LEVEL II SCOUR ANALYSIS FOR BRIDGE 33 (BETHTH00310033) on TOWN HIGHWAY 31, crossing LILLIESVILLE BROOK, BETHEL, VERMONT

U.S. Geological Survey
Open-File Report 96-191

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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By MICHAEL A. IVANOFF and ROBERT E. HAMMOND

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Pembroke, New Hampshire

1996

U.S. DEPARTMENT OF THE INTERIOR
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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.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 33 (BETHTH00310033) ON TOWN HIGHWAY 31, CROSSING LILLIESVILLE BROOK, BETHEL, VERMONT

By Michael A. Ivanoff and Robert E. Hammond

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BETHTH00310033 on town highway 31 crossing the Lilliesville 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 6.85-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left banks have shrub and brush, and the right banks are forested.

In the study area, Lilliesville Brook has an incised, straight channel with a slope of approximately 0.02 ft/ft, an average channel top width of 37 ft and an average channel depth of 4 ft. The predominant channel bed material is gravel and cobble (D_{50} is 66.8 mm or 0.219 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 13 and 14, 1994, indicated that the reach was stable.

The town highway 31 crossing of Lilliesville Brook is a 41-ft-long, one-lane bridge consisting of one 39-foot steel-beam span with a 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 35 degrees to the opening while the opening-skew-to-roadway is 0 degrees.

Scour protection measures in place at the site were type-1 stone fill (less than 12 inches diameter) at the downstream left wingwall, left abutment, and upstream and downstream sides of the left road embankment. 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). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

Bethel, VT. Quadrangle, 1:24,000, 1980

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 BETHTH00310033 *Stream* Lilliesville Brook

County Windsor *Road* TH031 *District* 04

Description of Bridge

Bridge length 41.0 *ft* *Bridge width* 14.0 *ft* *Max span length* 39.0 *ft*

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

Abutment type Concrete *Embankment type* N/A

Stone fill on abutment? Yes *Date of inspection* 10/14/94

Description of stone fill Type-1, around the downstream left wingwall, left abutment, and upstream and downstream sides of the left road embankment.

Brief description of piers/abutments Concrete abutments and wingwalls. The left abutment is 5 degrees from vertical and the right abutment is 10 degrees from vertical.

Y 35

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

There is a moderate bend in the channel upstream of its approach to the bridge.

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	10/14/94	0	0
Level II	10/13/94	--	--

Potential for debris Moderate due to stone and concrete debris under the bridge obstructing flow.

Describe any features near or at the bridge that may affect flow (include observation date) 10/14/94 - There is a stone and concrete debris pile under the bridge.

Description of the Geomorphic Setting

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

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

Date of inspection 10/14/94

DS left: Steep channel bank to a terrace

DS right: Steep channel bank to a narrow terrace

US left: Steep channel bank to a narrow terrace

US right: Steep valley wall

Description of the Channel

Average top width 47.0 *ft* ***Average depth*** 4 *ft*

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

Narrow, incised channel with only slight sinuosity.

Vegetative co[ver] 10/14/94

shrub and brushland

DS left: forested with town highway 31 on the terrace

DS right: shrub and brushland with town highway 31 on the terrace

US left: forested

US right: Y

Do banks appear stable? ***If not, describe location and type of instability and date of observation.*** 10/14/94 -- Assessed as stable, however slight fluvial erosion noted on both upstream banks. Also, a cut bank and point bar were noted upstream. See appendix E for more details.

Describe any obstructions in channel and date of observation. 10/14/94 -- Stone and concrete debris near mid-channel under the bridge.

Hydrology

Drainage area 6.85 ***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:*** Area is primarily forested.

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 1650 ***ft³/s*** ***Q500*** 2200 ***ft³/s***

The 100 and 500 - year discharges were computed from an area relationship with a downstream site which has a drainage area of 7.1 mi^2 $[(6.85/7.1)^{0.7}]$. The flood frequency estimates for the downstream site were available from the VTAOT database (VTAOT 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 US end of the right abutment (elev. 498.54 ft, arbitrary datum). RM2 is a chiseled X on top of the DS end of the left abutment (elev. 498.74 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-62	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	9	1	Road Grade section
APPRO	57	1	Approach section

[1] For location of cross-sections see plan-view sketch included with Level I field form, Appendix E.
For more detail on how cross-sections were developed see WSPRO input file.

