LEVEL II SCOUR ANALYSIS FOR BRIDGE 36 (BRIDTH00050036) on TOWN HIGHWAY 5, crossing BRIDGEWATER HOLLOW BROOK, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-387

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

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By SCOTT A. OLSON and ERICK M. BOEHMLER

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Pembroke, New Hampshire

1996

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

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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 36 (BRIDTH00050036) ON TOWN HIGHWAY 5, CROSSING BRIDGEWATER HOLLOW BROOK, BRIDGEWATER, VERMONT

***By* Scott A. Olson and Erick M. Boehmler**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00050036 on town highway 5 crossing Bridgewater Hollow Brook, Bridgewater, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). 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, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in Appendix D.

The site is in the Green Mountain section of the New England physiographic province of central Vermont. The 3.60-mi^2 drainage area is in a predominantly forested basin. In the vicinity of the study site, the banks have dense woody vegetation coverage.

In the study area, Bridgewater Hollow Brook has an incised, sinuous channel with a slope of approximately 0.028 ft/ft, an average channel top width of 24 ft and an average channel depth of 4 ft. The predominant channel bed material is cobble (D_{50} is 196 mm or 0.644 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 2, 1994, indicated that the reach was stable.

The town highway 5 crossing of Bridgewater Hollow Brook is a 30-ft-long, one-lane bridge consisting of one 27-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 skewed approximately 30 degrees to the opening and the opening-skew-to-roadway is also 30 degrees.

The scour protection measures at this site were sparse type-2 stone fill (less than 36 inches diameter) along both abutments, upstream wingwalls, and the downstream left wingwall and type-1 stone fill (less than 12 inches diameter) along the downstream 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, 1995). 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.

There was no contraction scour for all modelled flows. Abutment scour ranged from 4.9 to 7.0 ft. The worst-case abutment scour 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, 1995, 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.

Delectable Mountain, VT. Quadrangle, 1:24,000, 1966

NORTH

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

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

LEVEL II SUMMARY

Structure Number BRIDTH00050036 ***Stream*** Bridgewater Hollow Brook

County Windsor ***Road*** TH005 ***District*** 04

Description of Bridge

Bridge length 30 ***ft*** ***Bridge width*** 16 ***ft*** ***Max span length*** 27 ***ft***

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

Abutment type Vertical ***Embankment type*** None

Stone fill on abutment? Yes ***Date of inspection*** 11/02/94

Description of stone fill Sparse type-2 along both abutments, both upstream wingwalls, and the downstream left wingwall. Type-1 along the downstream right wingwall.

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

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 30

There is a mild channel bend through the 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	11/02/94	0	0
Level II	11/02/94	--	--

Potential for debris Moderate.

Describe any features near or at the bridge that may affect flow (include observation date)

Bridgewater Hollow Brook's confluence with the North Branch of the Ottauquechee River is 95 feet downstream of the bridge.

Description of the Geomorphic Setting

General topography The channel is located in a narrow, incised, upland valley.

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

Date of inspection 11/02/95

DS left: Moderately sloping bank

DS right: Moderately sloping bank

US left: Moderately sloping bank

US right: Steep valley wall

Description of the Channel

Average top width 24 ***ft*** ***Average depth*** 4 ***ft***

Predominant bed material Cobbles ***Bank material*** Cobbles

Sinuous but stable

with non-alluvial channel boundaries and no flood plains.

11/02/95

Vegetative co Forested

DS left: Forested

DS right: Forested

US left: Forested

US right: Y

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

November 2, 1994--

None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 3.60 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province/section	***Percent of drainage area***
New England / Green Mountain	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization:*** None.

Is there a USGS gage on the stream of interest? No

USGS gage description

USGS gage number

Gage drainage area ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 1,150 ***ft³/s*** ***Q500*** 1,620 ***ft³/s***

The 100- and 500-year discharges are based on a drainage area relationship [(3.6/4.4)exp 0.7] with bridge number 32 in Bridgewater. Bridge number 32 crosses the North Branch of the Ottauquechee River and has 100-year discharge estimate available from the VTAOT database (VTAOT, written communication, May, 1995). The 500-year discharge at bridge 32 was estimated by multiplying the Q100 by 1.7 (Richardson and others, 1993). The drainage area above bridge number 32 is 4.4 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 downstream end of the left abutment (elev. 498.54 ft, arbitrary datum). RM2 is a chiseled X on top of the upstream end of the right abutment (elev. 500.11 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-44	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	41	2	Modelled Approach section (Templated from APTEM)
APTEM	66	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 reflect 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 0.060 to 0.065, and overbank "n" values ranged from 0.040 to 0.090.

