LEVEL II SCOUR ANALYSIS FOR BRIDGE 49 (BETHTH00790049) on TOWN HIGHWAY 79, crossing LOCUST CREEK, BETHEL, VERMONT

U.S. Geological Survey
Open-File Report 96-303

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

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By MICHAEL A. IVANOFF and SCOTT A. OLSON

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

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Denver, CO 80225

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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 49 (BETHTH00790049) ON TOWN HIGHWAY 79, CROSSING LOCUST CREEK, BETHEL, VERMONT

By **Michael A. Ivanoff and Scott A. Olson**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BETHTH00790049 on town highway 79 crossing Locust Creek, 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 24.4-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks are forested.

In the study area, Locust Creek has an incised, sinuous channel with a slope of approximately 0.015 ft/ft, an average channel top width of 74 ft and an average channel depth of 6 ft. The predominant channel bed material is gravel and cobble (D_{50} is 124 mm or 0.407 ft). The geomorphic assessment at the time of the Level I and Level II site visit on September 21 & 26, 1994, respectively, with a check on 12/15/94, indicated that the reach was stable.

The town Highway 79 crossing of Locust Creek is a 55-ft-long, one-lane bridge consisting of one 50-foot concrete span (Vermont Agency of Transportation, written commun., August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 50 degrees to the opening while the opening-skew-to-roadway is 45 degrees.

Scour protection measures in place at the site were type-1 stone fill (less than 12 inches diameter) at the upstream right and downstream left road embankment, type-2 stone fill (less than 36 inches diameter) at the upstream left bank, upstream wingwalls, and downstream left 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 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 these computed results follow.

Contraction scour for all modelled flows ranged from 0.0 ft to 1.0 ft. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 10.3 ft to 13.3 ft. with the worst-case abutment scour also occurring at the 100-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 depths, are presented in tables 1 and 2. A cross-section of the computed scour 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. 22). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection, 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.

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.

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LEVEL II SUMMARY

Structure Number BETHTH00790049 ***Stream*** Locust Creek

County Windsor ***Road*** TH 79 ***District*** 04

Description of Bridge

Bridge length 55.0 ***ft*** ***Bridge width*** 50.0 ***ft*** ***Max span length*** 23.4 ***ft***

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

Abutment type Concrete ***Embankment type*** Sloping

Stone fill on abutment? No ***Date of inspection*** 9/21 & 12/15/94

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

Concrete abutments and wingwalls.

Y 50

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

There is a mild bend in the channel into the upstream bridge face and a moderate bend in the channel downstream of 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	9/21 &12/15/94	0	0
Level II	9/26/94	--	--

Potential for debris Moderate due to steep banks and forested setting.

Describe any features near or at the bridge that may affect flow (include observation date) 9/21 & 12/15/94 -- None

Description of the Geomorphic Setting

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

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

Date of inspection 9/21 &12/15/94

DS left: Steep channel bank with town highway 79 parallel to the stream

DS right: Steep valley wall

US left: Moderate channel bank slope to a narrow floodplain

US right: Moderate channel bank slope with town highway 79 parallel to the stream

Description of the Channel

Average top width 74 ***ft***

Average depth 6 ***ft***

Predominant bed material Gravel / Cobbles

Bank material Cobbles

Narrow, incised channel with only slight sinuosity.

9/21 & 12/15/94

Vegetative co

forested with town highway 79 parallel to the stream

DS left: forested

DS right: forested with grass on the narrow floodplain near the bridge

US left: forested with town highway 79 parallel to the stream

US right:

Do banks appear stable? Y

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

9/21/94 & 12/15/94-- Assessed as stable, however slight fluvial erosion noted on both downstream banks. Also, a cut bank and point bar were noted downstream. See appendix E for more details.

Describe any obstructions in channel and date of observation.

9/26/94 -- None

Hydrology

Drainage area 24.4 ***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; 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/p No

Calculated Discharges

Q100 4250 ***ft³/s*** ***Q500*** 5500 ***ft³/s***

The 100- and 500-year discharges were selected from a range of values defined by several empirical methods applicable to a watershed of this size in this region (Benson, 1962; Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887) and a drainage area relationship [(24.4/24.1) to the 0.7 power] with Barnard bridge #35, also on Locust Creek. Barnard bridge #35 had flood frequency estimates available from VTAOT (written communication, May 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 Add 0.48 ft. to USGS survey to obtain VTAOT plans' datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled X in a chiseled square on top of the US end of the left abutment (elev. 499.84 ft, arbitrary datum). RM2 is a chiseled X in a chiseled square on top of the DS end of the left abutment (elev. 499.68 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-58	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	18	1	Road Grade section
APPRO	61	2	Modelled Approach section (Templated from ATEMP)
ATEMP	100	1	Approach section as surveyed (Used as a template)

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

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). 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 0.047 to 0.054.