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). 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 0.060.

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 0.0212 ft/ft which was computed from surveyed thalweg points downstream of the bridge.

The surveyed approach section (APPRO), was used for the modeled section, 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 model defaulted to critical depth at the bridge section for the 100-year and 500-year discharges. Further analysis showed the water-surface profile passing through critical depth within the constriction. Thus, critical depth was assumed to be a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 501.1 *ft*
Average low steel elevation 497.5 *ft*

100-year discharge 1,650 *ft³/s*
Water-surface elevation in bridge opening 486.8 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 137 *ft²*
Average velocity in bridge opening 12.1 *ft/s*
Maximum WSPRO tube velocity at bridge 15.3 *ft/s*

Water-surface elevation at Approach section with bridge 489.9
Water-surface elevation at Approach section without bridge 488.6
Amount of backwater caused by bridge 1.3 *ft*

500-year discharge 2,200 *ft³/s*
Water-surface elevation in bridge opening 487.9 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 171 *ft²*
Average velocity in bridge opening 12.9 *ft/s*
Maximum WSPRO tube velocity at bridge 16.5 *ft/s*

Water-surface elevation at Approach section with bridge 491.2
Water-surface elevation at Approach section without bridge 489.3
Amount of backwater caused by bridge 1.9

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

Water-surface elevation at Approach section with bridge --
Water-surface elevation at Approach section without bridge --
Amount of backwater caused by bridge -- *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 clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18) for the 100-year and 500-year discharges. 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.

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	1.2	1.3	--
Depth to armoring	28.4	38.5	--
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	10.0	8.7	--
Right abutment	10.0	12.8	--
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	1.9	2.2	--
Right abutment	1.9	2.2	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