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 0.0285 ft/ft which was determined from surveyed thalweg points downstream of the structure.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.054 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

For both the 100- and 500-year discharges, flow overtopped the deck. The incipient overtopping discharge was 911 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.1 *ft*
Average low steel elevation 497.4 *ft*

100-year discharge 1,150 *ft³/s*
Water-surface elevation in bridge opening 497.7 *ft*
Road overtopping? Y *Discharge over road* 74 *ft³/s*
Area of flow in bridge opening 126 *ft²*
Average velocity in bridge opening 8.6 *ft/s*
Maximum WSPRO tube velocity at bridge 11.9 *ft/s*

Water-surface elevation at Approach section with bridge 499.3
Water-surface elevation at Approach section without bridge 498.1
Amount of backwater caused by bridge 1.2 *ft*

500-year discharge 1,620 *ft³/s*
Water-surface elevation in bridge opening 498.0 *ft*
Road overtopping? Y *Discharge over road* 261 *ft³/s*
Area of flow in bridge opening 126 *ft²*
Average velocity in bridge opening 10.8 *ft/s*
Maximum WSPRO tube velocity at bridge 12.9 *ft/s*

Water-surface elevation at Approach section with bridge 500.2
Water-surface elevation at Approach section without bridge 499.2
Amount of backwater caused by bridge 1.0

Incipient overtopping discharge 911 *ft³/s*
Water-surface elevation in bridge opening 497.4 *ft*
Area of flow in bridge opening 123 *ft²*
Average velocity in bridge opening 7.4 *ft/s*
Maximum WSPRO tube velocity at bridge 10.5 *ft/s*

Water-surface elevation at Approach section with bridge 498.6
Water-surface elevation at Approach section without bridge 497.4
Amount of backwater caused by bridge 1.2 *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 each of the modelled discharges, there was orifice flow at the bridge. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). The results of Laursen's clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) were also computed and can be found in appendix F. 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 was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping. The 500-year discharge resulted in the worst case computed abutment scour.

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	1.3	4.1	0.6
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	4.9	7.0	5.2
Right abutment	6.2	6.9	5.5
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	1.7	2.3	1.2
Right abutment	1.7	2.3	1.2
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

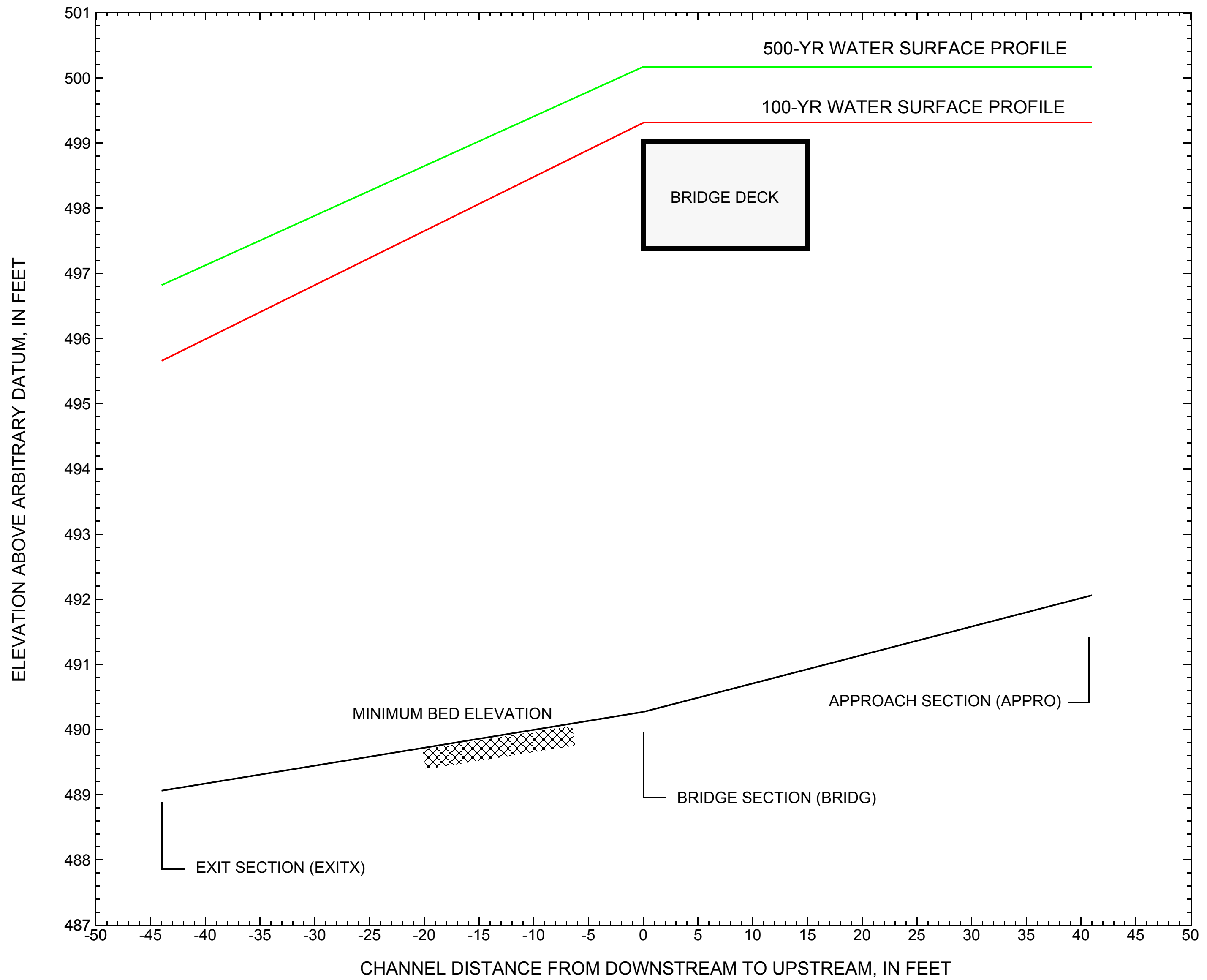

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00050036 on town highway 5, crossing Bridgewater Hollow Brook, Bridgewater, Vermont.

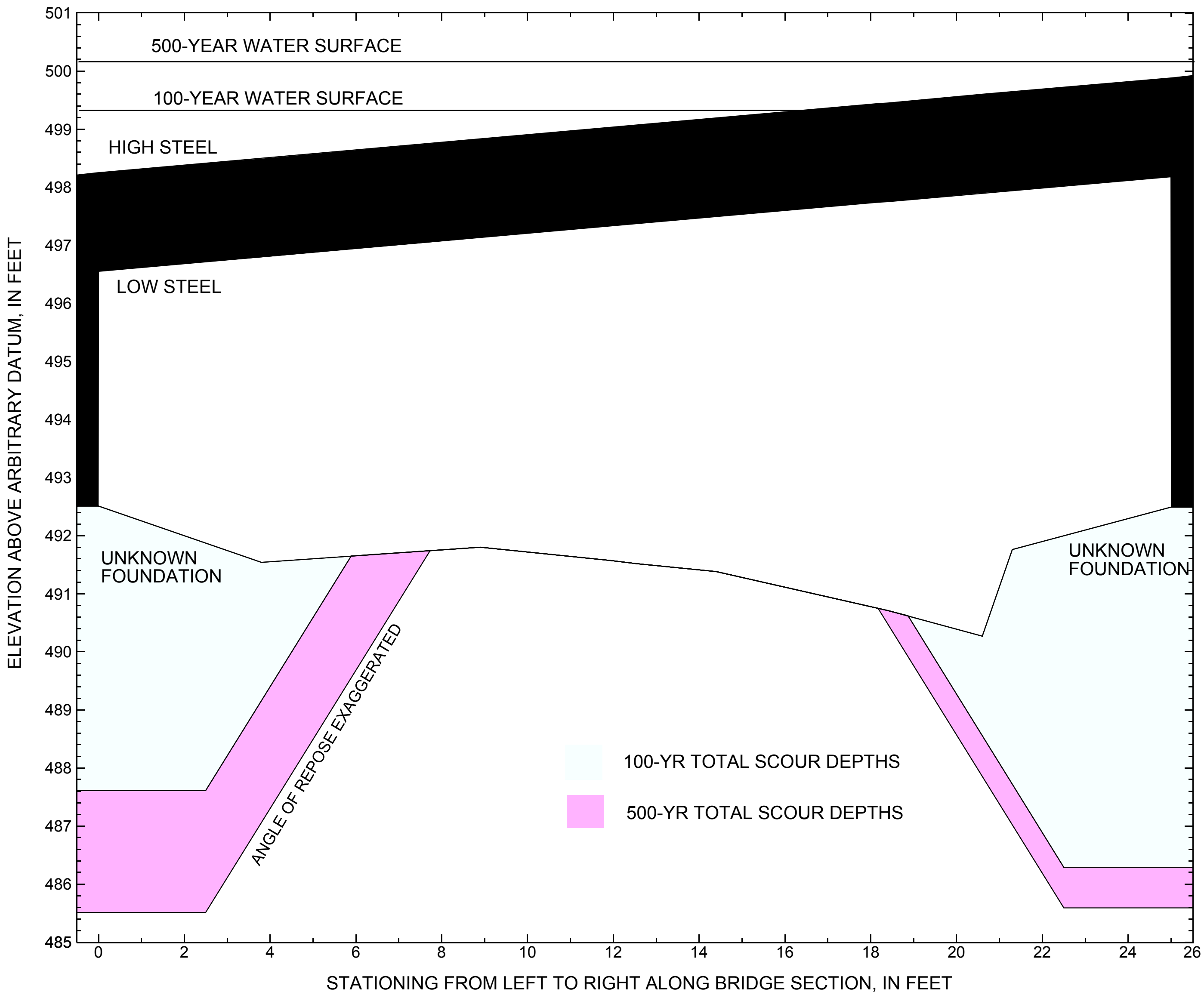

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00050036 on town highway 5, crossing Bridgewater Hollow Brook, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00050036 on Town Highway 5, crossing Bridgewater Hollow Brook, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 1,150 cubic-feet per second											
Left abutment	0.0	--	496.73	--	492.5	0.0	4.9	--	4.9	487.6	--
Right abutment	25.0	--	498.03	--	492.5	0.0	6.2	--	6.2	486.3	--

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure BRIDTH00050036 on Town Highway 5, crossing Bridgewater Hollow Brook, Bridgewater, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 1,620 cubic-feet per second											
Left abutment	0.0	--	496.73	--	492.5	0.0	7.0	--	7.0	485.5	--
Right abutment	25.0	--	498.03	--	492.5	0.0	6.9	--	6.9	485.6	--

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, Delectable Mountain, 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 brid036.wsp
T2        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
T3        HYDRAULIC ANALYSIS OF BRID036       SAO
*
J1         * * 0.005
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          1150 1620 911
SK         0.0285 0.0285 0.0285
*
XS   EXITX    -44
GR         -105.5, 505.      -88.0, 498.       -5.3, 497.16      0.0, 493.98
GR            5.9, 489.74     10.9, 489.06     18.6, 489.90     22.3, 493.30
GR           31.4, 498.32
N            0.040        0.065
SA                  -5.3
*
XS   FULLV   0 * * * 0.0262
*
BR   BRIDG   0 497.4 30
GR            0.0, 496.73      0.0, 492.51      3.8, 491.54      8.9, 491.80
GR           14.4, 491.38     18.4, 490.71     20.6, 490.27     21.3, 491.76
GR           25.0, 492.49     25.0, 498.03      0.0, 496.73
N            0.060
CD            1 30.2 * * 45 5.0
*
XR   RDWAY     8 16 2
GR           -5.0, 505        -5.0, 498.21      0.0, 498.21     27.7, 499.92
GR           30.0, 500.04     30.0, 505
*
XT   APTEM     66
GR          -70.0, 504.36    -46.6, 502.65    -23.4, 500.95     -6.0, 500.83
GR            0.0, 498.57      8.5, 494.52     10.5, 493.53     12.8, 493.41
GR           15.4, 493.62     18.3, 494.41     25.8, 497.51     34.3, 503.12
GR           41.1, 504.48     56.8, 506.28     70.0, 507.79
*
AS   APPRO     41
GT           -1.35
N            0.090        0.065
SA                  -6.0
*
HP 1 BRIDG    497.74 1 497.74
HP 2 BRIDG    497.74 * * 1079
HP 2 RDWAY    499.31 * * 74
HP 1 APPRO    499.31 1 499.31
HP 2 APPRO    499.31 * * 1150
*
HP 1 BRIDG    498.03 1 498.03
HP 2 BRIDG    498.03 * * 1359
HP 2 RDWAY    500.17 * * 261
HP 1 APPRO    500.17 1 500.17
HP 2 APPRO    500.17 * * 1620
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
       CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
       HYDRAULIC ANALYSIS OF BRID036       SAO
          *** RUN DATE & TIME: 11-30-95  14:59
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     125.    5807.     5.    49.                       3630.
  497.74          125.    5807.     5.    49.  1.00     0.    25.   3630.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      497.74     0.0    25.0   125.5    5807.    1079.   8.60
X STA.        0.0         2.7         4.3         5.7         7.1         8.5
  A(I)            10.7         7.4         6.7         6.4         6.5
  V(I)            5.03        7.27        8.00        8.38        8.27

X STA.        8.5         9.8        11.1        12.3        13.5        14.6
  A(I)             6.2         6.1         6.1         5.8         5.8
  V(I)            8.66        8.87        8.87        9.23        9.29

X STA.       14.6        15.6        16.6        17.5        18.4        19.3
  A(I)             5.6         5.6         5.3         5.4         5.2
  V(I)            9.67        9.63       10.10       10.01       10.40

X STA.       19.3        20.0        20.7        21.8        23.0        25.0
  A(I)             4.5         4.8         5.8         5.7         9.6
  V(I)           11.89       11.28        9.25        9.42        5.61

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.
        WSEL     LEW     REW    AREA        K        Q    VEL
      499.31    -5.0    17.8    15.3     260.      74.   4.84
X STA.       -5.0        -4.2        -3.6        -3.1        -2.5        -2.0
  A(I)             0.9         0.6         0.6         0.6         0.6
  V(I)            3.98        5.92        6.29        6.39        6.37

X STA.       -2.0        -1.5        -0.9        -0.4         0.1         0.7
  A(I)             0.6         0.6         0.6         0.6         0.6
  V(I)            6.40        6.42        6.40        6.13        6.08

X STA.        0.7         1.3         2.0         2.7         3.5         4.4
  A(I)             0.6         0.7         0.7         0.7         0.8
  V(I)            5.77        5.64        5.41        5.03        4.73

X STA.        4.4         5.4         6.7         8.2        10.5        17.8
  A(I)             0.8         0.9         1.0         1.2         1.7
  V(I)            4.47        4.21        3.63        3.20        2.21

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            2     151.    8506.    36.    39.                       1755.
  499.31          151.    8506.    36.    39.  1.00    -6.    31.   1755.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
        WSEL     LEW     REW    AREA        K        Q    VEL
      499.31    -5.5    30.6   151.2    8506.    1150.   7.61

X STA.       -5.5         3.1         5.5         7.1         8.4         9.5
  A(I)            14.6         9.8         8.2         7.5         7.0
  V(I)            3.93        5.87        7.00        7.66        8.16

X STA.        9.5        10.5        11.3        12.1        12.9        13.7
  A(I)             6.6         6.0         5.9         5.8         5.8
  V(I)            8.70        9.51        9.77        9.83        9.87

X STA.       13.7        14.6        15.4        16.2        17.1        18.1
  A(I)             5.8         5.7         6.1         6.0         6.3
  V(I)            9.94       10.04        9.45        9.52        9.18

X STA.       18.1        19.2        20.5        22.1        24.1        30.6
  A(I)             6.8         7.1         7.8         8.8        13.3
  V(I)            8.47        8.10        7.35        6.51        4.31
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
        HYDRAULIC ANALYSIS OF BRID036       SAO
           *** RUN DATE & TIME: 11-30-95  14:59
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     126.    5487.     0.    54.                           0.
   498.03          126.    5487.     0.    54.  1.00     0.    25.       0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.03     0.0    25.0   126.2    5487.    1359.  10.77
X STA.         0.0         2.5         4.1         5.5         6.8         8.1
  A(I)            10.2         7.0         6.4         6.1         5.9
  V(I)            6.68        9.69       10.59       11.09       11.43

X STA.         8.1         9.3        10.5        11.7        12.8        13.9
  A(I)             5.9         5.8         5.8         5.5         5.5
  V(I)           11.42       11.77       11.79       12.27       12.36

X STA.        13.9        14.9        15.9        16.8        17.7        18.6
  A(I)             5.5         5.3         5.4         5.3         5.3
  V(I)           12.39       12.76       12.69       12.88       12.70

X STA.        18.6        19.5        20.4        21.6        22.9        25.0
  A(I)             5.4         5.7         6.9         6.7        10.5
  V(I)           12.47       11.93        9.90       10.15        6.47

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.17    -5.0    30.0    40.8     998.     261.   6.39
X STA.        -5.0        -3.7        -2.8        -2.0        -1.2        -0.5
  A(I)             2.6         1.7         1.6         1.5         1.5
  V(I)            5.10        7.58        8.31        8.62        8.67

X STA.        -0.5         0.3         1.1         2.0         2.8         3.8
  A(I)             1.5         1.5         1.6         1.6         1.7
  V(I)            8.50        8.47        8.34        8.05        7.81

X STA.         3.8         4.8         5.9         7.1         8.5         9.9
  A(I)             1.7         1.8         1.9         2.0         2.1
  V(I)            7.58        7.18        7.01        6.65        6.30

X STA.         9.9        11.7        13.8        16.3        20.0        30.0
  A(I)             2.2         2.5         2.6         3.1         4.2
  V(I)            5.87        5.28        4.98        4.24        3.10

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      13.     142.    25.    25.                          54.
             2     183.   11322.    38.    41.                        2286.
   500.17          196.   11463.    63.    67.  1.11   -31.    32.    1868.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.17   -31.2    31.9   196.4   11463.    1620.   8.25
X STA.       -31.2         0.8         3.8         5.8         7.3         8.6
  A(I)            26.5        12.3        10.2         9.4         8.6
  V(I)            3.06        6.57        7.98        8.64        9.39

X STA.         8.6         9.7        10.7        11.6        12.5        13.4
  A(I)             8.2         7.6         7.4         7.1         7.2
  V(I)            9.86       10.62       10.90       11.36       11.32

X STA.        13.4        14.3        15.2        16.1        17.1        18.2
  A(I)             7.1         7.3         7.4         7.5         7.8
  V(I)           11.37       11.12       10.96       10.77       10.38

X STA.        18.2        19.4        20.8        22.5        24.8        31.9
  A(I)             8.3         8.8         9.8        11.4        16.4
  V(I)            9.79        9.16        8.27        7.12        4.93
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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
        HYDRAULIC ANALYSIS OF BRID036       SAO
           *** RUN DATE & TIME: 11-30-95  14:59
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      123.    6115.    10.    43.                       2386.
   497.40           123.    6115.    10.    43.  1.00     0.    25.   2386.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL      LEW      REW    AREA         K        Q    VEL
       497.40      0.0     25.0   122.9     6115.     911.   7.41
X STA.          0.0        2.8        4.5        6.0        7.5        9.0
  A(I)             11.2        7.8        7.2        7.1        6.9
  V(I)             4.06       5.85       6.33       6.42       6.56

X STA.          9.0       10.4       11.8       13.1       14.0       14.9
  A(I)              6.7        6.8        6.3        4.7        4.6
  V(I)             6.77       6.70       7.28       9.64       9.81

X STA.         14.9       15.7       16.5       17.3       18.1       18.8
  A(I)              4.5        4.4        4.4        4.4        4.4
  V(I)            10.15      10.24      10.47      10.29      10.31

X STA.         18.8       19.6       20.4       21.5       22.8       25.0
  A(I)              4.6        4.7        6.2        6.0        9.8
  V(I)             9.84       9.64       7.40       7.58       4.63

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2      128.    6826.    33.    36.                       1427.
   498.65           128.    6826.    33.    36.  1.00    -4.    30.   1427.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      41.
         WSEL      LEW      REW    AREA         K        Q    VEL
       498.65     -3.8     29.6   128.3     6826.     911.   7.10
X STA.         -3.8        4.0        6.1        7.6        8.8        9.8
  A(I)             12.3        8.2        7.0        6.4        5.9
  V(I)             3.70       5.55       6.51       7.12       7.73

X STA.          9.8       10.7       11.5       12.3       13.0       13.8
  A(I)              5.4        5.1        5.1        4.9        4.9
  V(I)             8.37       8.87       8.90       9.28       9.32

X STA.         13.8       14.5       15.3       16.1       17.0       17.9
  A(I)              5.0        5.0        5.1        5.2        5.3
  V(I)             9.11       9.20       8.95       8.82       8.52

X STA.         17.9       18.9       20.1       21.6       23.6       29.6
  A(I)              5.8        6.1        6.7        7.6       11.3
  V(I)             7.83       7.51       6.84       5.97       4.05

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
        HYDRAULIC ANALYSIS OF BRID036       SAO
           *** RUN DATE & TIME: 11-30-95  14:59

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

EXITX:XS   ******    -3.      124.  1.34 *****  497.00  494.94   1150.  495.66
      -44. ******    27.     6810.  1.00 ***** *******    0.80    9.30

FULLV:FV      44.    -3.      128.  1.26  1.20  498.21 *******   1150.  496.95
        0.    44.    27.     7116.  1.00  0.00    0.01    0.77    9.00
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80     0.98     498.09     498.02

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   496.45     506.44    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   496.45     506.44     498.02

APPRO:AS      41.    -2.      111.  1.68  1.36  499.78  498.02   1150.  498.10
       41.    41.    29.     5596.  1.00  0.21    0.00    0.97   10.40
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
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WSPRO OUTPUT FILE (continued)

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 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   496.82     497.74     498.18     497.40

 ===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      44.     0.     126.  1.15 *****  498.89  495.81   1079.  497.74
        0. ******    25.    5802.  1.00 ***** *******    0.68    8.59

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.478  0.000  497.40 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      8.    25.  0.46  0.90  499.75    0.00     74.  499.31

           Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:     74.    19.    -5.    14.   1.1   0.8   4.8   5.0   1.2   2.9
   RT:      0.    16.    14.    30.   2.4   1.9   7.1   6.3   2.5   3.0

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

APPRO:AS      11.    -6.     151.  0.90  0.30  500.21  498.02   1150.  499.31
       41.    12.    31.    8497.  1.00  0.96    0.00    0.66    7.61

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

  FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -44.    -3.    27.   1150.    6810.    124.    9.30  495.66
   FULLV:FV       0.    -3.    27.   1150.    7116.    128.    9.00  496.95
   BRIDG:BR       0.     0.    25.   1079.    5802.    126.    8.59  497.74
   RDWAY:RG       8.*******    74.     74.       0.      0.    2.00  499.31
   APPRO:AS      41.    -6.    31.   1150.    8497.    151.    7.61  499.31