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

The surveyed approach section (ATEMP) was moved along the approach channel slope (0.025 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

The modeled 100 and 500-yr discharges overtop the roadway embankment. The incipient overtopping discharge was determined to be 3020 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.7 *ft*
Average low steel elevation 496.2 *ft*

100-year discharge 4,250 *ft³/s*
Water-surface elevation in bridge opening 496.4 *ft*
Road overtopping? Y *Discharge over road* 544 *ft³/s*
Area of flow in bridge opening 305 *ft²*
Average velocity in bridge opening 12.2 *ft/s*
Maximum WSPRO tube velocity at bridge 14.2 *ft/s*

Water-surface elevation at Approach section with bridge 499.8
Water-surface elevation at Approach section without bridge 496.9
Amount of backwater caused by bridge 2.9 *ft*

500-year discharge 5,500 *ft³/s*
Water-surface elevation in bridge opening 496.4 *ft*
Road overtopping? Y *Discharge over road* 1902 *ft³/s*
Area of flow in bridge opening 305 *ft²*
Average velocity in bridge opening 11.8 *ft/s*
Maximum WSPRO tube velocity at bridge 13.7 *ft/s*

Water-surface elevation at Approach section with bridge 500.6
Water-surface elevation at Approach section without bridge 498.0
Amount of backwater caused by bridge 2.6

Incipient overtopping discharge 3,020 *ft³/s*
Water-surface elevation in bridge opening 496.4 *ft*
Area of flow in bridge opening 305 *ft²*
Average velocity in bridge opening 9.7 *ft/s*
Maximum WSPRO tube velocity at bridge 11.4 *ft/s*

Water-surface elevation at Approach section with bridge 498.9
Water-surface elevation at Approach section without bridge 495.5
Amount of backwater caused by bridge 3.4 *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 contraction scour equation (Richardson and others, 1995, p. 145-146) for the 100-year and 500-year 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 (Richardson and others, 1995, p. 35, equation 18) were also computed and can be found in appendix F. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

The length to depth ratio of the embankment blocking flow exceeded 25 in all cases except for left abutment at the incipient roadway overflow discharge. Although the HIRE equation (Richardson and others, 1993, p. 50, equation 25) is applicable when this ratio exceeds 25, the results from the HIRE equation were not used. Hydraulic Engineering Circular 18 recommends that the field conditions are similar to the field conditions from which the HIRE equation was derived (Richardson and others, 1993). Since the equation was developed from Army Corp of Engineers' data obtained for spur dikes in the Mississippi River, the HIRE equation was not adopted for the upland V-shaped valley in this study.

The 100-year discharge analysis resulted in the worst case contraction and total scour. Thus, figure 8 only displays the 100-year scour depths.

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	1.0	0.7	0
Depth to armoring	7.2	5.7	2.0
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	12.8	10.3	12.8
Right abutment	13.3	13.3	12.4
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	3.5	3.4	2.6
Right abutment	3.5	3.4	2.6
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--
	--	--	--

