167.5      265.9
  A(I)           115.0      141.8      131.3      143.2      203.5
  V(I)            5.04       4.09       4.42       4.05       2.85

     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      360     46408     40     56                         6081
    505.06           360     46408     40     56  1.00      0     58     6081
```

```
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       505.06     0.3    57.6   359.6   46408.    4853.  13.49

X STA.        0.3        6.7        9.8       12.3       14.7       16.9
  A(I)            34.5       20.9       17.7       16.4       15.7
  V(I)            7.04      11.60      13.74      14.77      15.48

X STA.       16.9       19.1       21.2       23.3       25.3       27.4
  A(I)            15.3       15.2       14.7       14.5       14.5
  V(I)           15.86      16.00      16.55      16.76      16.78

X STA.       27.4       29.4       31.5       33.5       35.7       38.0
  A(I)            14.6       14.5       14.7       15.2       15.7
  V(I)           16.67      16.69      16.51      15.98      15.41

X STA.       38.0       40.5       43.4       46.7       50.7       57.6
  A(I)            16.3       17.4       18.7       21.2       32.1
  V(I)           14.85      13.95      12.99      11.47       7.56

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      790     72275    108    112                        12141
   508.08           790     72275    108    112  1.00    -14     93    12141

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      82.
         WSEL     LEW     REW    AREA        K        Q    VEL
       508.08   -14.8    92.8   789.9   72275.    4853.   6.14

X STA.      -14.8       -1.3        3.0        6.5        9.8       12.9
  A(I)            60.7       41.3       35.6       34.5       32.5
  V(I)            4.00       5.87       6.81       7.02       7.47

X STA.       12.9       16.0       19.0       22.0       24.9       27.8
  A(I)            32.8       32.2       32.0       31.7       31.9
  V(I)            7.40       7.52       7.58       7.64       7.62

X STA.       27.8       30.8       34.0       37.5       41.2       45.1
  A(I)            32.5       33.4       35.0       35.1       36.8
  V(I)            7.47       7.26       6.94       6.92       6.59

X STA.       45.1       49.1       53.5       58.7       66.4       92.8
  A(I)            37.9       40.5       44.3       51.9       77.1
  V(I)            6.40       5.99       5.47       4.67       3.15

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid0026.wsp
        CREATED ON 24-APR-95 FOR BRIDGE BRIDTH00340026 USING FILE brid0026.dca
        Ottauquechee River, Town Highway 34, Town of Bridgewater
           *** RUN DATE & TIME: 11-01-95  13:12

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

EXITX:XS   ******    -28      900  1.72 *****  509.55  506.02    8030  507.84
       -63 ******    165    82357  1.39 ***** *******    0.86    8.92

FULLV:FV       64    -29     1098  1.27  0.50  510.04 *******    8030  508.77
         0     64    198    99790  1.53  0.00   -0.01    0.73    7.32
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       82    -16      948  1.12  0.57  510.61 *******    8030  509.49
        82     82     99    92934  1.00  0.00   -0.01    0.52    8.47
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
```

```
 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   508.77     507.70

            <<<<<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       64      0      466  2.70 *****  510.41  505.12    6138  507.71
         0 ******     58    47759  1.00 ***** *******    0.82   13.18

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   6.  0.800  0.000  507.70 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      21.    60.  0.13  0.45  513.13    0.00   1893.  512.63

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    612.    65.   -70.    -5.   2.5   1.6   6.7   5.8   2.1   3.1
   RT:   1281.   158.    61.   219.   2.1   1.4   6.5   5.9   1.9   3.2

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

APPRO:AS       41    -21     1566  0.45  0.27  513.26  505.97    8030  512.80
        82     45    224   172117  1.11  0.00    0.00    0.38    5.13

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -64.   -29.   165.   8030.   82357.     900.    8.92  507.84
   FULLV:FV       0.   -30.   198.   8030.   99790.    1098.    7.32  508.77
   BRIDG:BR       0.     0.    58.   6138.   47759.     466.   13.18  507.71
   RDWAY:RG      21.*******   612.   1893.******************    1.00  512.63
   APPRO:AS      82.   -22.   224.   8030.  172117.    1566.    5.13  512.80