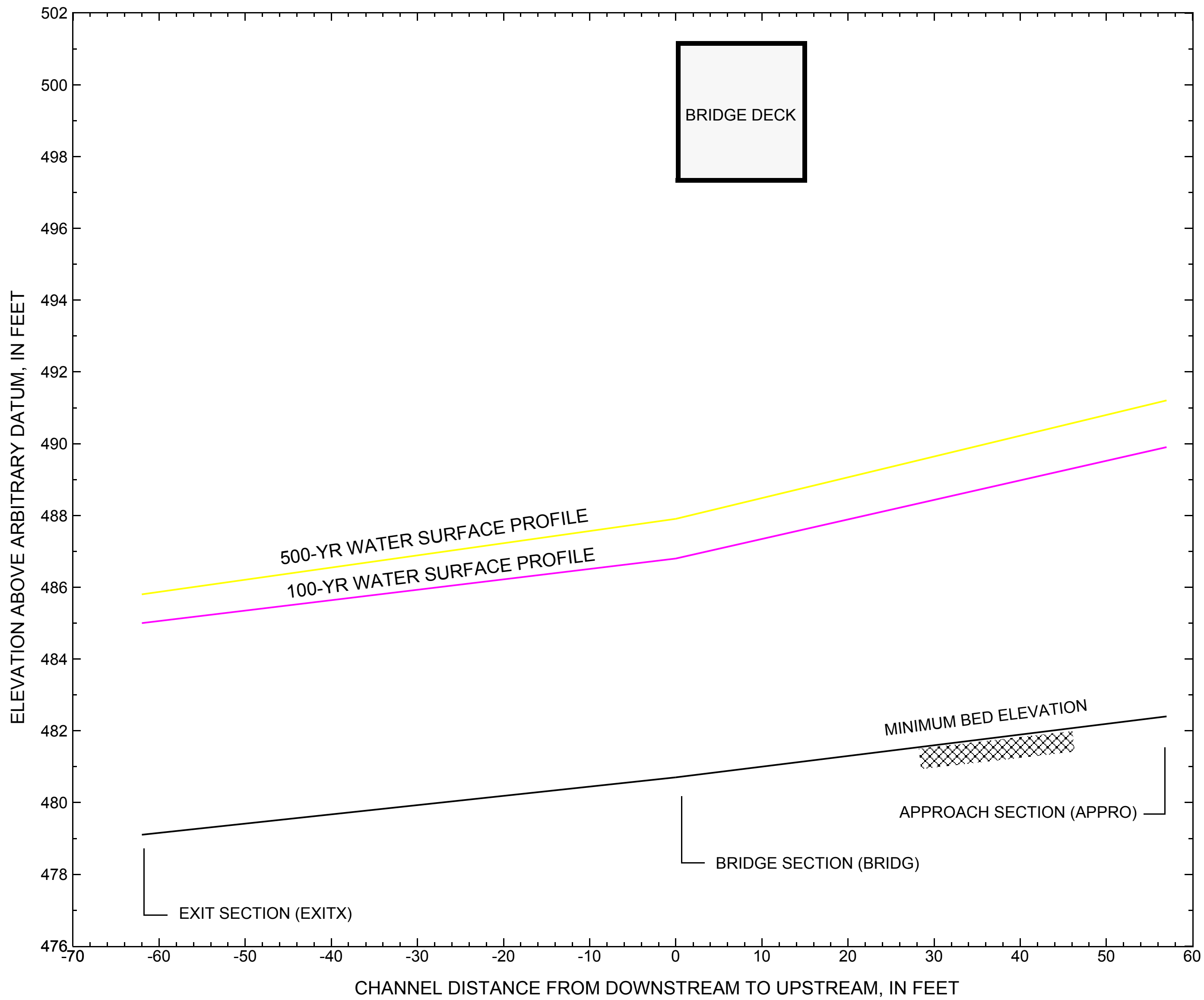

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BETHTH00310033 on town highway 31, crossing Lilliesville Brook, Bethel, Vermont.