 SECOND USER DEFINED TABLE.
   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
   EXITX:XS    494.94    0.80  489.06  505.00************  1.34  497.00  495.66
   FULLV:FV  ********    0.77  490.21  506.15  1.20  0.00  1.26  498.21  496.95
   BRIDG:BR    495.81    0.68  490.27  498.03************  1.15  498.89  497.74
   RDWAY:RG  ****************  498.21  505.00  0.46******  0.90  499.75  499.31
   APPRO:AS    498.02    0.66  492.06  506.44  0.30  0.96  0.90  500.21  499.31

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
        HYDRAULIC ANALYSIS OF BRID036        SAO
           *** RUN DATE & TIME: 11-30-95  14:59

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

EXITX:XS   ******    -5.     160.  1.59 *****  498.41  496.07   1620.  496.82
      -44. ******    29.    9595.  1.00 ***** *******    0.81   10.12

FULLV:FV      44.    -5.     165.  1.49  1.20  499.62 *******   1620.  498.13
        0.    44.    29.   10010.  1.00  0.00    0.01    0.78    9.80
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80     0.95     499.23     499.04

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   497.63     506.44    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   497.63     506.44     499.04

APPRO:AS      41.    -5.     149.  1.85  1.29  501.09  499.04   1620.  499.24
       41.    41.    30.    8313.  1.00  0.18    0.00    0.94   10.90
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
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 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   498.13     497.40

            <<<<<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      44.     0.     126.  1.80 *****  499.83  496.52   1359.  498.03
        0. ******    25.    5487.  1.00 ***** *******    0.84   10.77

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  497.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.    25.  0.50  1.17  500.84    0.00    261.  500.17

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    198.    19.    -5.    14.   2.0   1.6   6.8   6.4   2.3   3.0
   RT:     63.    14.    14.    28.   1.1   0.7   5.0   6.7   1.4   2.9

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

APPRO:AS      11.   -31.     196.  1.17  0.40  501.34  499.04   1620.  500.17
       41.    11.    32.   11472.  1.11  0.96    0.00    0.87    8.24

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -44.    -5.    29.   1620.    9595.     160.   10.12  496.82
   FULLV:FV      0.     -5.    29.   1620.   10010.     165.    9.80  498.13
   BRIDG:BR      0.      0.    25.   1359.    5487.     126.   10.77  498.03
   RDWAY:RG      8.*******   198.    261.       0.       0.    2.00  500.17
   APPRO:AS      41.   -31.    32.   1620.   11472.     196.    8.24  500.17

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    496.07    0.81  489.06  505.00************  1.59  498.41  496.82
   FULLV:FV  ********    0.78  490.21  506.15  1.20  0.00  1.49  499.62  498.13
   BRIDG:BR    496.52    0.84  490.27  498.03************  1.80  499.83  498.03
   RDWAY:RG  ****************  498.21  505.00  0.50******  1.17  500.84  500.17
   APPRO:AS    499.04    0.87  492.06  506.44  0.40  0.96  1.17  501.34  500.17

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid036.wsp
        CREATED ON 27-SEP-95 FOR BRIDGE BRIDTH00050036 USING FILE brid036.dca
        HYDRAULIC ANALYSIS OF BRID036       SAO
           *** RUN DATE & TIME: 11-30-95  14:59

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

EXITX:XS   ******    -2.     104.  1.20 *****  496.15  494.25    911.  494.95
      -44. ******    25.    5395.  1.00 ***** *******    0.79    8.78

FULLV:FV      44.    -2.     107.  1.12  1.20  497.36 *******    911.  496.24
        0.    44.    26.    5643.  1.00  0.00    0.01    0.76    8.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.00     497.42     497.40

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   495.74     506.44    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   495.74     506.44     497.40