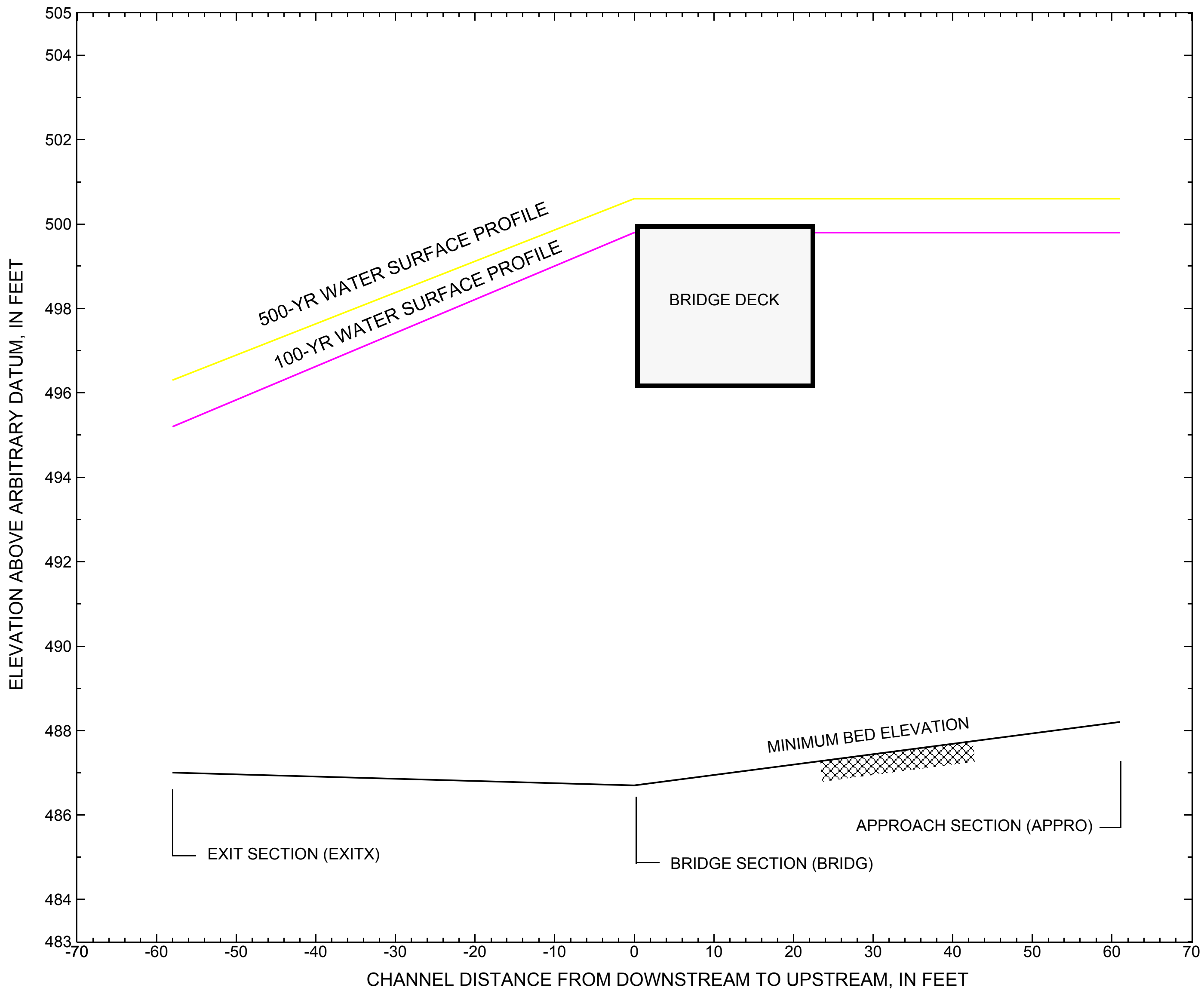

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BETHTH00790049 on town highway 79, crossing Locust Creek, Bethel, Vermont.