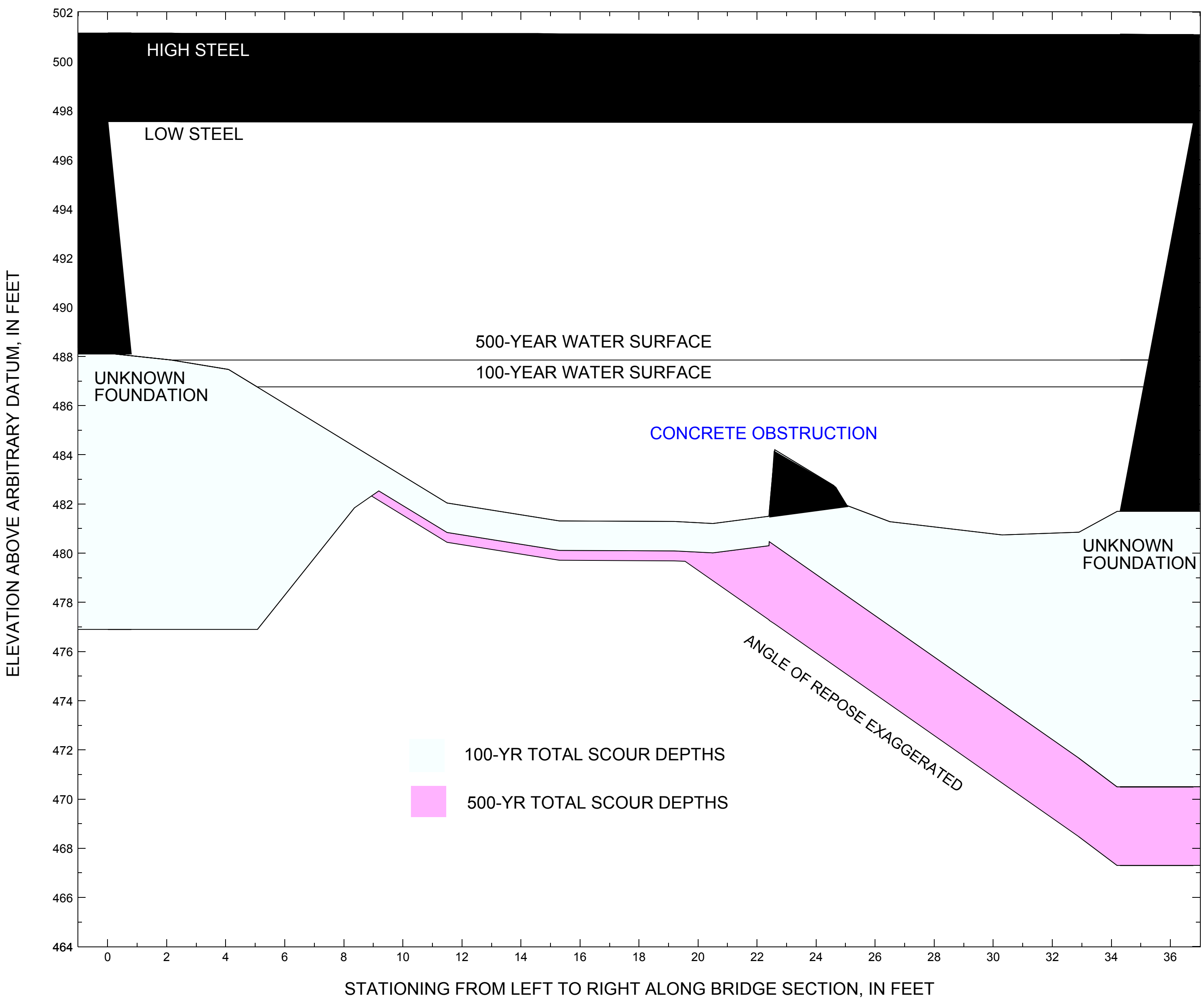

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BETHTH00310033 on town highway 31, crossing Lilliesville Brook, Bethel, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BETHTH00310033 on Town Highway 31, crossing Lilliesville 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	--	488.1	1.2	10.0	--	11.2	476.9	--
Right abutment	36.8	--	497.5	--	481.7	1.2	10.0	--	11.2	470.5	--

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 BETHTH00310033 on Town Highway 31, crossing Lilliesville 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	--	488.1	1.6	8.7	--	10.3	477.8	--
Right abutment	36.8	--	497.5	--	481.7	1.6	12.8	--	14.4	467.3	--

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

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U.S. Geological Survey, 1980, Bethel, 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

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE beth033.wsp
T2        CREATED ON 04-DEC-95 FOR BRIDGE BETHTH00310033 USING FILE beth033.dca
T3        Hydraulic analysis for Bethel bridge 33 by MAI
*
Q          1650.0,    2200.0
SK         0.0212   0.0212
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -62
*
GR          -24.3, 498.88     -9.7, 489.28      0.0, 484.75      6.8, 480.56
GR            9.3, 479.86     12.2, 479.50     16.2, 479.13     20.3, 479.32
GR           20.8, 479.88     20.8, 479.54     36.1, 482.01     42.7, 482.35
GR           50.5, 483.13     54.6, 486.04     58.6, 487.30     71.2, 497.93
N           0.060
*
XS   FULLV      0  * * *   0.0331
*
BR   BRIDG   0     497.5
*
GR            0.0, 497.52      0.8, 488.13      4.1, 487.47     11.5, 482.04
GR           11.5, 482.04     15.3, 481.31     19.2, 481.29     20.5, 481.21
GR           22.4, 481.50     22.6, 484.21     24.6, 482.75     25.0, 481.96
GR           26.5, 481.28     30.3, 480.74     32.9, 480.85     34.2, 481.70
GR           36.8, 497.50      0.0, 497.52
*
CD         1   30.1 * *     30.0     21.9
N           0.050
*
XR   RDWAY      9      15.0   2
*
GR         -112.9, 511.01    -95.6, 504.16    -73.5, 502.75    -37.4, 501.61
GR           -9.9, 500.91     -1.3, 501.14      0.0, 501.18     19.2, 501.10
GR           37.6, 501.06     38.8, 501.07     90.4, 500.17    103.8, 499.67
GR          115.6, 500.53    134.4, 500.75    151.8, 504.93
*
AS   APPRO     57
*
GR          -16.0, 499.75     -2.3, 488.16      0.0, 485.94      8.1, 483.25
GR            8.2, 483.30     11.5, 482.47     14.7, 482.45     17.9, 482.56
GR           22.2, 483.38     22.2, 483.38     29.5, 486.63     36.4, 488.51
GR           41.2, 487.09     52.2, 486.56     66.5, 496.30     85.8, 504.40
N           0.060
*
HP 1 BRIDG  486.76 1 486.76
HP 2 BRIDG  486.76 * * 1650
HP 1 APPRO  489.91 1 489.91
HP 2 APPRO  489.91 * * 1650
*
HP 1 BRIDG  487.86 1 487.86
HP 2 BRIDG  487.86 * * 2200
HP 1 APPRO  491.19 1 491.19
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE beth033.wsp
        CREATED ON 04-DEC-95 FOR BRIDGE BETHTH00310033 USING FILE beth033.dca
        Hydraulic analysis for Bethel bridge 33 by MAI
           *** RUN DATE & TIME: 12-08-95  15:17
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      137      9263     30     40                         1656
   486.76           137      9263     30     40  1.00      5     35     1656