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    506.02    0.86  495.39  527.45************  1.72  509.55  507.84
   FULLV:FV  ********    0.73  495.39  527.45  0.50  0.00  1.27  510.04  508.77
   BRIDG:BR    505.12    0.82  495.01  507.71************  2.70  510.41  507.71
   RDWAY:RG  ****************  510.17  523.19  0.13******  0.45  513.13  512.63
   APPRO:AS    505.97    0.38  497.18  518.12  0.27  0.00  0.45  513.26  512.80

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

EXITX:XS   ******    -30     1312  2.00 *****  511.66  508.25   11600  509.66
       -63 ******    223   118966  1.64 ***** *******    0.88    8.84

FULLV:FV       64    -31     1593  1.43  0.50  512.14 *******   11600  510.70
         0     64    248   145117  1.74  0.00   -0.02    0.71    7.28
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       82    -19     1228  1.47  0.59  512.76 *******   11600  511.28
        82     82    178   129199  1.06  0.02    0.01    0.69    9.44
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   510.70     507.70

            <<<<<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       64      0      466  2.68 *****  510.39  505.09    6114  507.71
         0 ******     58    47759  1.00 ***** *******    0.82   13.13

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   6.  0.800  0.000  507.70 ****** ****** ******
```

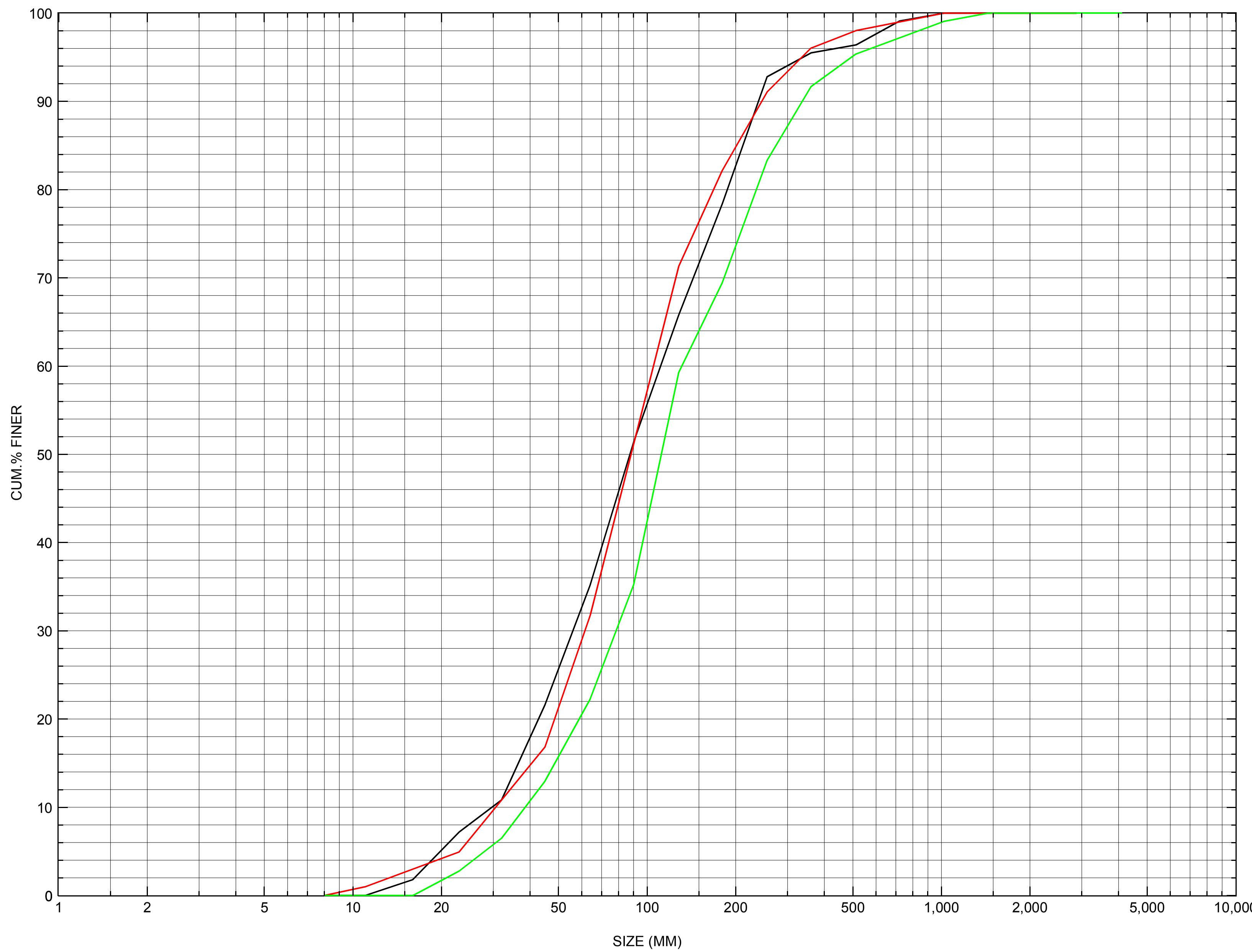
```
    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      21.    60.  0.14  0.54  515.06    0.00   5489.  514.24