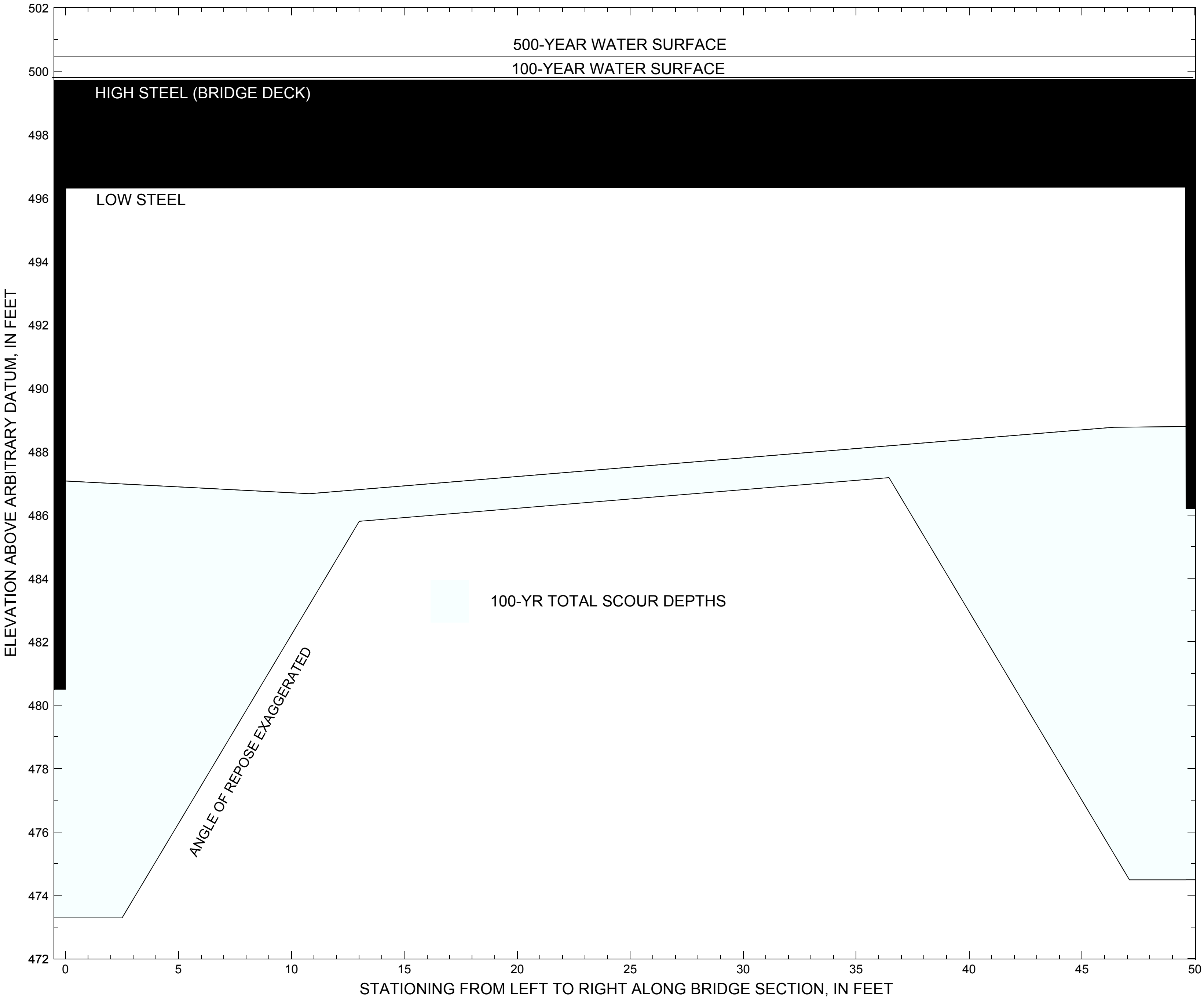

Figure 8. Scour elevations for the 100-year discharge at structure BETHTH00790049 on town highway 79, crossing Locust Creek, Bethel, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BETHTH00790049 on Town highway 79, crossing Locust Creek, 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 4,250 cubic-feet per second											
Left abutment	0.0	496.7	496.4	480.5	487.1	1.0	12.8	--	13.8	473.3	-7
Right abutment	49.7	496.7	496.2	486.5	488.8	1.0	13.3	--	14.3	474.5	-12

[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 BETHTH00790049 on Town Highway 79, crossing Locust Creek, 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 5,500 cubic-feet per second											
Left abutment	0.0	496.7	496.4	480.5	487.1	0.7	10.3	--	11.0	476.1	-4
Right abutment	49.7	496.7	496.2	486.5	488.8	0.7	13.3	--	14.0	474.8	-12

[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 beth049.wsp
T2        Hydraulic analysis for structure BETHTH00790049   Date: 11-MAR-96
T3        Hydraulic analysis for Bethel bridge 49 over Locust Creek by MAI
Q           4250.0   5500.0   3020.0
SK          0.0150   0.0150   0.0150
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -58           0.
GR         -100.7, 499.57    -47.9, 498.94    -32.1, 498.62    -26.4, 498.53
GR           -7.6, 489.90      0.0, 488.34     13.0, 487.00     17.6, 487.64
GR           21.2, 486.99     33.2, 488.28     40.1, 490.33     43.3, 492.51
GR           49.8, 492.25     82.0, 513.81
*
N           0.032        0.054
SA                 -26.4
*
XS   FULLV      0  * * *  -0.0064
*
*            SRD     LSEL    XSSKEW
BR   BRIDG     0    496.15      45.0
GR            0.0, 496.42      0.0, 488.60      0.2, 487.09     10.8, 486.67
GR           46.4, 488.77     49.6, 488.79     49.7, 496.15      0.0, 496.42
*
*        BRTYPE  BRWDTH       WWANGL    WWWID
CD          1      48.0 * *     40.3     13.1
N           0.047
*
*            SRD    EMBWID   IPAVE
XR   RDWAY     18      23.4     2
GR         -161.8, 500.30   -123.1, 499.57    -57.6, 498.96      0.0, 499.69
GR            0.0, 503.46     27.6, 503.53     49.7, 503.39     49.7, 499.76
GR           94.1, 499.02    155.5, 499.53    238.9, 500.82    378.5, 502.97
*
XT   ATEMP    100           0.
GR         -105.8, 508.27    -88.5, 504.77    -82.3, 504.86    -69.5, 500.77
GR          -41.6, 498.77    -24.5, 496.87    -15.3, 497.17      5.1, 490.78
GR            7.7, 490.36     23.4, 489.15     32.0, 489.56     40.2, 490.23
GR           43.2, 491.26     66.6, 497.99     78.2, 498.99    133.0, 499.53
GR          216.7, 500.82    357.3, 502.97
*
AS   APPRO     61
GT          -0.975
N           0.065        0.052        0.090
SA                 -20.4         61.5
*
HP 1 BRIDG   496.42 1 496.42
HP 2 BRIDG   496.42 * * 3713
HP 2 RDWAY   499.80 * * 544
HP 1 APPRO   499.80 1 499.80
HP 2 APPRO   499.80 * * 4250
*
HP 1 BRIDG   496.42 1 496.42
HP 2 BRIDG   496.42 * * 3578
HP 2 RDWAY   500.61 * * 1902
HP 1 APPRO   500.61 1 500.61
HP 2 APPRO   500.61 * * 5500
*
HP 1 BRIDG   496.42 1 496.42
HP 2 BRIDG   496.42 * * 2962
HP 1 APPRO   498.94 1 498.94
HP 2 APPRO   498.94 * * 3020
*
EX
ER
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APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V042094           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File beth049.wsp
        Hydraulic analysis for structure BETHTH00790049   Date: 11-MAR-96
        Hydraulic analysis for Bethel bridge 49 over Locust Creek by MAI
           *** RUN DATE & TIME: 03-20-96  10:03
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      305     22280      0     87                     15441038
   496.42           305     22280      0     87  1.00      0     50 15441038
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       496.42     0.0    49.7   304.5   22280.    3713.  12.19