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

         WSEL     LEW     REW    AREA         K        Q    VEL
       486.76     5.1    35.0   136.6    9263.    1650.  12.08

X STA.         5.1       10.7       12.3       13.6       14.8       15.8
  A(I)            11.5        7.5        6.5        6.1        5.7
  V(I)            7.15      11.01      12.69      13.60      14.56

X STA.        15.8       16.8       17.8       18.9       19.8       20.8
  A(I)             5.7        5.4        5.5        5.4        5.5
  V(I)           14.51      15.14      15.01      15.14      15.02

X STA.        20.8       23.4       25.4       26.5       27.5       28.4
  A(I)            11.3        8.0        5.8        5.5        5.4
  V(I)            7.29      10.28      14.35      15.13      15.34

X STA.        28.4       29.4       30.3       31.3       32.5       35.0
  A(I)             5.6        5.6        6.2        6.8       11.7
  V(I)           14.66      14.67      13.41      12.19       7.05

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      57.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      257     15813     61     66                         2980
   489.91           257     15813     61     66  1.00     -3     57     2980

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      57.

         WSEL     LEW     REW    AREA         K        Q    VEL
       489.91    -4.4    57.1   256.9   15813.    1650.   6.42

X STA.        -4.4        2.4        4.9        6.8        8.5       10.0
  A(I)            18.9       12.8       11.5       10.8       10.1
  V(I)            4.38       6.43       7.15       7.64       8.17

X STA.        10.0       11.3       12.6       13.9       15.2       16.5
  A(I)             9.8        9.6        9.5        9.7        9.7
  V(I)            8.44       8.56       8.68       8.47       8.51

X STA.        16.5       17.8       19.3       20.8       22.5       24.7
  A(I)             9.9       10.3       10.8       11.2       12.6
  V(I)            8.33       7.99       7.64       7.36       6.54

X STA.        24.7       27.5       33.2       43.3       48.5       57.1
  A(I)            13.6       17.9       21.9       16.0       20.1
  V(I)            6.06       4.62       3.77       5.15       4.10
```

WSPRO OUTPUT FILE (continued)

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

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      171     12548     33     44                         2203
    487.86           171     12548     33     44  1.00      2     35     2203

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

          WSEL     LEW     REW    AREA        K        Q    VEL
        487.86     2.2    35.2   170.8   12548.    2200.  12.88

 X STA.         2.2       10.0       11.9       13.3       14.5       15.6
   A(I)            15.6       10.0        8.4        7.8        7.4
   V(I)            7.07      10.99      13.07      14.16      14.95

 X STA.        15.6       16.7       17.8       18.8       19.8       20.8
   A(I)             6.9        7.0        6.7        6.7        6.7
   V(I)           15.98      15.79      16.31      16.47      16.35

 X STA.        20.8       22.9       25.0       26.1       27.2       28.1
   A(I)            12.3        9.6        7.1        6.8        6.7
   V(I)            8.91      11.43      15.46      16.09      16.53

 X STA.        28.1       29.1       30.2       31.2       32.5       35.2
   A(I)             6.9        7.2        7.5        8.7       14.8
   V(I)           15.83      15.29      14.64      12.70       7.44
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      57.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      338     23931     65     70                         4374
    491.19           338     23931     65     70  1.00     -5     59     4374

     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      57.

          WSEL     LEW     REW    AREA        K        Q    VEL
        491.19    -5.9    59.0   337.8   23931.    2200.   6.51

 X STA.        -5.9        2.0        4.7        6.9        8.7       10.4
   A(I)            26.0       17.3       15.4       14.4       13.8
   V(I)            4.23       6.36       7.13       7.66       7.99

 X STA.        10.4       11.9       13.4       14.8       16.3       17.8
   A(I)            13.0       12.9       12.8       13.0       12.9
   V(I)            8.45       8.50       8.63       8.45       8.50

 X STA.        17.8       19.4       21.1       23.0       25.2       28.2
   A(I)            13.4       13.7       14.7       15.7       17.4
   V(I)            8.22       8.01       7.46       7.00       6.31

 X STA.        28.2       32.9       40.6       45.3       49.8       59.0
   A(I)            20.3       24.7       19.7       19.8       26.6
   V(I)            5.42       4.45       5.57       5.54       4.14
```

