LEVEL II SCOUR ANALYSIS FOR BRIDGE 35 (BETHTH00190035) on TOWN HIGHWAY 19, crossing GILEAD BROOK, BETHEL, VERMONT

U.S. Geological Survey
Open-File Report 96-239

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

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By MICHAEL A. IVANOFF and DONALD L. SONG

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Pembroke, New Hampshire
1996

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

U.S. GEOLOGICAL SURVEY
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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 35 (BETHTH00190035) ON TOWN HIGHWAY 19, CROSSING GILEAD BROOK, BETHEL, VERMONT

By **Michael A. Ivanoff and Donald L. Song**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BETHTH00190035 on town highway 19 crossing Gilead Brook, Bethel, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Bethel. The 6.40-mi^2 drainage area is predominantly rural and forested. In the vicinity of the study site, the immediate banks have woody vegetation coverage with pasture beyond.

In the study area, Gilead Brook is an incised, sinuous channel with a slope of approximately 0.015 ft/ft, an average channel top width of 31 ft and an average channel depth of 2.5 ft. The predominant channel bed material is gravel and cobble (D_{50} is 62.5 mm or 0.205 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 20, 1994, indicated that the reach was stable.

The town highway 19 crossing of Gilead Brook is a 30-ft-long, one-lane bridge consisting of one 24-foot steel-beam span with timber deck (Vermont Agency of Transportation, written commun., August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 5 degrees to the opening while the opening-skew-to-roadway is 10 degrees.

The scour protection measures at the site included type-1 stone fill (less than 12 inches diameter) at the downstream wingwalls, left abutment, and upstream right road embankment; type-2 stone fill (less than 36 inches diameter) is at 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 streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.1 to 2.1 ft. with the worst-case scenario occurring at the 500-year discharge. Abutment scour ranged from 3.9 to 9.5 ft. 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. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

Randolph, VT. Quadrangle, 1:24,000, 1981

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 BETHTH00190035 ***Stream*** Gilead Brook

County Windsor ***Road*** TH019 ***District*** 04

Description of Bridge

Bridge length 30 ***ft*** ***Bridge width*** 16.1 ***ft*** ***Max span length*** 24 ***ft***

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

Abutment type Vertical ***Embankment type*** N/A

Stone fill on abutment? No ***Date of inspection*** 10/20/94

Description of stone fill Type-1, at the downstream wingwalls, left abutment, and upstream right road embankment; type-2 stone fill at the upstream right wingwall

Brief description of piers/abutments Concrete abutments and wingwalls. The right abutment footing is noted as having 0.25 feet exposed at the upstream end.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 5

There is a slight channel bend into the upstream bridge face impacting the right abutment. 10/20/94

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

	Date of inspection	***Percent of channel blocked horizontally***	***Percent of channel blocked vertically***
Level I	10/20/94	0	0
Level II	--	--	--

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) 10/20/94 - Point bar noted 85 feet upstream of the bridge with 85% covered by vegetation in the form of grass and seedlings.

Description of the Geomorphic Setting

General topography The channel has a flat narrow flood plain with steep valley walls on both sides.

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

Date of inspection 10/20/94

DS left: Moderate channel bank slope to a flood plain

DS right: Moderate channel bank slope to a flood plain

US left: Moderate channel bank slope to a flood plain

US right: Moderate channel bank slope to valley wall

Description of the Channel

Average top width 31 ***ft*** ***Average depth*** 2.5 ***ft***

Predominant bed material Gravel ***Bank materia*** Gravel

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

10/18/95

Vegetative co Trees on the immediate bank with pasture on overbank

DS left: Trees on the immediate bank with pasture on overbank

DS right: Trees on the immediate bank with pasture on overbank

US left: Trees.

US right:

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

10/20/94 -- Assessed as stable, however moderate fluvial erosion on the upstream right bank and light fluvial erosion on the upstream left bank. Cut banks on the upstream and downstream right banks.

None

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 6.40 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
Green Mountain	100

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

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

USGS gage description

USGS gage number

Gage drainage area ***mi²***

Is there a lake/ No

Calculated Discharges

Q100 1,650 ***ft³/s*** ***Q500*** 2,200 ***ft³/s***

The 100- and 500-year discharges were extrapolated from flood frequency data available for this site in VTAOT files (VTAOT, written commun, May 1995). The discharges were in an acceptable range defined by discharges determined from empirical methods (FHWA, 1983; Johnson and Tasker, 1974; Potter, 1957a & b; 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 No

Description of reference marks used to determine USGS datum. RM1 is a chiseled X at the downstream end of the right abutment (elev. 498.56 ft, arbitrary datum). RM2 is a chiseled square on top of the upstream end of the right abutment (elev. 498.56 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-26	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	52	1	Modelled Approach section

[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 0.034 to 0.068, and overbank "n" values ranged from 0.035 to 0.080.

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 0.0150 ft/ft determined from surveyed thalweg points downstream of the bridge.

The 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 1170 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.9 *ft*
Average low steel elevation 497.3 *ft*

100-year discharge 1,650 *ft³/s*
Water-surface elevation in bridge opening 497.5 *ft*
Road overtopping? Y *Discharge over road* 170 *ft³/s*
Area of flow in bridge opening 137 *ft²*
Average velocity in bridge opening 10.7 *ft/s*
Maximum WSPRO tube velocity at bridge 12.4 *ft/s*

Water-surface elevation at Approach section with bridge 500.3
Water-surface elevation at Approach section without bridge 498.2
Amount of backwater caused by bridge 2.1 *ft*

500-year discharge 2,200 *ft³/s*
Water-surface elevation in bridge opening 497.5 *ft*
Road overtopping? Y *Discharge over road* 629 *ft³/s*
Area of flow in bridge opening 137 *ft²*
Average velocity in bridge opening 11.5 *ft/s*
Maximum WSPRO tube velocity at bridge 13.3 *ft/s*

Water-surface elevation at Approach section with bridge 501.2
Water-surface elevation at Approach section without bridge 498.6
Amount of backwater caused by bridge 2.6

Incipient overtopping discharge 1,170 *ft³/s*
Water-surface elevation in bridge opening 497.5 *ft*
Area of flow in bridge opening 137 *ft²*
Average velocity in bridge opening 8.5 *ft/s*
Maximum WSPRO tube velocity at bridge 9.8 *ft/s*

Water-surface elevation at Approach section with bridge 499.3
Water-surface elevation at Approach section without bridge 497.8
Amount of backwater caused by bridge 1.5 *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, 500-year, and incipient road-overflow discharges. 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 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, 1995, p. 32, equation 20) 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 HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the length to depth ratio of the embankment blocking flow exceeded 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	1.7	2.1	0.1
Depth to armoring	7.6	11.8	2.2
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour	7.1	9.5	3.9
Left abutment	7.3	7.0	7.5
Right abutment			
Pier scour	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3			

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:	2.2	2.4	1.4
Left abutment	2.2	2.4	1.4
Right abutment	--	--	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2			

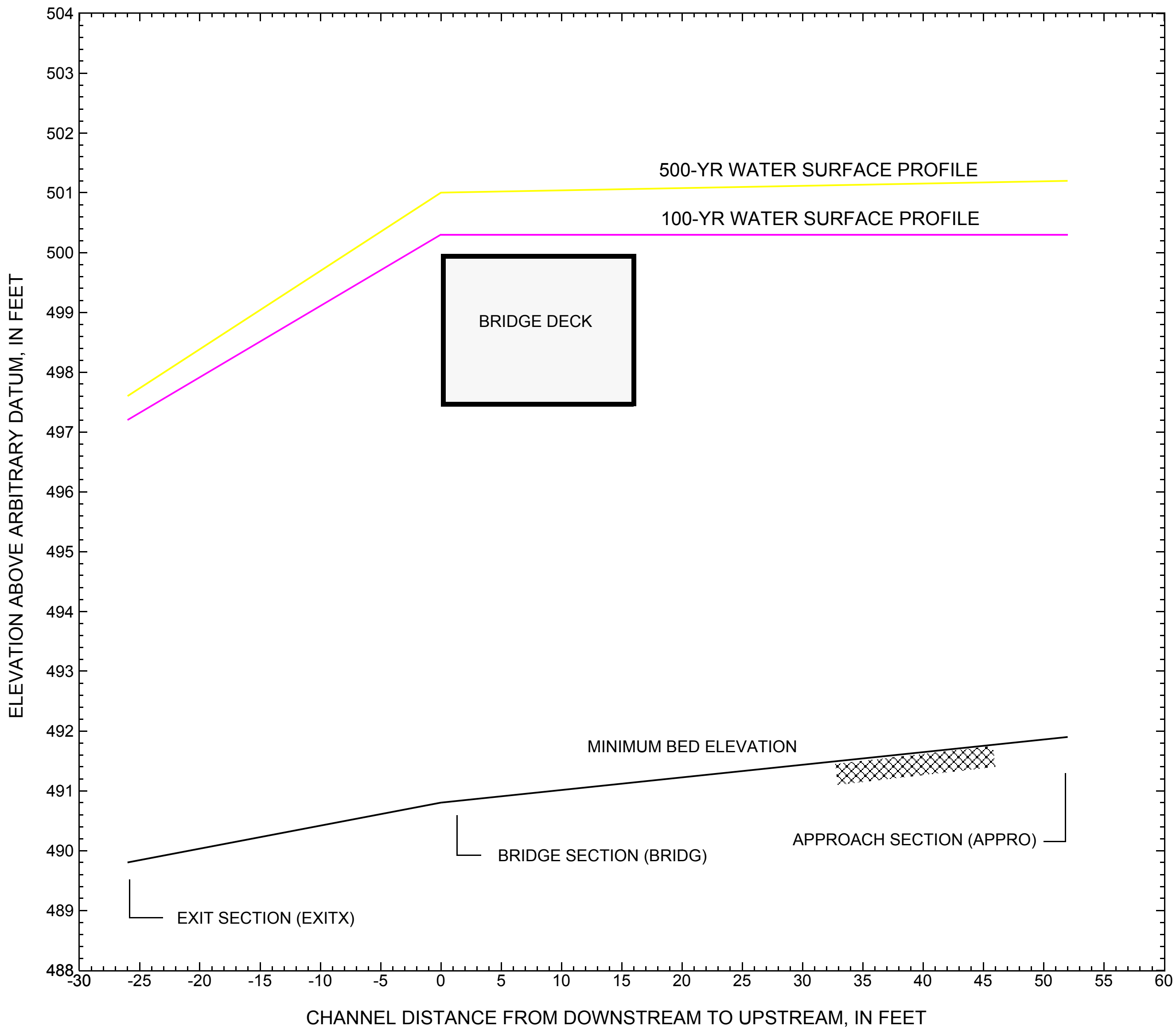

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BETHTH00190035 on town highway 19, crossing Gilead Brook, Bethel, Vermont.

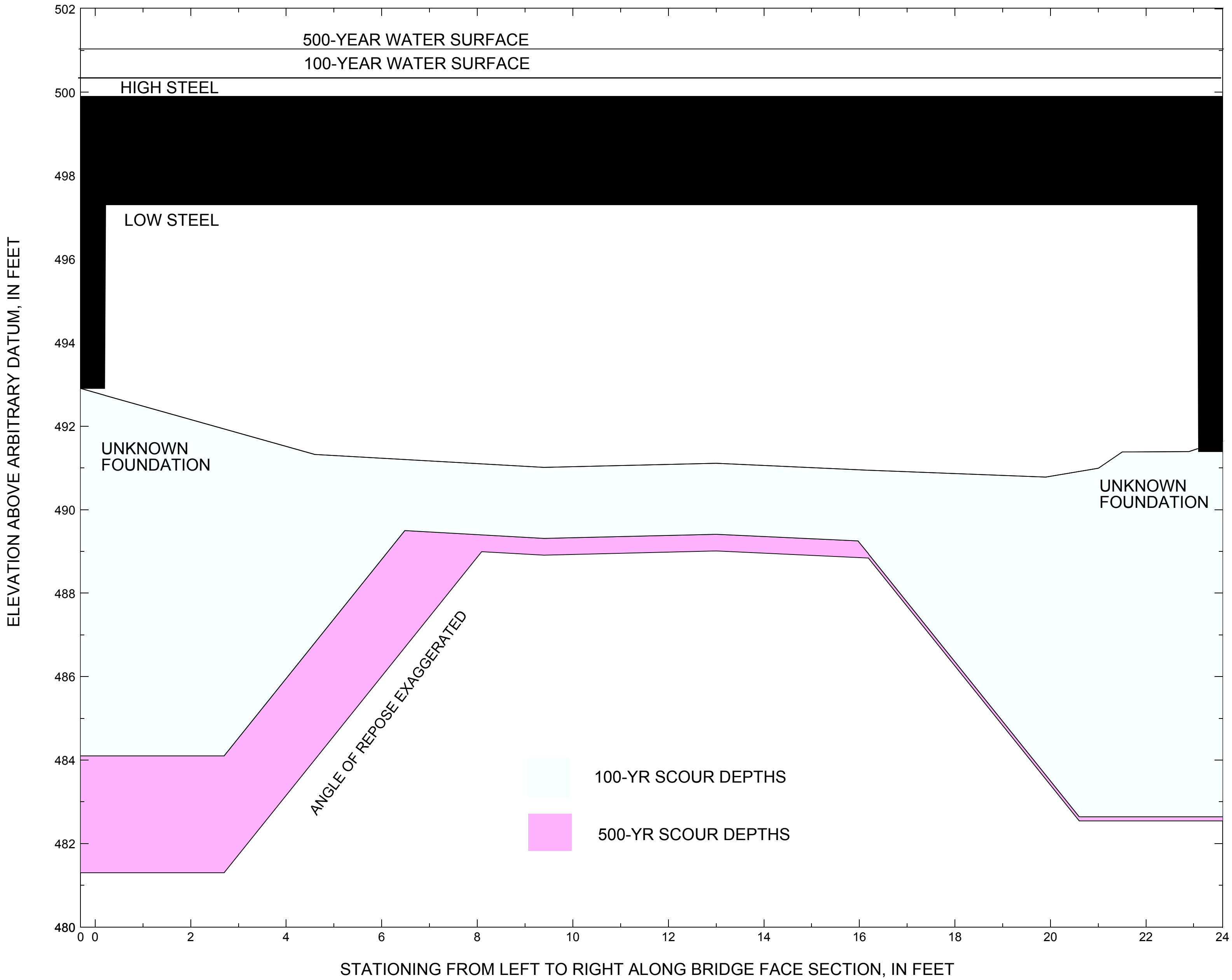

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BETHTH00190035 on town highway 19, crossing Gilead Brook, Bethel, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BETHTH00190035 on Town Highway 19, crossing Gilead Brook, Bethel, 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 1,650 cubic-feet per second											
Left abutment	0.0	--	497.5	--	492.9	1.7	7.1	--	8.8	484.1	--
Right abutment	23.1	--	497.2	--	491.6	1.7	7.3	--	9.0	482.6	--

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 BETHTH00190035 on Town Highway 19, crossing Gilead Brook, Bethel, 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 2,200 cubic-feet per second											
Left abutment	0.0	--	497.5	--	492.9	2.1	9.5	--	11.6	481.3	--
Right abutment	23.1	--	497.2	--	491.6	2.1	7.0	--	9.1	482.5	--

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, 1981, Randolph, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

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T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE beth035.wsp
T2        CREATED ON 07-DEC-95 FOR BRIDGE BETHTH00190035 USING FILE beth035.dca
T3        Hydraulic analysis for Bethel bridge 35 by MAI
*
Q          1650       2200   1170
SK         0.015    0.015   0.015
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX     -26
*
GR         -252.4, 516.20   -211.1, 506.29   -173.4, 503.80   -112.4, 504.45
GR          -76.3, 504.44    -55.3, 502.01    -23.1, 496.87     -3.4, 496.80
GR            0.0, 493.92      2.9, 491.28      2.9, 491.27      5.1, 490.73
GR            6.3, 489.93      8.1, 489.78     13.6, 490.47     18.7, 490.77
GR           19.5, 491.24     22.9, 493.49     24.8, 495.36     43.9, 495.87
GR           82.3, 496.21    111.9, 496.94    123.5, 497.68    195.1, 506.88
N           0.035        0.068        0.035
SA                  -3.4         24.8
*
XS   FULLV      0  * * *   0.015
*
BR   BRIDG   0     497.3   10
*
GR            0.0, 497.50      0.2, 492.90      4.6, 491.32      9.4, 491.01
GR           13.0, 491.11     16.2, 490.94     19.9, 490.78     21.0, 490.99
GR           21.5, 491.38     22.9, 491.39     23.1, 491.64     23.1, 497.17
GR            0.0, 497.50
CD         1   26.7   *  *  40  8
N           0.034
*
XR   RDWAY      8      16.1   2
*
GR         -247.0, 512.80   -159.8, 506.81    -78.9, 502.95    -18.6, 500.17
GR            0.0, 499.89     25.3, 499.90     65.6, 499.20    133.1, 503.23
*
AS   APPRO      52
*
GR         -139.8, 506.16   -119.1, 499.04    -72.3, 498.70    -40.9, 499.76
GR          -28.1, 500.09    -17.9, 498.92    -15.7, 498.91    -11.7, 495.92
GR           -9.0, 493.39      0.0, 493.46      6.6, 492.88     11.1, 492.58
GR           15.7, 492.81     18.4, 491.93     20.5, 492.84     20.7, 492.74
GR           27.3, 494.98     30.4, 497.06     49.8, 497.60     77.1, 499.88
GR          101.1, 503.23    143.0, 506.88
N           0.035        0.080        0.060        0.080
SA                 -40.9         -17.9        30.4
*
HP 1 BRIDG   497.50 1 497.50
HP 2 BRIDG   497.50 * * 1471
HP 2 RDWAY   500.25 * * 170
HP 1 APPRO   500.34 1 500.34
HP 2 APPRO   500.34 * * 1650
*
HP 1 BRIDG   497.50 1 497.50
HP 2 BRIDG   497.50 * * 1579
HP 2 RDWAY   500.96 * * 629
HP 1 APPRO   501.19 1 501.19
HP 2 APPRO   501.19 * * 2200
*
HP 1 BRIDG   497.50 1 497.50
HP 2 BRIDG   497.50 * * 1170
HP 1 APPRO   499.25 1 499.25
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE beth035.wsp
       CREATED ON 07-DEC-95 FOR BRIDGE BETHTH00190035 USING FILE beth035.dca
       Hydraulic analysis for Bethel bridge 35 by MAI
          *** RUN DATE & TIME: 12-14-95  14:10
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     137.   10941.     0.    56.                          0.
  497.50          137.   10941.     0.    56.  1.00     0.    23.      0.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      497.50     0.0    23.1   137.3   10941.    1471.  10.71

X STA.         0.0        2.4        3.8        4.9        6.0        7.0
  A(I)            11.4        7.6        6.8        6.6        6.2
  V(I)            6.47       9.70      10.84      11.10      11.86

X STA.         7.0        8.1        9.0       10.0       11.0       11.9
  A(I)             6.2        6.0        6.1        6.0        6.0
  V(I)           11.79      12.22      12.06      12.27      12.35

X STA.        11.9       12.9       13.9       14.9       15.9       16.8
  A(I)             6.0        6.0        6.1        6.1        6.1
  V(I)           12.26      12.28      12.07      12.09      12.08

X STA.        16.8       17.8       18.9       19.9       21.1       23.1
  A(I)             6.2        6.5        6.7        7.3       11.5
  V(I)           11.86      11.38      10.98      10.02       6.40

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.
        WSEL     LEW     REW    AREA        K        Q    VEL
      500.25   -20.3    83.2    50.6    1344.     170.   3.36

X STA.       -20.3        3.5       20.9       30.7       36.2       40.2
  A(I)             5.4        6.2        3.7        2.7        2.3
  V(I)            1.57       1.38       2.30       3.17       3.66

X STA.        40.2       43.7       46.7       49.4       51.8       54.0
  A(I)             2.2        2.1        2.0        1.9        1.8
  V(I)            3.85       4.09       4.22       4.42       4.61

X STA.        54.0       56.1       58.1       59.9       61.8       63.5
  A(I)             1.8        1.8        1.7        1.8        1.7
  V(I)            4.67       4.77       4.90       4.84       4.89

X STA.        63.5       65.2       67.0       69.3       72.5       83.2
  A(I)             1.8        1.9        2.0        2.3        3.4
  V(I)            4.85       4.57       4.18       3.65       2.48

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      52.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     106.    5354.    82.    82.                        685.
            2      14.     183.    23.    23.                         61.
            3     305.   24739.    48.    52.                       4350.
            4     103.    3092.    50.    50.                        837.
  500.34          528.   33368.   203.   207.  1.34  -123.    80.   4164.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      52.
        WSEL     LEW     REW    AREA        K        Q    VEL
      500.34  -122.9    80.4   527.8   33368.    1650.   3.13

X STA.      -122.9      -96.4      -77.3      -54.7       -9.3       -6.0
  A(I)            33.9       29.3       31.7       53.3       22.4
  V(I)            2.43       2.82       2.60       1.55       3.68

X STA.        -6.0       -3.1       -0.2        2.6        5.2        7.6
  A(I)            20.7       19.6       19.7       18.7       18.1
  V(I)            3.98       4.21       4.18       4.40       4.55

X STA.         7.6       10.0       12.3       14.7       17.0       19.2
  A(I)            18.0       17.7       18.0       17.9       17.7
  V(I)            4.58       4.66       4.58       4.61       4.66

X STA.        19.2       21.7       24.6       29.1       42.9       80.4
  A(I)            19.3       19.7       24.4       43.5       64.1
  V(I)            4.29       4.18       3.38       1.89       1.29
```

WSPRO OUTPUT FILE (continued)

```
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     137.   10941.     0.    56.                          0.
   497.50          137.   10941.     0.    56.  1.00     0.    23.      0.
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.50     0.0    23.1   137.3   10941.    1579.  11.50

X STA.         0.0        2.4        3.8        4.9        6.0        7.0
  A(I)            11.4        7.6        6.8        6.6        6.2
  V(I)            6.95      10.41      11.64      11.92      12.73

X STA.         7.0        8.1        9.0       10.0       11.0       11.9
  A(I)             6.2        6.0        6.1        6.0        6.0
  V(I)           12.66      13.11      12.95      13.17      13.26

X STA.        11.9       12.9       13.9       14.9       15.9       16.8
  A(I)             6.0        6.0        6.1        6.1        6.1
  V(I)           13.17      13.18      12.95      12.97      12.96

X STA.        16.8       17.8       18.9       19.9       21.1       23.1
  A(I)             6.2        6.5        6.7        7.3       11.5
  V(I)           12.73      12.21      11.78      10.76       6.87

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.96   -35.7    95.1   133.8    5297.     629.   4.70

X STA.       -35.7      -14.5       -6.4        2.9       13.8       24.5
  A(I)            10.1        7.4        9.6       11.6       11.4
  V(I)            3.11       4.26       3.26       2.70       2.76

X STA.        24.5       30.0       34.8       39.0       42.9       46.5
  A(I)             6.0        5.6        5.3        5.2        5.0
  V(I)            5.23       5.58       5.92       6.01       6.30

X STA.        46.5       49.9       53.1       56.1       59.1       62.0
  A(I)             5.0        4.9        4.7        4.8        4.9
  V(I)            6.30       6.45       6.64       6.56       6.46
X STA.        62.0       64.9       67.9       71.6       76.9       95.1
  A(I)             5.0        5.1        5.6        6.5        9.9
  V(I)            6.35       6.12       5.57       4.84       3.17

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      52.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     177.   12285.    84.    85.                       1452.
             2      33.     795.    23.    23.                        228.
             3     346.   30533.    48.    52.                       5257.
             4     148.    5247.    56.    56.                       1363.
   501.19          704.   48860.   212.   216.  1.29  -125.    86.   6409.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      52.

         WSEL     LEW     REW    AREA        K        Q    VEL
       501.19  -125.4    86.5   704.2   48860.    2200.   3.12

X STA.      -125.4     -104.6      -90.1      -76.8      -63.2      -42.1
  A(I)            38.7       33.4       32.0       32.5       38.5
  V(I)            2.84       3.29       3.44       3.39       2.85

X STA.       -42.1       -9.4       -5.7       -2.2        1.2        4.4
  A(I)            69.6       29.3       26.7       26.3       25.4
  V(I)            1.58       3.76       4.12       4.19       4.33

X STA.         4.4        7.4       10.3       13.1       15.9       18.7
  A(I)            24.8       24.6       23.9       24.0       24.9
  V(I)            4.44       4.46       4.60       4.58       4.41

X STA.        18.7       21.7       25.3       32.6       47.3       86.5
  A(I)            25.5       27.0       38.0       57.1       81.9
  V(I)            4.31       4.07       2.89       1.93       1.34
```

WSPRO OUTPUT FILE (continued)

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

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     137.   10941.     0.    56.                          0.
   497.50          137.   10941.     0.    56.  1.00     0.    23.      0.
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       497.50     0.0    23.1   137.3   10941.    1170.   8.52

X STA.         0.0        2.4        3.8        4.9        6.0        7.0
  A(I)            11.4        7.6        6.8        6.6        6.2
  V(I)            5.15       7.72       8.63       8.83       9.43

X STA.         7.0        8.1        9.0       10.0       11.0       11.9
  A(I)             6.2        6.0        6.1        6.0        6.0
  V(I)            9.38       9.72       9.59       9.76       9.82

X STA.        11.9       12.9       13.9       14.9       15.9       16.8
  A(I)             6.0        6.0        6.1        6.1        6.1
  V(I)            9.76       9.77       9.60       9.61       9.60

X STA.        16.8       17.8       18.9       19.9       21.1       23.1
  A(I)             6.2        6.5        6.7        7.3       11.5
  V(I)            9.43       9.05       8.73       7.97       5.09

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      52.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      22.     472.    64.    64.                         75.
             2       0.       3.     3.     3.                          1.
             3     252.   18040.    48.    52.                       3274.
             4      54.    1227.    39.    39.                        355.
   499.25          329.   19742.   154.   158.  1.31  -120.    70.   2384.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      52.

         WSEL     LEW     REW    AREA        K        Q    VEL
       499.25  -119.7    69.6   328.8   19742.    1170.   3.56

X STA.      -119.7       -9.7       -6.7       -4.2       -1.8        0.6
  A(I)            39.3       17.3       14.9       14.0       13.6
  V(I)            1.49       3.38       3.92       4.18       4.30

X STA.         0.6        2.8        4.9        6.8        8.7       10.5
  A(I)            12.9       13.0       12.2       12.1       11.9
  V(I)            4.54       4.51       4.80       4.84       4.90

X STA.        10.5       12.3       14.0       15.9       17.6       19.3
  A(I)            11.8       11.6       12.0       11.7       11.8
  V(I)            4.97       5.03       4.86       4.99       4.97

X STA.        19.3       21.2       23.4       26.2       34.5       69.6
  A(I)            12.7       13.2       14.4       23.4       44.8
  V(I)            4.62       4.42       4.05       2.50       1.31
```

WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******   -25.     250.  0.75 *****  497.92  497.11   1650.  497.17
      -26. ******   115.   13462.  1.11 ***** *******    0.92    6.59

 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.90     497.58     497.50

 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   496.67     516.59    0.50

 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   496.67     516.59     497.50

FULLV:FV      26.   -25.     253.  0.73  0.38  498.31  497.50   1650.  497.58
        0.    26.   116.   13664.  1.11  0.00    0.01    0.90    6.51
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      52.   -15.     226.  0.94  0.76  499.18 *******   1650.  498.25
       52.    52.    58.   13714.  1.13  0.10    0.01    0.77    7.30
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   497.58     497.30

            <<<<<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      26.     0.     137.  1.79 *****  499.29  496.36   1471.  497.50
        0. ******    23.   10941.  1.00 ***** *******    0.77   10.72
TYPE PPCD FLOW      C     P/A     LSEL    BLEN    XLAB    XRAB
      1. ****    6.  0.800  0.000  497.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.    36.  0.09  0.20  500.46    0.00    170.  500.25

            Q    WLEN    LEW     REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:     28.    32.   -20.     12.   0.4   0.3   2.8   3.4   0.5   2.7
   RT:    143.    71.    12.     83.   1.0   0.6   3.8   3.4   0.8   2.8

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

APPRO:AS      25.  -123.     528.  0.20  0.18  500.54  497.09   1650.  500.34
       52.    27.    80.   33353.  1.34  0.00    0.00    0.40    3.13

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   EXITX:XS     -26.   -25.   115.   1650.   13462.     250.    6.59  497.17
   FULLV:FV       0.   -25.   116.   1650.   13664.     253.    6.51  497.58
   BRIDG:BR       0.     0.    23.   1471.   10941.     137.   10.72  497.50
   RDWAY:RG       8.*******    28.    170.       0.*********    2.00  500.25
   APPRO:AS      52.  -123.    80.   1650.   33353.     528.    3.13  500.34

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    497.11    0.92  489.78  516.20************  0.75  497.92  497.17
   FULLV:FV    497.50    0.90  490.17  516.59  0.38  0.00  0.73  498.31  497.58
   BRIDG:BR    496.36    0.77  490.78  497.50************  1.79  499.29  497.50
   RDWAY:RG  ***************  499.20  512.80  0.09******  0.20  500.46  500.25
   APPRO:AS    497.09    0.40  491.93  506.88  0.18  0.00  0.20  500.54  500.34
```

WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******   -28.     311.  0.83 *****  498.41  497.50   2200.  497.58
      -26. ******   122.   17950.  1.06 ***** *******    0.89    7.08

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.89     497.99     497.89

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   497.08     516.59    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   497.08     516.59     497.89

FULLV:FV      26.   -28.     315.  0.80  0.38  498.81  497.89   2200.  498.00
        0.    26.   122.   18305.  1.06  0.00    0.01    0.87    6.98
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.92     498.60     498.10

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   497.50     506.88    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   497.50     506.88     498.10

APPRO:AS      52.   -15.     252.  1.38  0.88  499.98  498.10   2200.  498.60
       52.    52.    62.   15625.  1.16  0.29    0.00    0.92    8.72
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                      WS3N,LSEL =   498.00     497.30

            <<<<<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      26.     0.     137.  2.06 *****  499.56  496.60   1579.  497.50
        0. ******    23.   10941.  1.00 ***** *******    0.83   11.50

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  497.30 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.    36.  0.07  0.20  501.32    0.00    629.  500.96

            Q    WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    168.    48.   -36.    12.   1.1   0.8   4.7   4.5   1.1   2.9
   RT:    461.    83.    12.    95.   1.8   1.2   5.5   4.7   1.5   3.0

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

APPRO:AS      25.  -125.     705.  0.20  0.18  501.39  498.10   2200.  501.19
       52.    27.    87.   48924.  1.29  0.00    0.00    0.34    3.12

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -26.   -28.   122.   2200.   17950.     311.    7.08  497.58
   FULLV:FV       0.   -28.   122.   2200.   18305.     315.    6.98  498.00
   BRIDG:BR       0.     0.    23.   1579.   10941.     137.   11.50  497.50
   RDWAY:RG       8.*******   168.    629.*****************    2.00  500.96
   APPRO:AS      52.  -125.    87.   2200.   48924.     705.    3.12  501.19

SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS      FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    497.50     0.89  489.78  516.20************  0.83  498.41  497.58
   FULLV:FV    497.89     0.87  490.17  516.59  0.38  0.00  0.80  498.81  498.00
   BRIDG:BR    496.60     0.83  490.78  497.50************  2.06  499.56  497.50
   RDWAY:RG   ****************  499.20  512.80  0.07******  0.20  501.32  500.96
   APPRO:AS    498.10     0.34  491.93  506.88  0.18  0.00  0.20  501.39  501.19
```

WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******    -3.     186.  0.70 *****  497.36  496.47   1170.  496.66
      -26. ******   100.    9545.  1.14 ***** *******    0.89    6.29

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.86     497.09     496.86

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   496.16     516.59    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   496.16     516.59     496.86

FULLV:FV      26.    -3.     188.  0.69  0.39  497.75  496.86   1170.  497.07
        0.    26.   101.    9666.  1.14  0.00    0.01    0.87    6.22
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      52.   -14.     194.  0.61  0.64  498.39 *******   1170.  497.78
       52.    52.    52.   11443.  1.07  0.00    0.00    0.64    6.03
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   496.42     497.69     498.02     497.30

 ===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      26.     0.     137.  1.13 *****  498.63  495.64   1170.  497.50
        0. ******    23.   10941.  1.00 ***** *******    0.62    8.52

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.475  0.000  497.30 ****** ****** ******

    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      25.  -120.     328.  0.26  0.17  499.50  496.30   1170.  499.25
       52.    27.    70.   19706.  1.31  0.24    0.00    0.49    3.57
FIRST USER DEFINED TABLE.

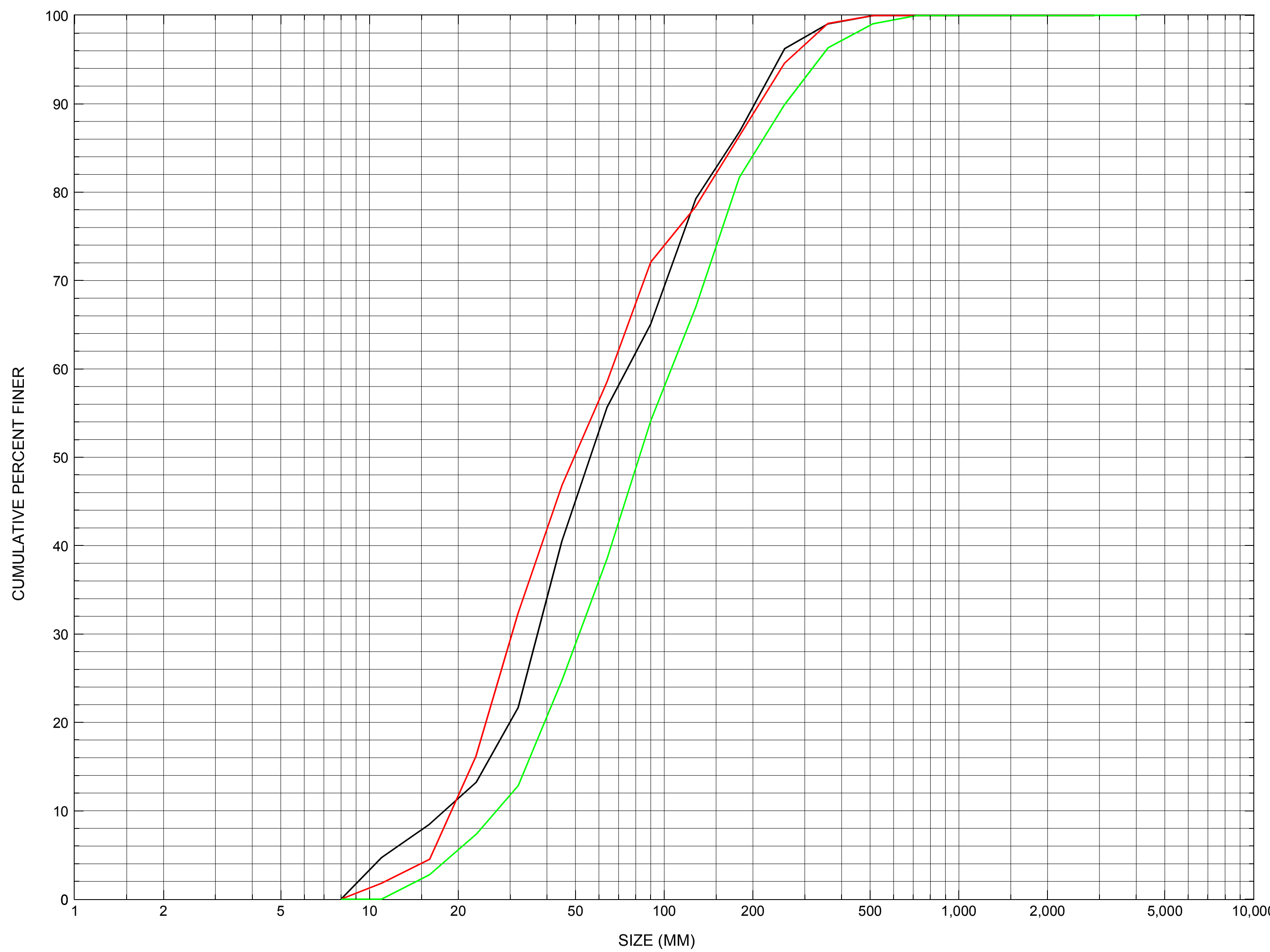
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -26.    -3.   100.   1170.    9545.     186.    6.29  496.66
   FULLV:FV       0.    -3.   101.   1170.    9666.     188.    6.22  497.07
   BRIDG:BR       0.     0.    23.   1170.   10941.     137.    8.52  497.50
   RDWAY:RG       8.**************      0.       0.       0.    2.00********
   APPRO:AS      52.  -120.    70.   1170.   19706.     328.    3.57  499.25

SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    496.47    0.89  489.78  516.20************  0.70  497.36  496.66
   FULLV:FV    496.86    0.87  490.17  516.59  0.39  0.00  0.69  497.75  497.07
   BRIDG:BR    495.64    0.62  490.78  497.50************  1.13  498.63  497.50
   RDWAY:RG  ****************  499.20  512.80************  0.26  499.38********
   APPRO:AS    496.30    0.49  491.93  506.88  0.17  0.24  0.26  499.50  499.25
```

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 BETHTH00190035, in Bethel, Vermont.

APPENDIX D:

HISTORICAL DATA FORM