X STA.         0.0        3.8        6.2        8.3       10.3       12.3
  A(I)            25.4       15.5       14.6       13.9       13.5
  V(I)            7.30      11.94      12.74      13.40      13.79

X STA.        12.3       14.3       16.2       18.3       20.3       22.4
  A(I)            13.2       13.0       13.2       13.1       13.3
  V(I)           14.03      14.25      14.07      14.16      13.93

X STA.        22.4       24.5       26.7       28.9       31.3       33.7
  A(I)            13.3       13.5       13.7       14.1       14.3
  V(I)           13.99      13.77      13.57      13.12      12.98

X STA.        33.7       36.2       38.9       41.7       44.9       49.7
  A(I)            14.3       15.3       15.4       17.0       24.9
  V(I)           12.98      12.13      12.05      10.91       7.46

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      18.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.80  -135.3   173.0   116.6    2600.     544.   4.67

X STA.      -135.3     -103.8      -92.2      -83.7      -76.6      -70.9
  A(I)             7.6        5.4        4.7        4.4        4.0
  V(I)            3.59       5.05       5.73       6.14       6.84

X STA.       -70.9      -65.7      -61.1      -56.8      -52.5      -47.7
  A(I)             3.8        3.7        3.5        3.4        3.6
  V(I)            7.12       7.45       7.69       7.95       7.56

X STA.       -47.7      -42.2      -35.6      -27.1       73.4       87.0
  A(I)             3.7        4.0        4.3       13.3        7.5
  V(I)            7.33       6.84       6.29       2.05       3.62

X STA.        87.0       96.0      105.3      116.2      131.6      173.0
  A(I)             6.6        6.7        7.0        8.2       11.2
  V(I)            4.14       4.05       3.89       3.31       2.43

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1       94      3332     49     49                          742
             2      701     82613     82     84                        11627
             3      178      3259    152    153                         1090
   499.80           973     89203    283    286  1.54    -69    214     8246
    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.80   -69.5   213.8   972.6   89203.    4250.   4.37

X STA.       -69.5      -15.6       -4.9        0.9        5.1        8.7
  A(I)           112.0       55.8       45.2       39.1       36.6
  V(I)            1.90       3.81       4.70       5.44       5.81

X STA.         8.7       12.0       15.1       18.1       21.0       23.7
  A(I)            34.9       33.9       32.9       33.1       31.6
  V(I)            6.09       6.27       6.46       6.43       6.72

X STA.        23.7       26.5       29.3       32.2       35.1       38.3
  A(I)            32.0       32.6       32.1       32.6       33.8
  V(I)            6.65       6.52       6.63       6.52       6.28

X STA.        38.3       41.5       45.5       50.6       58.2      213.8
  A(I)            34.3       37.8       40.9       48.4      193.1
  V(I)            6.19       5.62       5.20       4.39       1.10
```

WSPRO OUTPUT FILE (continued)

```
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      305     22280      0     87                      15441038
   496.42           305     22280      0     87  1.00      0     50 15441038

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       496.42     0.0    49.7   304.5   22280.    3578.  11.75

X STA.         0.0        3.8        6.2        8.3       10.3       12.3
  A(I)            25.4       15.5       14.6       13.9       13.5
  V(I)            7.04      11.51      12.28      12.91      13.28

X STA.        12.3       14.3       16.2       18.3       20.3       22.4
  A(I)            13.2       13.0       13.2       13.1       13.3
  V(I)           13.52      13.73      13.56      13.64      13.42

X STA.        22.4       24.5       26.7       28.9       31.3       33.7
  A(I)            13.3       13.5       13.7       14.1       14.3
  V(I)           13.48      13.27      13.08      12.65      12.51

X STA.        33.7       36.2       38.9       41.7       44.9       49.7
  A(I)            14.3       15.3       15.4       17.0       24.9
  V(I)           12.51      11.69      11.61      10.52       7.19

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      18.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.61  -161.8   225.3   362.1   13839.    1902.   5.25

X STA.      -161.8     -128.6     -113.4     -101.2      -90.6      -81.5
  A(I)            20.7       16.0       14.5       13.6       12.7
  V(I)            4.60       5.95       6.55       6.99       7.51

X STA.       -81.5      -73.1      -65.3      -58.3      -51.3      -43.8
  A(I)            12.3       12.0       11.4       11.3       11.3
  V(I)            7.73       7.93       8.37       8.42       8.39

X STA.       -43.8      -35.4      -25.6       -4.3       71.2       87.0
  A(I)            11.9       12.8       23.7       26.2       21.2
  V(I)            7.96       7.41       4.02       3.63       4.48

X STA.        87.0      100.2      115.2      132.4      154.9      225.3
  A(I)            20.5       22.0       23.1       26.5       38.4
  V(I)            4.65       4.32       4.11       3.58       2.48

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      135      5857     52     52                          1240
             2      767     96058     82     84                         13317
             3      323      7212    205    205                          2294
   500.61          1225    109127    339    341  1.76    -71    267     9970

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.61   -72.1   266.7  1224.6  109127.    5500.   4.49

X STA.       -72.1      -21.8       -8.2       -1.2        3.7        7.6
  A(I)           128.7       68.6       54.5       47.2       42.1
  V(I)            2.14       4.01       5.05       5.83       6.54

X STA.         7.6       11.2       14.6       17.8       20.9       24.0
  A(I)            40.6       39.5       38.3       37.3       38.0
  V(I)            6.77       6.97       7.18       7.37       7.23

X STA.        24.0       27.0       30.0       33.2       36.4       39.8
  A(I)            37.2       36.7       38.0       37.6       39.9
  V(I)            7.40       7.48       7.24       7.30       6.88

X STA.        39.8       43.7       48.4       54.7       77.1      266.7
  A(I)            41.6       45.4       49.4       96.3      267.5
  V(I)            6.61       6.05       5.57       2.86       1.03
```

WSPRO OUTPUT FILE (continued)

```
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      305     22280      0     87                     15441038
    496.42           305     22280      0     87  1.00      0     50 15441038

     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
          WSEL     LEW     REW    AREA        K        Q    VEL
        496.42     0.0    49.7   304.5   22280.    2962.   9.73

 X STA.        0.0        3.8        6.2        8.3       10.3       12.3
   A(I)            25.4       15.5       14.6       13.9       13.5
   V(I)            5.83       9.53      10.16      10.69      11.00

 X STA.       12.3       14.3       16.2       18.3       20.3       22.4
   A(I)            13.2       13.0       13.2       13.1       13.3
   V(I)           11.19      11.37      11.22      11.30      11.11

 X STA.       22.4       24.5       26.7       28.9       31.3       33.7
   A(I)            13.3       13.5       13.7       14.1       14.3
   V(I)           11.16      10.99      10.83      10.47      10.35

 X STA.       33.7       36.2       38.9       41.7       44.9       49.7
   A(I)            14.3       15.3       15.4       17.0       24.9
   V(I)           10.35       9.68       9.61       8.71       5.95

     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1       57      1742     37     37                          402
              2      630     69239     82     84                         9918
              3       71       952     96     97                          344
    498.94           758     71933    216    218  1.29    -57    158     7093

     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      61.
          WSEL     LEW     REW    AREA        K        Q    VEL
        498.94   -57.6   158.0   758.1   71933.    3020.   3.98

 X STA.      -57.6      -10.3       -2.2        2.8        6.5        9.7
   A(I)            89.3       45.2       37.8       33.6       30.8
   V(I)            1.69       3.34       4.00       4.49       4.90

 X STA.        9.7       12.8       15.7       18.4       21.1       23.7
   A(I)            30.0       29.1       28.3       28.4       27.2
   V(I)            5.04       5.19       5.34       5.32       5.56

 X STA.       23.7       26.2       28.9       31.5       34.2       37.1
   A(I)            27.3       27.8       27.4       27.9       29.0
   V(I)            5.53       5.42       5.51       5.41       5.21

 X STA.       37.1       40.0       43.4       47.7       53.6      158.0
   A(I)            28.8       31.1       34.5       38.0      106.7
   V(I)            5.24       4.86       4.38       3.97       1.42
```

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   ******    -18      411  1.66 *****  496.91  494.26    4250  495.25
       -57 ******     54    34683  1.00 ***** *******    0.77   10.33

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "FULLV"     KRATIO =  1.47

FULLV:FV       58    -22      537  0.97  0.59  497.49 *******    4250  496.52
         0     58     57    51082  1.00  0.00   -0.01    0.54    7.92
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       61    -32      471  1.31  0.52  498.18 *******    4250  496.87
        61     61     66    41194  1.04  0.17   -0.01    0.74    9.02
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   496.52     496.15

            <<<<<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       58      0      305  2.31 *****  498.73  494.65    3713  496.42
         0 ******     50    22280  1.00 ***** *******    0.87   12.19

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  496.15 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.    38.  0.09  0.46  500.17    0.00    544.  499.80

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    295.   135.  -135.     0.   0.8   0.5   3.9   4.6   0.8   2.8
   RT:    249.   123.    50.   173.   0.8   0.4   3.8   4.7   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       13    -69      973  0.46  0.13  500.26  495.41    4250  499.80
        61     17    214    89257  1.54  0.00    0.00    0.52    4.37

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -58.   -19.    54.   4250.   34683.     411.   10.33  495.25
   FULLV:FV       0.   -23.    57.   4250.   51082.     537.    7.92  496.52
   BRIDG:BR       0.     0.    50.   3713.   22280.     305.   12.19  496.42
   RDWAY:RG      18.*******   295.    544.*********       0.    2.00  499.80
   APPRO:AS      61.   -70.   214.   4250.   89257.     973.    4.37  499.80

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    494.26    0.77  486.99  513.81************  1.66  496.91  495.25
   FULLV:FV  ********    0.54  486.62  513.44  0.59  0.00  0.97  497.49  496.52
   BRIDG:BR    494.65    0.87  486.67  496.42************  2.31  498.73  496.42
   RDWAY:RG  ****************  498.96  503.53  0.09******  0.46  500.17  499.80
   APPRO:AS    495.41    0.52  488.17  507.29  0.13  0.00  0.46  500.26  499.80
```

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   ******    -21      491  1.95 *****  498.26  495.23    5500  496.31
       -57 ******     56    44890  1.00 ***** *******    0.78   11.20

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "FULLV"     KRATIO =  1.44

FULLV:FV       58    -24      632  1.18  0.61  498.86 *******    5500  497.68
         0     58     58    64494  1.00  0.00    0.00    0.56    8.71
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       61    -44      601  1.44  0.50  499.49 *******    5500  498.04
        61     61     81    57249  1.11  0.13    0.00    0.78    9.15
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   497.68     496.15

 ===265 ROAD OVERFLOW APPEARS EXCESSIVE.
                   QRD,QRDMAX,RATIO =    1902.      1855.    1.03

            <<<<<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       58      0      305  2.15 *****  498.57  494.48    3578  496.42
         0 ******     50    22280  1.00 ***** *******    0.84   11.75

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  496.15 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.    38.  0.10  0.55  501.06    0.00   1902.  500.61

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    989.   162.  -162.     0.   1.6   1.2   5.7   5.3   1.6   3.0
   RT:    913.   176.    50.   225.   1.6   1.0   5.4   5.3   1.4   3.0

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

APPRO:AS       13    -71     1224  0.55  0.13  501.16  496.51    5500  500.61
        61     16    267   109086  1.76  0.00    0.00    0.55    4.49

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -58.   -22.    56.   5500.   44890.     491.   11.20  496.31
   FULLV:FV       0.   -25.    58.   5500.   64494.     632.    8.71  497.68
   BRIDG:BR       0.     0.    50.   3578.   22280.     305.   11.75  496.42
   RDWAY:RG      18.*******   989.   1902.******************    2.00  500.61
   APPRO:AS      61.   -72.   267.   5500.  109086.    1224.    4.49  500.61

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    495.23    0.78  486.99  513.81************  1.95  498.26  496.31
   FULLV:FV  ********    0.56  486.62  513.44  0.61  0.00  1.18  498.86  497.68
   BRIDG:BR    494.48    0.84  486.67  496.42************  2.15  498.57  496.42
   RDWAY:RG  ****************  498.96  503.53  0.10******  0.55  501.06  500.61
   APPRO:AS    496.51    0.55  488.17  507.29  0.13  0.00  0.55  501.16  500.61
```

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   ******    -16      326  1.33 *****  495.39  493.15    3020  494.06
       -57 ******     52    24646  1.00 ***** *******    0.75    9.26

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "FULLV"     KRATIO =  1.53

FULLV:FV       58    -19      435  0.75  0.57  495.95 *******    3020  495.20
         0     58     55    37684  1.00  0.00   -0.01    0.51    6.94
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       61    -12      354  1.13  0.52  496.66 *******    3020  495.53
        61     61     61    28207  1.00  0.19   -0.01    0.69    8.52
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   493.86     497.45     497.60     496.15

 ===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       58      0      305  1.47 *****  497.89  493.67    2962  496.42
         0 ******     50    22280  1.00 ***** *******    0.69    9.73

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.492  0.000  496.15 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.        <<<<<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       13    -57      757  0.32  0.09  499.26  494.28    3020  498.94
        61     16    158    71864  1.29  1.15   -0.02    0.43    3.99

  FIRST USER DEFINED TABLE.

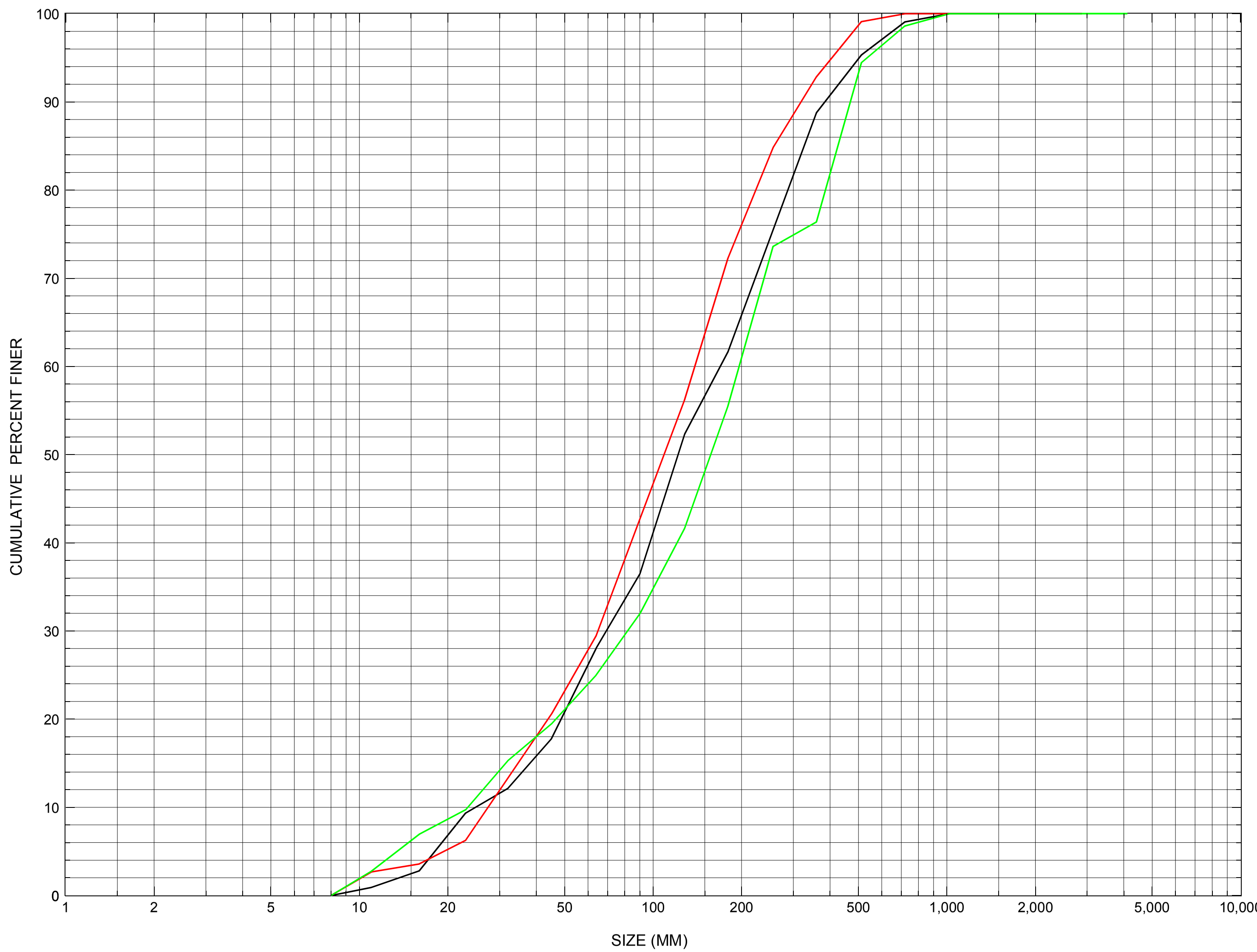
    XSID:CODE     SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -58.   -17.    52.   3020.   24646.     326.    9.26  494.06
   FULLV:FV       0.   -20.    55.   3020.   37684.     435.    6.94  495.20
   BRIDG:BR       0.     0.    50.   2962.   22280.     305.    9.73  496.42
   RDWAY:RG      18.**************       0.******************    2.00********
   APPRO:AS      61.   -58.   158.   3020.   71864.     757.    3.99  498.94

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXITX:XS    493.15    0.75  486.99  513.81************  1.33  495.39  494.06
   FULLV:FV  ********    0.51  486.62  513.44  0.57  0.00  0.75  495.95  495.20
   BRIDG:BR    493.67    0.69  486.67  496.42************  1.47  497.89  496.42
   RDWAY:RG  ****************  498.96  503.53************  0.11  501.81********
   APPRO:AS    494.28    0.43  488.17  507.29  0.09  1.15  0.32  499.26  498.94
```

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 BETHTH00790049, in Bethel, Vermont.

APPENDIX D:

HISTORICAL DATA FORM