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   1630.    67.   -72.    -5.   4.1   3.2   9.2   7.7   4.0   3.1
   RT:   3860.   192.    61.   253.   3.7   2.6   8.8   7.6   3.4   3.1

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

APPRO:AS       41    -24     2070  0.54  0.31  515.20  507.83   11600  514.66
       82      46    266   242834  1.10  0.00    0.00    0.39    5.61

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

   FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -64.   -31.   223.  11600.  118966.    1312.    8.84  509.66
   FULLV:FV       0.   -32.   248.  11600.  145117.    1593.    7.28  510.70
   BRIDG:BR       0.     0.    58.   6114.   47759.     466.   13.13  507.71
   RDWAY:RG      21.******* 1630.   5489.*****************    1.00  514.24
   APPRO:AS      82.   -25.   266.  11600.  242834.    2070.    5.61  514.66

  SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    508.25    0.88  495.39  527.45************  2.00  511.66  509.66
   FULLV:FV  ********    0.71  495.39  527.45  0.50  0.00  1.43  512.14  510.70
   BRIDG:BR    505.09    0.82  495.01  507.71************  2.68  510.39  507.71
   RDWAY:RG  ****************  510.17  523.19  0.14******  0.54  515.06  514.24
   APPRO:AS    507.83    0.39  497.18  518.12  0.31  0.00  0.54  515.20  514.66

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

EXITX:XS   ******    -25      563  1.28 *****  506.88  503.79    4853  505.60
      -63 ******     90    49753  1.11 ***** *******    0.73    8.62

FULLV:FV       64    -26      663  0.99  0.50  507.38 *******    4853  506.39
        0      64    109    60072  1.19  0.00   -0.01    0.64    7.32
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       82    -12      691  0.77  0.54  507.91 *******    4853  507.14
       82      82     89    60064  1.00  0.00    0.00    0.48    7.02
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   505.06     507.80     508.12     507.70

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                  WS,QBO,QRD =   510.71      4818.        19.

 ===270 REJECTED 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       64      0      359  2.83  0.65  507.89  503.80    4853  505.06
        0      64     58    46381  1.00  0.36    0.00    0.80   13.50

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   1.  1.000 ******  507.70 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      21.       <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>
```

WSPRO OUTPUT FILE (continued)

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

APPRO:AS       41    -14      795  0.58  0.32  508.70  503.89    4853  508.12
        82     46     93    72866  1.00  0.50    0.00    0.40    6.11

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.435  0.082   66863.     0.    57.   507.86

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
   EXITX:XS     -64.   -26.    90.   4853.   49753.     563.    8.62  505.60
   FULLV:FV       0.   -27.   109.   4853.   60072.     663.    7.32  506.39
   BRIDG:BR       0.     0.    58.   4853.   46381.     359.   13.50  505.06
   RDWAY:RG      21.**************      0.       0.       0.    1.00********
   APPRO:AS      82.   -15.    93.   4853.   72866.     795.    6.11  508.12

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    503.79    0.73  495.39  527.45************  1.28  506.88  505.60
   FULLV:FV  ********    0.64  495.39  527.45  0.50  0.00  0.99  507.38  506.39
   BRIDG:BR    503.80    0.80  495.01  507.71  0.65  0.36  2.83  507.89  505.06
   RDWAY:RG  ****************  510.17  523.19************  0.30  510.91********
   APPRO:AS    503.89    0.40  497.18  518.12  0.32  0.50  0.58  508.70  508.12
```

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 BRIDTH00340026, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM