LEVEL II SCOUR ANALYSIS FOR BRIDGE 37 (BETHTH00070037) on TOWN HIGHWAY 7, crossing GILEAD BROOK, BETHEL, VERMONT

U.S. Geological Survey
Open-File Report 96-233

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 37 (BETHTH00070037) on TOWN HIGHWAY 7, crossing GILEAD BROOK, BETHEL, VERMONT

By MICHAEL A. IVANOFF and MATTHEW A. WEBER

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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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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 37 (BETHTH00070037) ON TOWN HIGHWAY 7, CROSSING GILEAD BROOK, BETHEL, VERMONT

***By* Michael A. Ivanoff and Matthew A. Weber**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BETHTH00070037 on town highway 7 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 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 Bethel. The 6.66-mi^2 drainage area is predominantly rural and forested. In the vicinity of the study site, the upstream banks have dense woody vegetation coverage and the downstream banks are grass covered.

In the study area, Gilead Brook is an incised, sinuous channel with a slope of approximately 0.017 ft/ft, an average channel top width of 36 ft and an average channel depth of 4 ft. The predominant channel bed material is cobble (D_{50} is 119 mm or 0.391 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 19, 1994, indicated that the reach was laterally unstable.

The town highway 7 crossing of the Gilead Brook is a 32-ft-long, one-lane bridge consisting of one 28-foot span steel beam with timber deck (Vermont Agency of Transportation, written commun., August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls on the upstream side. The channel is skewed approximately 35 degrees to the opening while the opening-skew-to-roadway is 30 degrees.

The left abutment footing was undermined by 0.5 feet at the time of the Level I assessment. The scour protection measures at the site included type-2 stone fill (less than 36 inches diameter) at the upstream right and left wingwalls, and upstream side of the left and right road embankments. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993).

Total scour at a highway crossing is comprised of three components: 1) long-term aggradation or degradation; 2) contraction scour (due to reduction in flow area caused by a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute scour depths for contraction and local scour and a summary of the results follows.

Contraction scour for all modelled flows was 0.0 ft. Abutment scour ranged from 8.8 ft to 12.4 ft and the worst-case abutment scour occurred at the 100-year discharge. Scour depths and depths to armoring are summarized on p. 14 in the section titled "Scour Results". Scour elevations, based on the calculated depths are presented in tables 1 and 2; a graph of the scour elevations is presented in figure 8 Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

For all scour presented in this report, "the scour depths adopted [by VTAOT] may differ from the equation values based on engineering judgement" (Richardson and others, 1993, p. 21, 27). 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, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results.

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 BETHTH00070037 ***Stream*** Gilead Brook

County Windsor ***Road*** TH007 ***District*** 04

Description of Bridge

Bridge length 32 ***ft*** ***Bridge width*** 28 ***ft*** ***Max span length*** 13.5 ***ft***

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

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

Stone fill on abutment? No ***Date of inspection*** 10/19/94

Description of stone fill Type-2, around the upstream end of the upstream right wingwall, upstream left wingwall, upstream left and right bank, upstream side of the left and right road approach, and downstream side of the left road approach.

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

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

Is there a channel bend in the upstream reach? (mild, moderate, severe) There is a moderate channel bend into the upstream bridge face.

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	10/19/94	0	0
Level II	10/19/94	--	--

Potential for debris Low. There are some trees leaning over the channel upstream.

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

Description of the Geomorphic Setting

General topography The stream valley has a flat to slightly irregular terraces with steep valley walls on both sides.

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

Date of inspection 10/19/95

DS left: Moderate channel bank slope to a narrow terrace

DS right: Moderate channel bank slope to a narrow terrace

US left: Moderate channel bank slope to a narrow terrace

US right: Steep channel bank to a narrow terrace

Description of the Channel

Average top width 35.5 ***ft*** ***Average depth*** 3.5 ***ft***

Predominant bed material Gravel / Cobbles ***Bank materia*** Gravel/Cobbles

Sinuous and laterally unstable with semi-alluvial channel boundaries and a narrow terraces.

10/19/95

Vegetative co Brush

DS left: Brush

DS right: Trees

US left: Brush with gravel road on terrace.

US right: N

Do banks appear stable? The assessment of 10/19/96 indicated a laterally unstable channel with a cut bank on the left bank upstream.

date of observation.

None

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 6.66 ***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 on the left overbank area

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 1,700 ***ft³/s*** ***Q500*** 2,200 ***ft³/s***

The 100- and 500-year discharges are based on an area relationship with Bethel bridge 38 [(6.7/8.8) to the 0.7 power]. Discharges at Bethel bridge38, which has a drainage area of 8.8 square miles, were from VTAOT files (Written commun., 1995)

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 right abutment (elev. 496.78 ft, arbitrary datum). RM2 is a chiseled X on top of the US end of the right abutment footing (elev. 490.75ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-46	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	14	1	Road Grade section
APPRO	46	2	Modelled Approach section (Templated from ATEMP)
ATEMP	58	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 0.050 to 0.070, and overbank "n" values ranged from 0.055 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 0.0170 ft/ft determined by thalweg points downstream of the bridge.

The surveyed approach section (ATEMP) was moved along the approach channel slope (0.029 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-yr and 500-yr discharges overtop the left roadway embankment but not the bridge deck. The incipient overtopping discharge was determined to be 1310 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.1 *ft*
Average low steel elevation 496.9 *ft*

100-year discharge 1,700 *ft^3/s*
Water-surface elevation in bridge opening 496.9 *ft*
Road overtopping? Y *Discharge over road* 119 *ft^3/s*
Area of flow in bridge opening 157 *ft^2*
Average velocity in bridge opening 9.9 *ft/s*
Maximum WSPRO tube velocity at bridge 12.6 *ft/s*

Water-surface elevation at Approach section with bridge 499.6 *ft*
Water-surface elevation at Approach section without bridge 495.4 *ft*
Amount of backwater caused by bridge 4.2 *ft*

500-year discharge 2,200 *ft^3/s*
Water-surface elevation in bridge opening 496.9 *ft*
Road overtopping? Y *Discharge over road* 481 *ft^3/s*
Area of flow in bridge opening 157 *ft^2*
Average velocity in bridge opening 10.8 *ft/s*
Maximum WSPRO tube velocity at bridge 13.7 *ft/s*

Water-surface elevation at Approach section with bridge 500.4 *ft*
Water-surface elevation at Approach section without bridge 496.2 *ft*
Amount of backwater caused by bridge 4.2 *ft*

Incipient overtopping discharge 1,310 *ft^3/s*
Water-surface elevation in bridge opening 496.9 *ft*
Area of flow in bridge opening 157 *ft^2*
Average velocity in bridge opening 8.3 *ft/s*
Maximum WSPRO tube velocity at bridge 10.6 *ft/s*

Water-surface elevation at Approach section with bridge 498.5 *ft*
Water-surface elevation at Approach section without bridge 494.6 *ft*
Amount of backwater caused by bridge 3.9 *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 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, 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. Contraction scour was computed as 0.0 feet for all modeled events.

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. Worst case abutment scour and total scour occurs for the 100 -yr model.

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	1.4	2.5	0.5
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	12.4	10.2	11.0
Right abutment	10.2	8.8	10.0
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:			
Left abutment	2.2	2.6	1.5
Right abutment	2.2	2.6	1.5
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

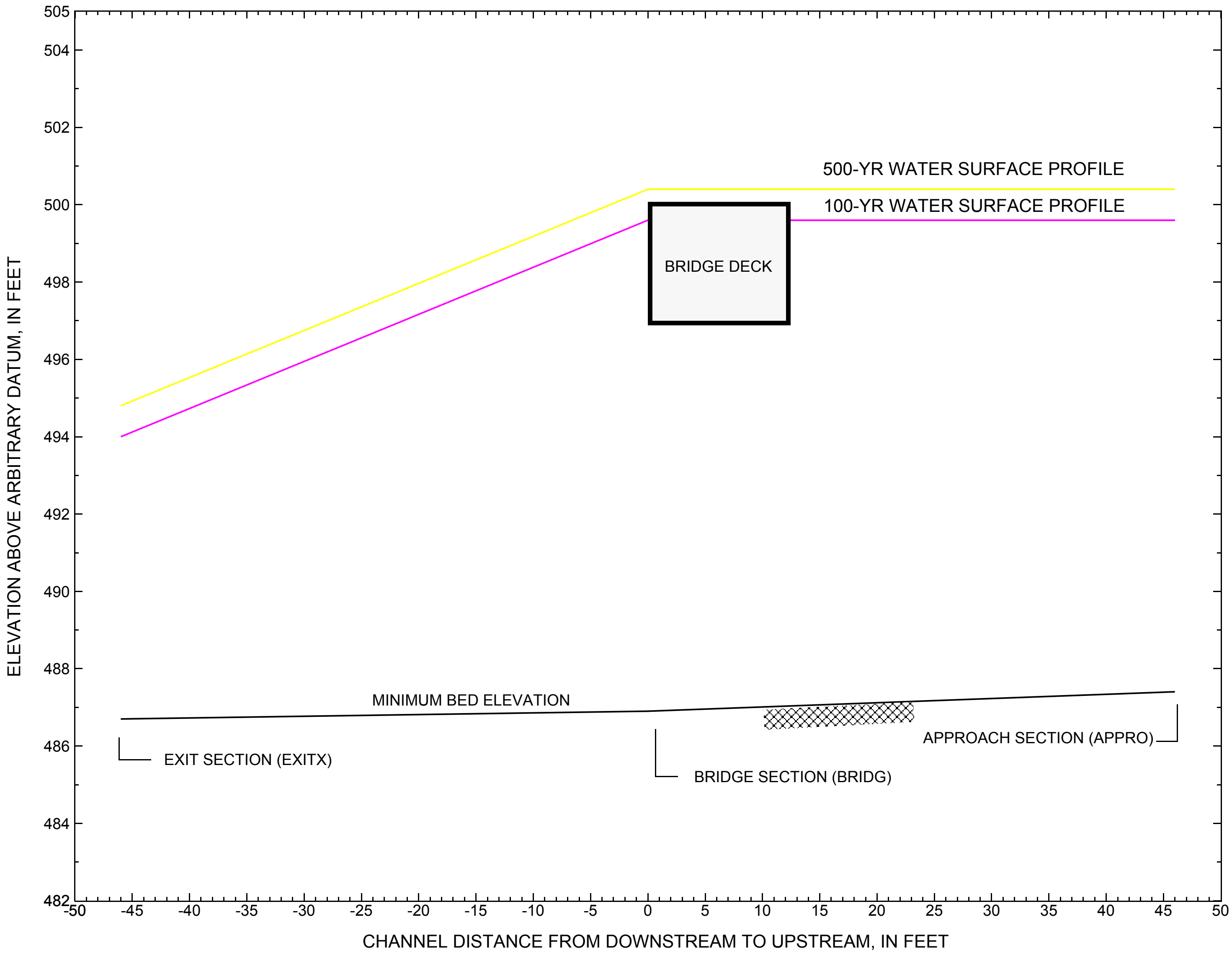

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BETHTH00070037 on town highway 7, crossing Gilead Brook, Bethel, Vermont.

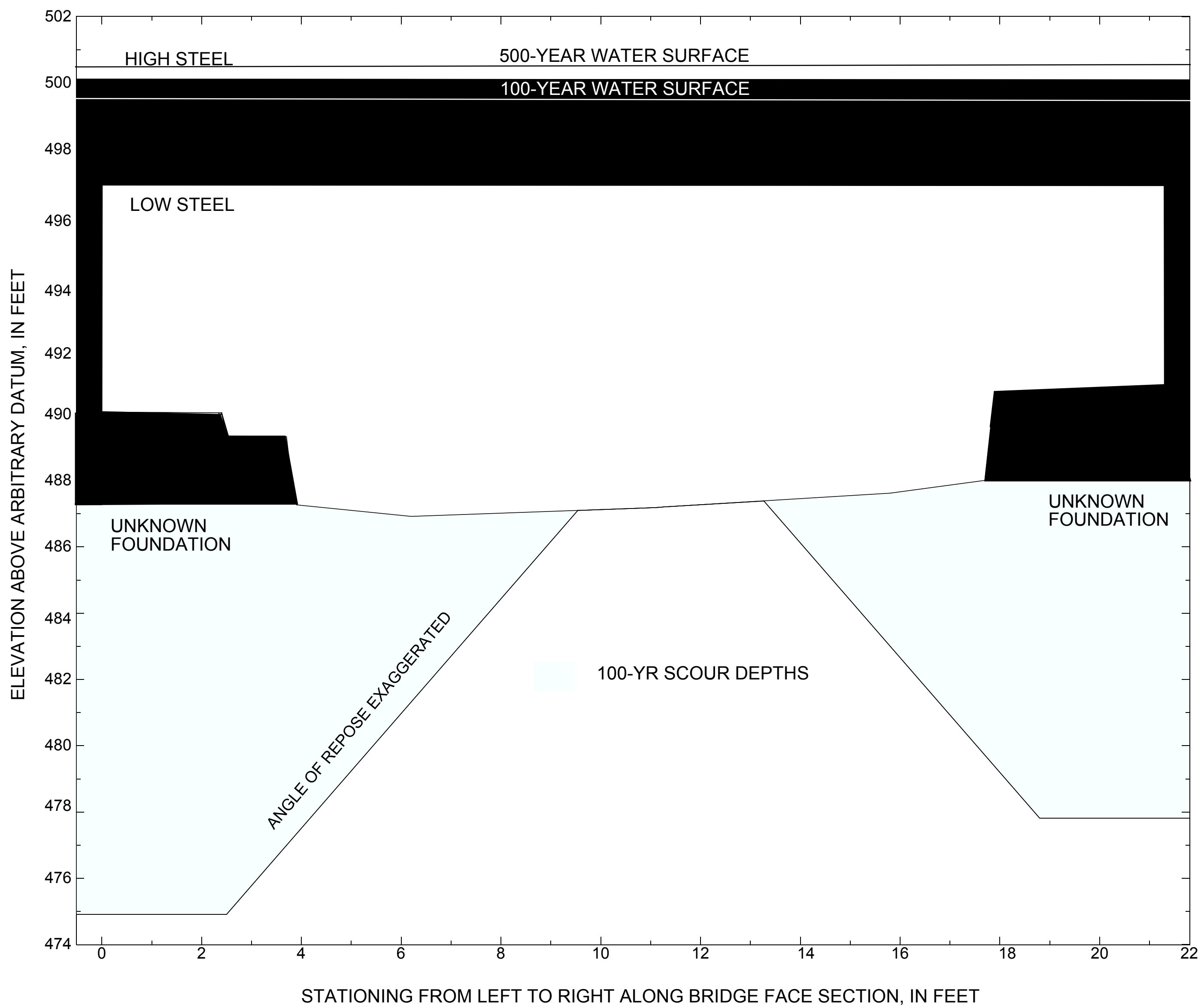

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BETHTH00070037 on town highway 7, crossing Gilead Brook, Bethel, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BETHTH00070037 on Town Highway 7, 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 1,700 cubic-feet per second											
Left abutment	0.0	--	496.9	--	487.3	0.0	12.4	--	12.4	474.9	--
Right abutment	21.3	--	496.8	--	488.0	0.0	10.2	--	10.2	477.8	--

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 BETHTH00070037 on Town Highway 7, 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	--	496.9	--	487.3	0.0	10.2	--	10.2	477.1	--
Right abutment	21.3	--	496.8	--	488.0	0.0	8.8	--	8.8	479.2	--

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 beth037.wsp
T2        CREATED ON 14-DEC-95 FOR BRIDGE BETHTH00070037 USING FILE beth037.dca
T3        Hydraulic analysis for Bethel bridge 37 over Gilead Brook by MAI
*
Q          1700.0     2200.0    1310.0
SK         0.0170     0.0170    0.0170
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -46
*
GR          -31.9, 498.56    -19.8, 495.91    -16.5, 493.17     -7.2, 489.74
GR            0.0, 487.96      7.3, 487.45     13.1, 486.69     16.1, 487.55
GR           20.8, 487.66     25.9, 491.34     32.6, 494.45     91.9, 495.29
GR           99.9, 500.12
*
N           0.070        0.080
SA                 32.6
*
XS   FULLV      0  * * *   0.014
*
BR   BRIDG   0     496.9      30.0
*
GR            0.0, 496.92      0.2, 490.07      2.4, 490.05      2.5, 489.35
GR            3.7, 489.33      3.8, 488.06      3.9, 487.27      6.2, 486.92
GR           11.1, 487.19     15.8, 487.62     17.7, 488.01     17.9, 490.68
GR           21.2, 490.86     21.3, 496.81      0.0, 496.92
*
CD         1   29.0 * *   51.5  4.8
N           0.050
*
XR   RDWAY     14      13.5   2
*
GR         -135.2, 505.40   -125.6, 501.26    -49.2, 498.48     -7.6, 500.20
GR            0.0, 500.15     24.3, 500.07    54.0, 500.79      126.4, 504.57
GR          164.9, 507.39
*
XT   ATEMP     58
*
GR          -98.4, 505.40    -89.1, 501.26    -35.9, 499.60    -18.5, 499.63
GR           -6.7, 493.88      0.0, 490.52      5.7, 489.93      6.7, 488.94
GR            7.5, 487.99     10.3, 487.73     12.9, 488.17     15.4, 489.01
GR           21.6, 493.04     27.2, 500.60     31.3, 500.63     39.1, 500.79
GR          111.5, 504.57    150.0, 507.39
*
AS   APPRO     46
GT             -0.35
N           0.065        0.065        0.055
SA                 -18.5         27.2
*
HP 1 BRIDG   496.92 1 496.92
HP 2 BRIDG   496.92 * * 1554
HP 2 RDWAY   499.59 * * 119
HP 2 RDWAY   499.59 * * 119
HP 1 APPRO   499.59 1 499.59
HP 2 APPRO   499.59 * * 1700
*
HP 1 BRIDG   496.92 1 496.92
HP 2 BRIDG   496.92 * * 1692
HP 2 RDWAY   500.36 * * 481
HP 1 APPRO   500.39 1 500.39
HP 2 APPRO   500.39 * * 2200
*
HP 1 BRIDG   496.92 1 496.92
HP 2 BRIDG   496.92 * * 1310
HP 1 APPRO   498.48 1 498.48
HP 2 APPRO   498.48 * * 1310
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE beth037.wsp
        CREATED ON 14-DEC-95 FOR BRIDGE BETHTH00070037 USING FILE beth037.dca
        Hydraulic analysis for Bethel bridge 37 over Gilead Brook by MAI
           *** RUN DATE & TIME: 01-30-96  09:22
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      157      9461      0     55                      8079995
   496.92           157      9461      0     55  1.00      0     21  8079995

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       496.92     0.0    21.3   157.0    9461.    1554.   9.90

X STA.         0.0        2.5        4.1        5.0        5.8        6.6
  A(I)            14.5       10.4        7.8        7.3        6.6
  V(I)            5.35       7.44       9.93      10.67      11.72

X STA.         6.6        7.4        8.1        8.9        9.6       10.3
  A(I)             6.6        6.3        6.3        6.2        6.2
  V(I)           11.78      12.36      12.32      12.52      12.58

X STA.        10.3       11.1       11.8       12.6       13.4       14.2
  A(I)             6.3        6.2        6.2        6.5        6.6
  V(I)           12.41      12.49      12.44      11.88      11.72

X STA.        14.2       15.0       15.9       16.9       18.6       21.3
  A(I)             6.8        7.2        7.9       11.0       13.8
  V(I)           11.39      10.83       9.82       7.04       5.61

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      14.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.59   -79.7   -22.4    31.8     457.     119.   3.74
X STA.       -79.7      -66.9      -63.1      -60.4      -58.3      -56.5
  A(I)             3.0        2.0        1.8        1.6        1.4
  V(I)            1.99       2.94       3.40       3.83       4.13

X STA.       -56.5      -54.9      -53.5      -52.2      -51.0      -49.9
  A(I)             1.4        1.3        1.3        1.2        1.2
  V(I)            4.23       4.59       4.66       4.84       4.94

X STA.       -49.9      -48.8      -47.7      -46.5      -45.1      -43.7
  A(I)             1.2        1.2        1.2        1.3        1.3
  V(I)            4.97       4.94       4.85       4.59       4.48

X STA.       -43.7      -42.0      -40.1      -37.6      -34.2      -22.4
  A(I)             1.4        1.5        1.7        1.9        2.9
  V(I)            4.23       3.93       3.57       3.09       2.06
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      46.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1        8        71     28     28                           22
             2      331     25681     45     53                         5077
   499.59           338     25752     74     81  1.04    -46     27     4043

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      46.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.59   -46.8    26.7   338.3   25752.    1700.   5.03
X STA.       -46.8       -8.1       -4.5       -2.1       -0.3        1.3
  A(I)            37.0       22.3       18.5       16.4       15.4
  V(I)            2.29       3.80       4.59       5.18       5.52

X STA.         1.3        2.9        4.3        5.7        7.1        8.2
  A(I)            14.5       14.0       13.8       15.2       13.5
  V(I)            5.86       6.08       6.17       5.60       6.28

X STA.         8.2        9.3       10.3       11.3       12.4       13.5
  A(I)            12.4       12.5       12.6       12.9       13.1
  V(I)            6.83       6.78       6.72       6.60       6.48

X STA.        13.5       14.8       16.1       17.8       20.0       26.7
  A(I)            13.9       15.1       16.3       19.1       29.5
  V(I)            6.12       5.63       5.22       4.45       2.88
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    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      157      9461      0     55                      8079995
   496.92           157      9461      0     55  1.00      0     21  8079995

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       496.92     0.0    21.3   157.0    9461.    1692.  10.78

X STA.         0.0        2.5        4.1        5.0        5.8        6.6
  A(I)            14.5       10.4        7.8        7.3        6.6
  V(I)            5.82       8.11      10.82      11.62      12.76

X STA.         6.6        7.4        8.1        8.9        9.6       10.3
  A(I)             6.6        6.3        6.3        6.2        6.2
  V(I)           12.83      13.46      13.42      13.64      13.70

X STA.        10.3       11.1       11.8       12.6       13.4       14.2
  A(I)             6.3        6.2        6.2        6.5        6.6
  V(I)           13.52      13.60      13.54      12.93      12.77

X STA.        14.2       15.0       15.9       16.9       18.6       21.3
  A(I)             6.8        7.2        7.9       11.0       13.8
  V(I)           12.40      11.79      10.69       7.66       6.11

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      14.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.36  -100.9    36.3   100.2    1757.     481.   4.80

X STA.      -100.9      -79.9      -73.7      -69.3      -65.8      -62.8
  A(I)             8.0        5.5        4.7        4.3        3.9
  V(I)            3.02       4.38       5.14       5.63       6.13

X STA.       -62.8      -60.1      -57.7      -55.4      -53.3      -51.3
  A(I)             3.9        3.7        3.6        3.6        3.6
  V(I)            6.19       6.51       6.60       6.61       6.73

X STA.       -51.3      -49.3      -47.3      -45.0      -42.6      -39.8
  A(I)             3.7        3.7        3.9        4.0        4.4
  V(I)            6.57       6.57       6.14       5.97       5.51

X STA.       -39.8      -36.4      -32.3      -26.7      -16.4       36.3
  A(I)             4.8        5.3        5.9        7.6       12.2
  V(I)            5.04       4.58       4.06       3.15       1.97

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      46.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1       40       764     54     54                          198
             2      367     30250     46     54                         5906
             3        1         4      9      9                            1
   500.39           408     31018    109    117  1.15    -71     37     4183

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      46.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.39   -72.4    36.7   408.4   31018.    2200.   5.39

X STA.       -72.4      -11.5       -6.8       -3.9       -1.7        0.1
  A(I)            60.3       26.2       22.1       19.4       17.9
  V(I)            1.83       4.21       4.98       5.66       6.16

X STA.         0.1        1.7        3.3        4.7        6.2        7.6
  A(I)            16.9       15.8       15.5       16.2       16.9
  V(I)            6.50       6.95       7.09       6.81       6.53

X STA.         7.6        8.7        9.8       10.9       12.1       13.3
  A(I)            14.4       14.5       14.2       14.9       15.2
  V(I)            7.65       7.59       7.74       7.40       7.26

X STA.        13.3       14.6       16.1       17.8       20.2       36.7
  A(I)            16.1       17.0       18.9       22.1       34.1
  V(I)            6.84       6.45       5.83       4.97       3.22
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   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      157      9461      0     55                      8079995
  496.92           157      9461      0     55  1.00      0     21  8079995

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      496.92     0.0    21.3   157.0    9461.    1310.   8.35

X STA.         0.0        2.5        4.1        5.0        5.8        6.6
  A(I)             14.5       10.4        7.8        7.3        6.6
  V(I)             4.51       6.28       8.37       8.99       9.88

X STA.         6.6        7.4        8.1        8.9        9.6       10.3
  A(I)              6.6        6.3        6.3        6.2        6.2
  V(I)             9.93      10.42      10.39      10.56      10.61

X STA.        10.3       11.1       11.8       12.6       13.4       14.2
  A(I)              6.3        6.2        6.2        6.5        6.6
  V(I)            10.46      10.53      10.48      10.01       9.88

X STA.        14.2       15.0       15.9       16.9       18.6       21.3
  A(I)              6.8        7.2        7.9       11.0       13.8
  V(I)             9.60       9.13       8.28       5.93       4.73

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      46.

    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            2      282     20485     43     50                         4104
  498.48           282     20485     43     50  1.00    -16     26     4104

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      46.

        WSEL     LEW     REW    AREA        K        Q    VEL
      498.48   -16.9    25.9   281.7   20485.    1310.   4.65

X STA.       -16.9       -6.3       -3.2       -1.0        0.7        2.2
  A(I)             27.1       18.3       15.7       14.2       12.8
  V(I)             2.41       3.58       4.16       4.62       5.10

X STA.         2.2        3.7        5.0        6.4        7.6        8.6
  A(I)             12.5       11.9       12.5       12.7       10.8
  V(I)             5.23       5.51       5.24       5.17       6.07

X STA.         8.6        9.6       10.6       11.5       12.5       13.6
  A(I)             10.6       10.7       10.7       10.9       11.1
  V(I)             6.18       6.14       6.12       6.01       5.91

X STA.        13.6       14.8       16.0       17.6       19.7       25.9
  A(I)             12.0       12.4       14.0       16.0       24.7
  V(I)             5.45       5.27       4.66       4.10       2.65
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WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******    -17      229  0.86 *****  494.86  492.45    1700  494.00
       -45 ******     32    13029  1.00 ***** *******    0.61    7.43

FULLV:FV       46    -17      237  0.80  0.74  495.61 *******    1700  494.82
         0     46     32    13713  1.00  0.00    0.01    0.58    7.17
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.85     495.37     494.78

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   494.32     507.04    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   494.32     507.04     494.78

APPRO:AS       46     -9      162  1.71  1.01  497.08  494.78    1700  495.37
        46     46     24     9629  1.00  0.45    0.00    0.85   10.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   498.92       0.00     494.77     498.48

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   494.71     498.57     498.85     496.90

 ===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       46      0      157  1.52 *****  498.44  494.39    1554  496.92
         0 ******     21     9461  1.00 ***** *******    0.64    9.90

    TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
      1. ****    5.  0.481  0.000  496.90 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
  RDWAY:RG      14.    33.  0.14  0.41  499.86   -0.02    119.  499.59

           Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
  LT:    119.    58.   -80.   -22.   1.1   0.6   3.8   3.7   0.8   2.8
  RT:      0.    31.    10.    42.   0.4   0.3   3.5   5.5   0.7   2.8

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

APPRO:AS       17    -46      339  0.41  0.19  500.00  494.78    1700  499.59
        46     18     27    25772  1.04  1.18   -0.02    0.42    5.02

  FIRST USER DEFINED TABLE.

   XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
  EXITX:XS     -46.   -18.    32.   1700.   13029.     229.    7.43  494.00
  FULLV:FV       0.   -18.    32.   1700.   13713.     237.    7.17  494.82
  BRIDG:BR       0.     0.    21.   1554.    9461.     157.    9.90  496.92
  RDWAY:RG      14.*******   119.    119.       0.       0.    2.00  499.59
  APPRO:AS      46.   -47.    27.   1700.   25772.     339.    5.02  499.59

 SECOND USER DEFINED TABLE.

   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
  EXITX:XS    492.45    0.61  486.69  500.12************  0.86  494.86  494.00
  FULLV:FV  ********    0.58  487.33  500.76  0.74  0.00  0.80  495.61  494.82
  BRIDG:BR    494.39    0.64  486.92  496.92************  1.52  498.44  496.92
  RDWAY:RG  ****************  498.48  507.39  0.14******  0.41  499.86  499.59
  APPRO:AS    494.78    0.42  487.38  507.04  0.19  1.18  0.41  500.00  499.59
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WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******    -18      277  1.01 *****  495.87  493.21    2200  494.85
       -45 ******     61    16865  1.04 ***** *******    0.76    7.94

FULLV:FV       46    -18      294  0.93  0.74  496.62 *******    2200  495.69
         0     46     75    17903  1.07  0.00    0.02    0.77    7.49
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.89     496.15     495.71

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   495.19     507.04    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   495.19     507.04     495.71

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.67

APPRO:AS       46    -11      190  2.09  1.04  498.24  495.71    2200  496.15
        46     46     24    11948  1.00  0.58    0.00    0.89   11.60
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   500.80       0.00     495.96     498.48

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   495.43     499.55     499.84     496.90

 ===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       46      0      157  1.81 *****  498.73  494.75    1692  496.92
         0 ******     21     9461  1.00 ***** *******    0.70   10.78

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.492  0.000  496.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      14.    33.  0.16  0.52  500.74   -0.01    481.  500.36

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    449.   111.  -101.    10.   1.9   0.9   4.9   4.7   1.2   2.9
   RT:     32.    26.    10.    36.   0.3   0.2   3.1   5.8   0.6   2.7

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

APPRO:AS       17    -71      408  0.52  0.23  500.91  495.71    2200  500.39
        46     18     36    30984  1.15  1.20   -0.01    0.53    5.39

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -46.   -19.    61.   2200.   16865.     277.    7.94  494.85
   FULLV:FV       0.   -19.    75.   2200.   17903.     294.    7.49  495.69
   BRIDG:BR       0.     0.    21.   1692.    9461.     157.   10.78  496.92
   RDWAY:RG      14.*******   449.    481.*********       0.    2.00  500.36
   APPRO:AS      46.   -72.    36.   2200.   30984.     408.    5.39  500.39

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL     WSEL
   EXITX:XS    493.21    0.76  486.69  500.12************  1.01  495.87  494.85
   FULLV:FV  ********    0.77  487.33  500.76  0.74  0.00  0.93  496.62  495.69
   BRIDG:BR    494.75    0.70  486.92  496.92************  1.81  498.73  496.92
   RDWAY:RG  ****************  498.48  507.39  0.16******  0.52  500.74  500.36
   APPRO:AS    495.71    0.53  487.38  507.04  0.23  1.20  0.52  500.91  500.39
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WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******    -16      191  0.73 *****  493.94  491.76    1310  493.21
       -45 ******     30    10046  1.00 ***** *******    0.60    6.86

FULLV:FV       46    -16      198  0.68  0.74  494.69 *******    1310  494.02
         0     46     30    10623  1.00  0.00    0.01    0.57    6.60
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.81     494.62     493.96

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   493.52     507.04    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   493.52     507.04     493.96

APPRO:AS       46     -8      137  1.41  0.97  496.03  493.96    1310  494.62
        46     46     23     7663  1.00  0.37    0.00    0.81    9.53
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   493.73     497.10     497.39     496.90

 ===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       46      0      157  1.07 *****  497.99  493.71    1301  496.92
         0 ******     21     9461  1.00 ***** *******    0.54    8.29

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.443  0.000  496.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      14.        <<<<<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       17    -16      282  0.34  0.16  498.82  493.96    1310  498.48
        46     18     26    20503  1.00  1.14   -0.01    0.32    4.65

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -46.   -17.    30.   1310.   10046.     191.    6.86  493.21
   FULLV:FV       0.   -17.    30.   1310.   10623.     198.    6.60  494.02
   BRIDG:BR       0.     0.    21.   1301.    9461.     157.    8.29  496.92
   RDWAY:RG      14.**************      0.       0.       0.    2.00********
   APPRO:AS      46.   -17.    26.   1310.   20503.     282.    4.65  498.48

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    491.76    0.60  486.69  500.12************  0.73  493.94  493.21
   FULLV:FV  ********    0.57  487.33  500.76  0.74  0.00  0.68  494.69  494.02
   BRIDG:BR    493.71    0.54  486.92  496.92************  1.07  497.99  496.92
   RDWAY:RG  ****************  498.48  507.39************  0.34  498.69********
   APPRO:AS    493.96    0.32  487.38  507.04  0.16  1.14  0.34  498.82  498.48
```
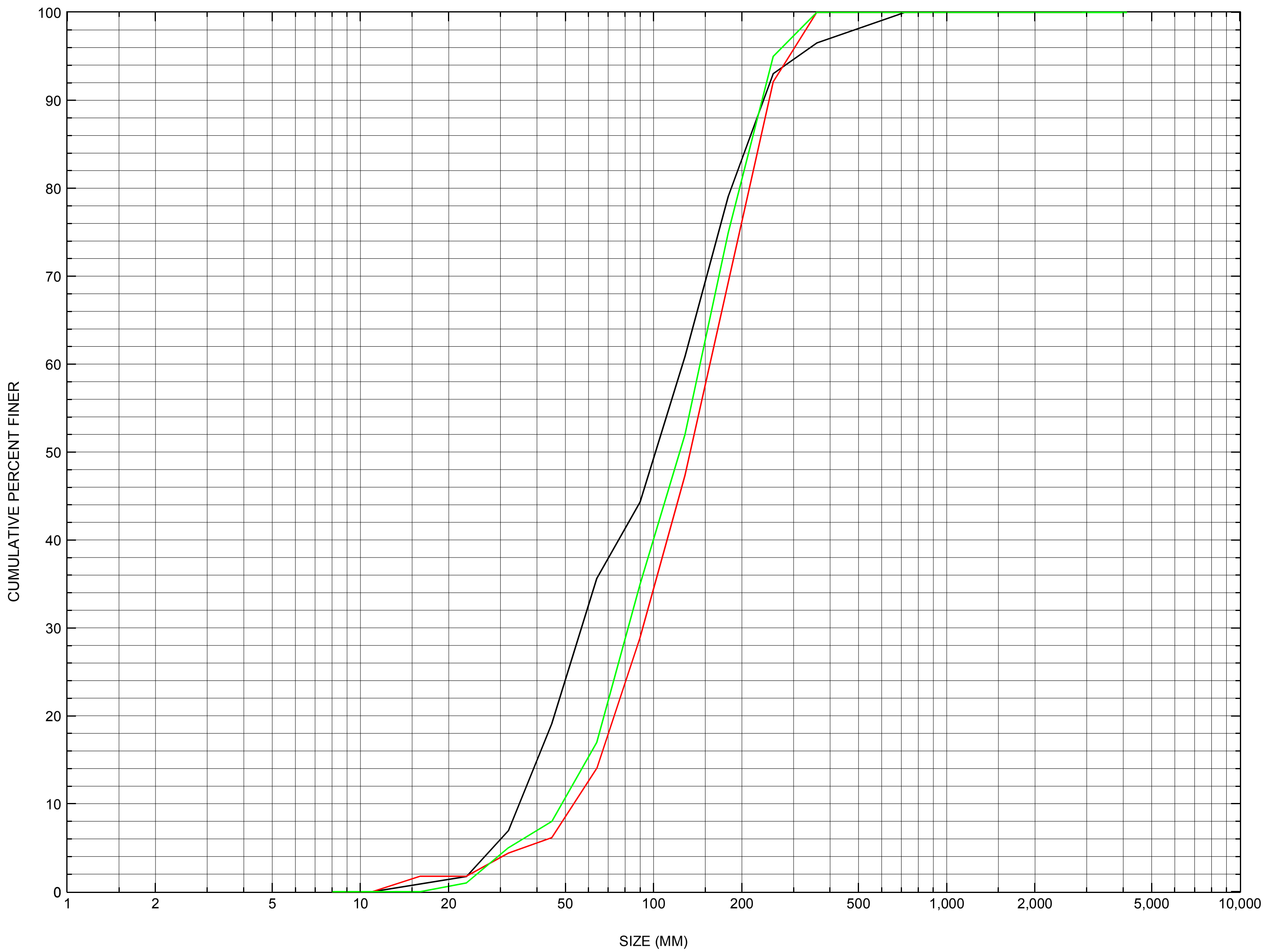

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BETHTH00070037, in Bethel, Vermont.

APPENDIX D:

HISTORICAL DATA FORM