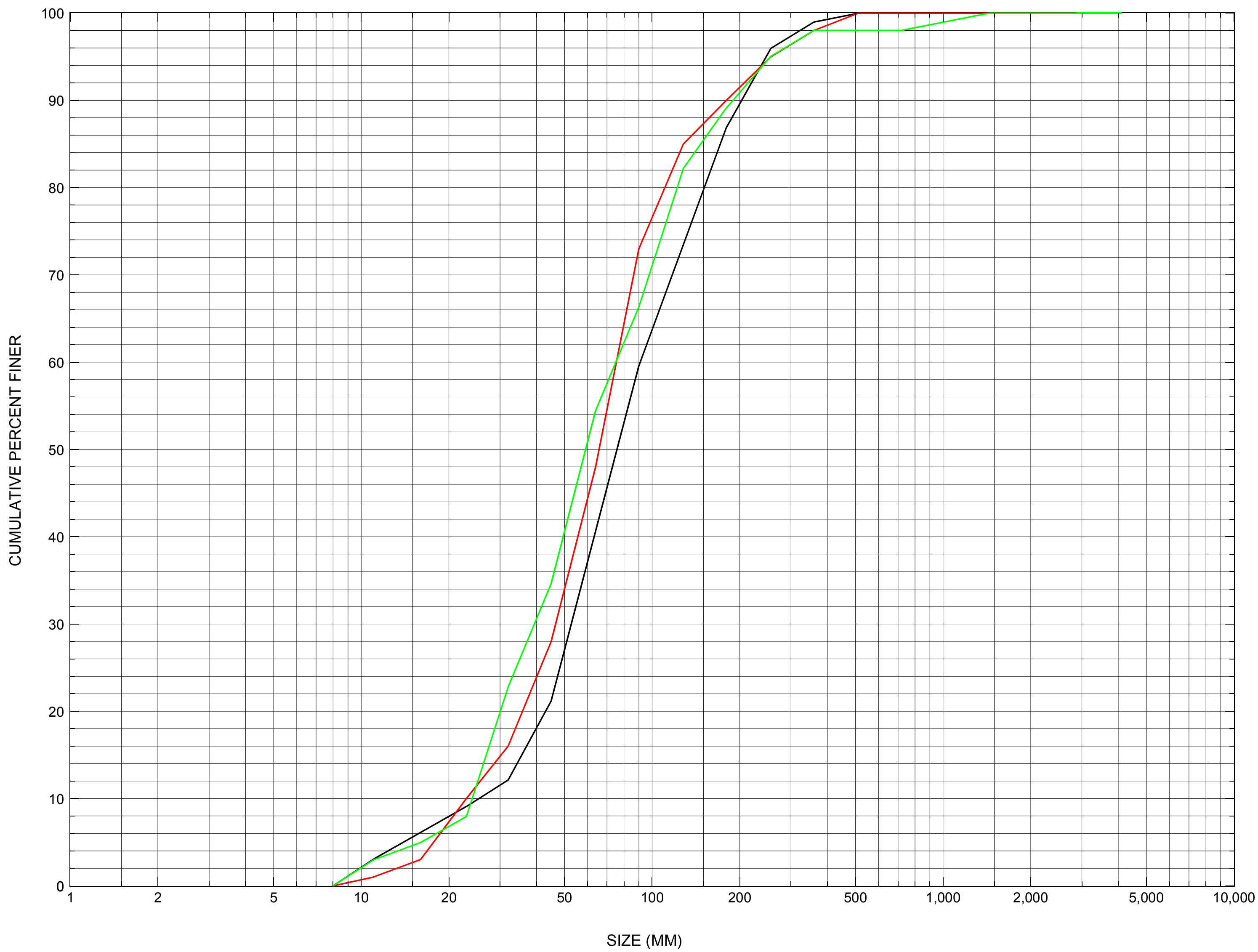
WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******      0      198  1.08 *****  486.12  484.37    1650  485.04
       -61 ******     53    11326  1.00 ***** *******    0.77    8.33

 ===125 FR# EXCEEDS FNTEST AT SECID “FULLV”:  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.96     486.52     486.42

 ===110 WSEL NOT FOUND AT SECID “FULLV”:  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   484.54     500.93    0.50

 ===115 WSEL NOT FOUND AT SECID “FULLV”:  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   484.54     500.93     486.42

FULLV:FV       62      0      168  1.50  1.69  488.02  486.42    1650  486.52
         0     62     52     8825  1.00  0.21    0.00    0.96    9.83
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
            FNTEST,FR#,WSEL,CRWS =  0.80    0.91     488.64     488.44

 ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   486.02     504.40    0.50

 ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   486.02     504.40     488.44

APPRO:AS       57     -2      180  1.30  1.92  489.93  488.44    1650  488.63
        57     57     55     9178  1.00  0.00   -0.01    0.91    9.14
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                 SECID “BRIDG”     Q,CRWS =    1650.     486.76

            <<<<<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       62      5      137  2.27 *****  489.03  486.76    1650  486.76
         0     62     35     9253  1.00 ***** *******    1.00   12.09

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.        <<<<<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       27     -3      257  0.64  0.56  490.55  488.44    1650  489.91
        57     30     57    15813  1.00  0.96   -0.01    0.55    6.42

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.491  0.086   14526.    -1.    29.   489.46

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -62.    -1.    53.   1650.   11326.     198.    8.33  485.04
   FULLV:FV       0.     0.    52.   1650.    8825.     168.    9.83  486.52
   BRIDG:BR       0.     5.    35.   1650.    9253.     137.   12.09  486.76
   RDWAY:RG       9.**************      0.******************     2.00********
   APPRO:AS      57.    -4.    57.   1650.   15813.     257.    6.42  489.91

SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX     HF    HO   VHD      EGL     WSEL
   EXITX:XS    484.37    0.77  479.13  498.88************  1.08  486.12  485.04
   FULLV:FV    486.42    0.96  481.18  500.93  1.69  0.21  1.50  488.02  486.52
   BRIDG:BR    486.76    1.00  480.74  497.52************  2.27  489.03  486.76
   RDWAY:RG  ****************  499.67  511.01*********************************
   APPRO:AS    488.44    0.55  482.45  504.40  0.56  0.96  0.64  490.55  489.91
```

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

EXITX:XS   ******     -1      241  1.30 *****  487.11  485.10    2200  485.81
       -61 ******     54    15105  1.00 ***** *******    0.78    9.15

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.97     487.23     487.15

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   485.31     500.93    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   485.31     500.93     487.15

FULLV:FV       62      0      205  1.78  1.66  489.01  487.15    2200  487.23
         0     62     53    11967  1.00  0.24    0.00    0.97   10.71
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.91     489.32     489.09

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   486.73     504.40    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   486.73     504.40     489.09

APPRO:AS       57     -3      220  1.55  1.85  490.86  489.09    2200  489.30
        57     57     56    12472  1.00  0.00    0.00    0.92   10.00
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID "BRIDG"     Q,CRWS =    2200.     487.86

            <<<<<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       62      2      171  2.58 *****  490.44  487.86    2200  487.86
         0     62     35    12540  1.00 ***** *******    1.00   12.89

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.        <<<<<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       27     -5      338  0.66  0.48  491.85  489.09    2200  491.19
        57     30     59    23910  1.00  0.93    0.00    0.50    6.52

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.488  0.158   20166.    -3.    30.   490.83
                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -62.    -2.    54.   2200.   15105.     241.    9.15  485.81
   FULLV:FV       0.    -1.    53.   2200.   11967.     205.   10.71  487.23
   BRIDG:BR       0.     2.    35.   2200.   12540.     171.   12.89  487.86
   RDWAY:RG       9.**************      0.*****************     2.00********
   APPRO:AS      57.    -6.    59.   2200.   23910.     338.    6.52  491.19

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    485.10    0.78  479.13  498.88************  1.30  487.11  485.81
   FULLV:FV    487.15    0.97  481.18  500.93  1.66  0.24  1.78  489.01  487.23
   BRIDG:BR    487.86    1.00  480.74  497.52************  2.58  490.44  487.86
   RDWAY:RG  ****************  499.67  511.01********************************
   APPRO:AS    489.09    0.50  482.45  504.40  0.48  0.93  0.66  491.85  491.19
```

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 BETHTH00310033, in Bethel, Vermont.

APPENDIX D:

HISTORICAL DATA FORM