APPRO:AS      41.     0.      90.  1.60  1.42  499.00  497.40    911.  497.40
       41.    41.    28.    4237.  1.00  0.24   -0.02    1.00   10.14
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
```
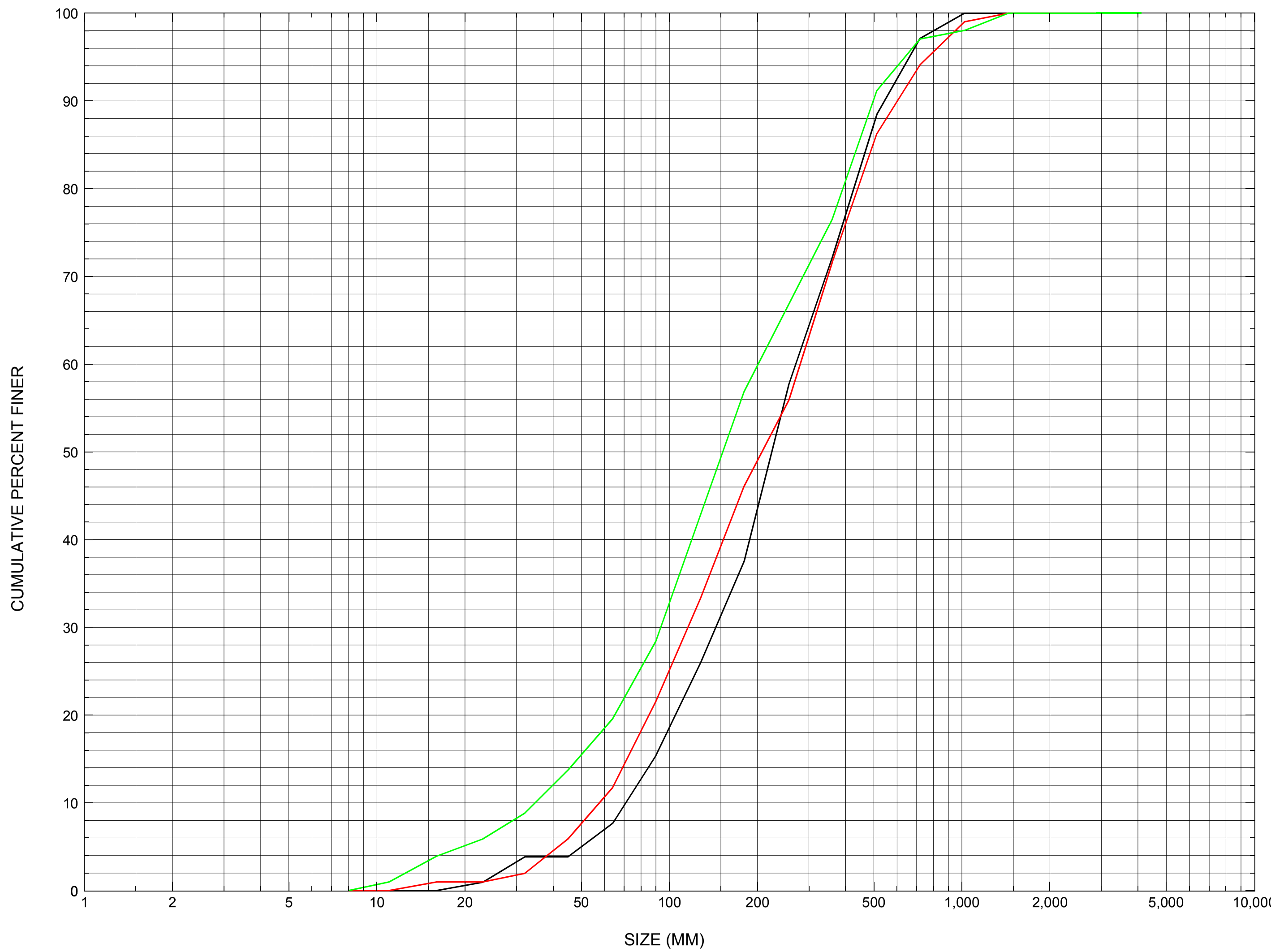

```
===230 REJECTED FLOW CLASS 1 SOLUTION.
            WS1,WSSD,WS3 =   497.40       0.00     496.57
                    CRWS =   497.40   ********     495.35
                    YMAX =   506.44   ********     498.03

===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                 WS,QBO,QRD =   503.10         0.       911.

===280 REJECTED FLOW CLASS 4 SOLUTION.

===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      44.     0.     123.  0.85 *****  498.25  495.35    907.  497.40
        0. ******    25.    6115.  1.00 ***** *******    0.59    7.38

    TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
      1. ****   2.  0.447  0.000  497.40 ****** ****** ******

   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      11.    -4.     128.  0.78  0.25  499.44  497.40    911.  498.65
       41.    13.    30.    6835.  1.00  0.00    0.00    0.64    7.10

      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
    ****** ****** ******** ****** ******   498.21

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

 FIRST USER DEFINED TABLE.
   XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
  EXITX:XS     -44.    -2.    25.    911.    5395.     104.    8.78  494.95
  FULLV:FV       0.    -2.    26.    911.    5643.     107.    8.49  496.24
  BRIDG:BR       0.     0.    25.    907.    6115.     123.    7.38  497.40
  RDWAY:RG       8.**************      0.       0.       0.    2.00********
  APPRO:AS      41.    -4.    30.    911.    6835.     128.    7.10  498.65

SECOND USER DEFINED TABLE.
   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
  EXITX:XS    494.25    0.79  489.06  505.00************  1.20  496.15  494.95
  FULLV:FV  ********    0.76  490.21  506.15  1.20  0.00  1.12  497.36  496.24
  BRIDG:BR    495.35    0.59  490.27  498.03************  0.85  498.25  497.40
  RDWAY:RG  ****************  498.21  505.00************  0.78  498.99********
  APPRO:AS    497.40    0.64  492.06  506.44  0.25  0.00  0.78  499.44  498.65
```

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 BRIDTH00050036, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM