LEVEL II SCOUR ANALYSIS FOR BRIDGE 31 (BRNATH00470031) on TOWN HIGHWAY 47, crossing LOCUST CREEK, BARNARD, VERMONT

U.S. Geological Survey
Open-File Report 96-384

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

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By Erick M. Boehmler and Micheal A. Ivanoff

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Pembroke, New Hampshire

1996

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

BF	bank full	LWW	left wingwall
cfs	cubic feet per second	MC	main channel
D_{50}	median diameter of bed material	RAB	right abutment
DS	downstream	RABUT	face of right abutment
elev.	elevation	RB	right bank
f/p	flood plain	ROB	right overbank
ft^2	square feet	RWW	right wingwall
ft/ft	feet per foot	TH	town highway
JCT	junction	UB	under bridge
LAB	left abutment	US	upstream
LABUT	face of left abutment	USGS	United States Geological Survey
LB	left bank	VTAOT	Vermont Agency of Transportation
LOB	left overbank	WSPRO	water-surface profile model

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 31 (BRNATH00470031) ON TOWN HIGHWAY 47, CROSSING LOCUST CREEK, BARNARD, VERMONT

***By* Erick M. Boehmler and Micheal A. Ivanoff**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRNATH00470031 on town highway 47 crossing Locust Creek, Barnard, 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, gleaned 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 Barnard. The 4.47-mi^2 drainage area is a predominantly rural and forested basin. In the vicinity of the study site, the banks have dense woody vegetation coverage except for areas of grass and brush on the upstream banks.

In the study area, Locust Creek has an incised, sinuous channel with a slope of approximately 0.006 ft/ft, an average channel top width of 34 ft and an average channel depth of 3 ft. The predominant channel bed materials are gravel and cobble (D_{50} is 55.2 mm or 0.181 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 12, 1994, indicated that the reach was stable.

The town highway 47 crossing of Locust Creek is a 28-ft-long, one-lane bridge consisting of one 25-foot span concrete slab superstructure (Vermont Agency of Transportation, written commun., August 23, 1994). The bridge is supported by vertical, concrete abutments with concrete wingwalls. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is 15 degrees.

The scour protection measures at the site were type-2 stone fill (less than 36 inches diameter) on the right and left abutments and all wingwalls. The banks upstream and downstream are not protected. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 1.5 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 6.6 to 9.2 ft. The worst-case abutment scour also occurred at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1993, p. 48). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

Delectable Mountain, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

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 BRNATH00470031 *Stream* Locust Creek

County Windsor *Road* TH 47 *District* 04

Description of Bridge

Bridge length 28 *ft* *Bridge width* 17.5 *ft* *Max span length* 25 *ft*

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

Abutment type Vertical *Embankment type* Vertical

Stone fill on abutment? Yes *Date of inspection* 10/12/94

Description of stone fill Type-2 on the right and left abutments, upstream left and right wingwall, and downstream left and right wingwall.

Abutments and wingwalls are concrete.

Is bridge skewed to flood flow according to N *survey?* Y *Angle* 20

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	10/12/94	0	0
Level II	10/12/94	--	--

Potential for debris Moderate. While the channel is stable overall, there is some localized zones of lateral instability noted with a high percentage of bank tree cover.

Describe any features near or at the bridge that may affect flow (include observation date) On 10/12/94, the stone fill along the abutments was noted to constrict flow in the lowest quarter of the bridge opening.

Description of the Geomorphic Setting

General topography The channel is located within a 185 foot-wide valley, with steep to moderately sloping valley walls on both sides.

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

Date of inspection 10/12/94

DS left: Gradually sloping channel bank to steep valley wall.

DS right: Gradually sloping channel bank to moderately sloping valley wall.

US left: Moderately sloping channel bank to steep valley wall

US right: Moderately sloping channel bank to moderately sloped valley wall.

Description of the Channel

Average top width 34 ***ft*** ***Average depth*** 3 ***ft***

Predominant bed material Gravel / Cobble ***Bank material*** Cobble / Boulder

Sinuous but stable with semi-alluvial to non-alluvial channel boundaries and no flood plains.

10/12/94

Vegetative co

Trees and shrubs

DS left: Trees, shrubs, and brush

DS right: Grass and brush giving way to trees and brush.

US left: Grass and brush giving way to trees, shrubs, and brush.

US right:

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

Localized zones of instability are evident beyond the study area. A cut-bank is noted on the left bank upstream with some trees leaning over the channel.

The assessment of 10/12/94 indicated the stone fill on each abutment constricts the lowest quarter of the channel through the bridge.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 4.47 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	*Percent of drainage area*
Green Mountain	100

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

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

USGS gage description

USGS gage number

Gage drainage area ***mi²***

Is there a lake/p [illegible] No

Calculated Discharges

Q100 1,200 ***ft³/s*** ***Q500*** 1,600 ***ft³/s***

The 100-year discharge is taken from flood frequency estimates in the VTAOT database (VTAOT, written communication, May 4, 1995). The 500-year discharge was extrapolated from the available data. The discharges used in the model were in a range defined by several empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; Benson, 1962; FHWA, 1983; Talbot, 1887).

Description of the Water-Surface Profile Model (WSPRO) Analysis

Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans) USGS survey

Datum tie between USGS survey and VTAOT plans Add 1597 feet to the USGS survey to obtain VTAOT plan's datum.

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. 96.76 ft, arbitrary datum). RM2 is a chiseled "X" on top of the US end of the right abutment (elev. 96.92 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-36	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	12	1	Road Grade section
APPRO	47	2	Modelled Approach section (Templated from APTEM)
APTEM	59	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 and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.045 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 0.006 ft/ft which was estimated from surveyed thalweg points downstream of the site.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.0291 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-year discharges do not overtop the roadway embankments or the bridge deck.

Although the upstream channel is skewed to the bridge opening, flow was assumed to align with the abutment walls when passing through the bridge.

Bridge Hydraulics Summary

Average bridge embankment elevation 97.8 *ft*
Average low steel elevation 95.8 *ft*

100-year discharge 1,200 *ft³/s*
Water-surface elevation in bridge opening 90.4 *ft*
Road overtopping? N *Discharge over road* 0 *ft³/s*
Area of flow in bridge opening 118 *ft²*
Average velocity in bridge opening 10.2 *ft/s*
Maximum WSPRO tube velocity at bridge 12.5 *ft/s*

Water-surface elevation at Approach section with bridge 91.7
Water-surface elevation at Approach section without bridge 91.2
Amount of backwater caused by bridge 0.5 *ft*

500-year discharge 1,600 *ft³/s*
Water-surface elevation in bridge opening 91.3 *ft*
Road overtopping? N *Discharge over road* 0 *ft³/s*
Area of flow in bridge opening 137 *ft²*
Average velocity in bridge opening 11.7 *ft/s*
Maximum WSPRO tube velocity at bridge 14.6 *ft/s*

Water-surface elevation at Approach section with bridge 93.2
Water-surface elevation at Approach section without bridge 92.2
Amount of backwater caused by bridge 1.0

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 500-year discharge. For the 100-year discharge, contraction scour was computed by use of the live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16). 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. In this case, the 500-year discharge model resulted in the worst case contraction scour with a scour depth of 1.5 ft. Armoring depths computed suggest that streambed armoring will not limit the depth of contraction scour.

Abutment scour for each modelled discharge was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). 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	0.0	1.5	--
Clear-water scour	--	--	--
Depth to armoring	9.8	26.2	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	7.1	9.2	--
Right abutment	6.6	7.8	--
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	2.0	2.4	--
Right abutment	2.0	2.4	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

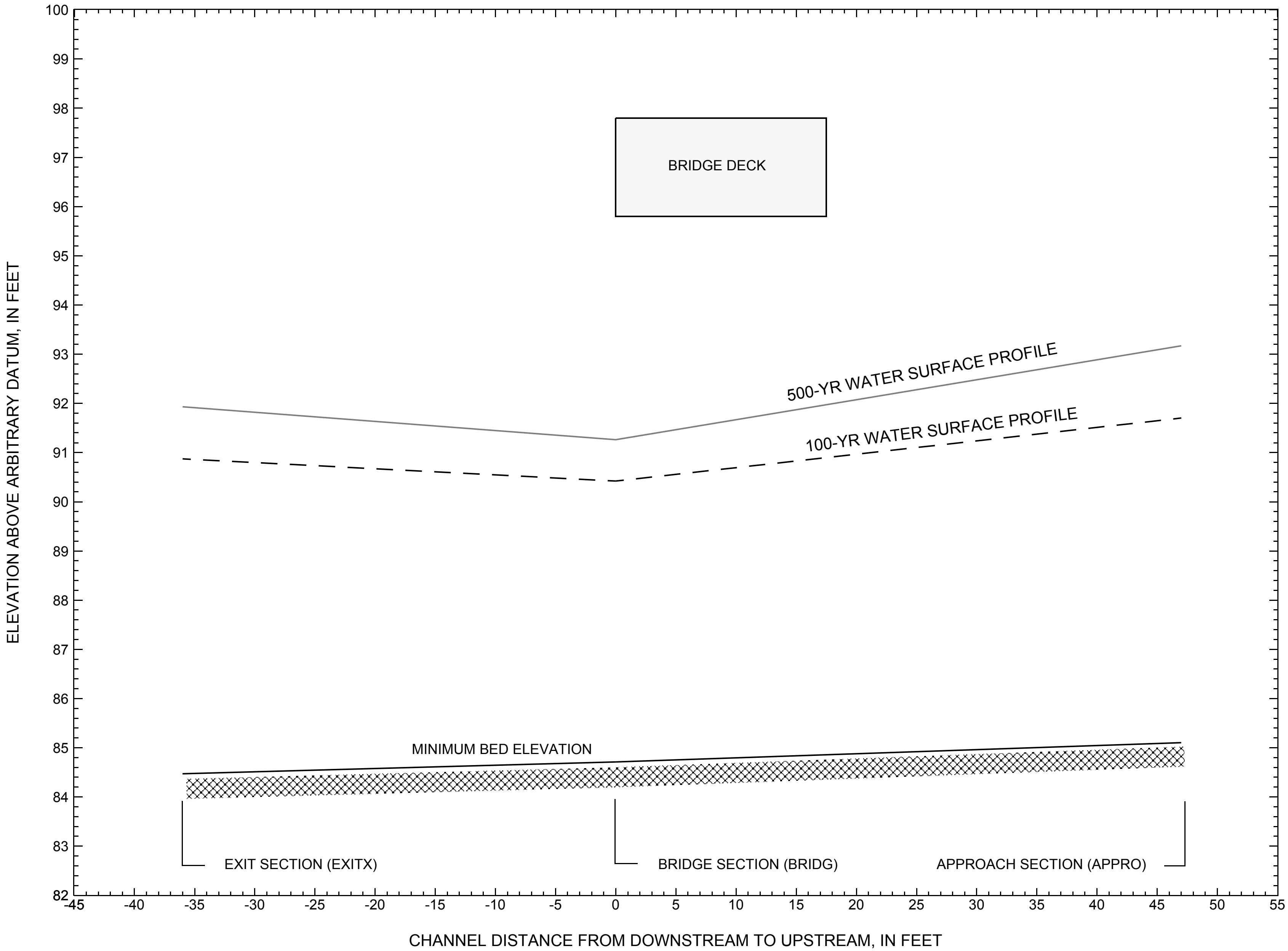

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRNATH00470031 on town highway 47, crossing Locust Creek, Barnard, Vermont.

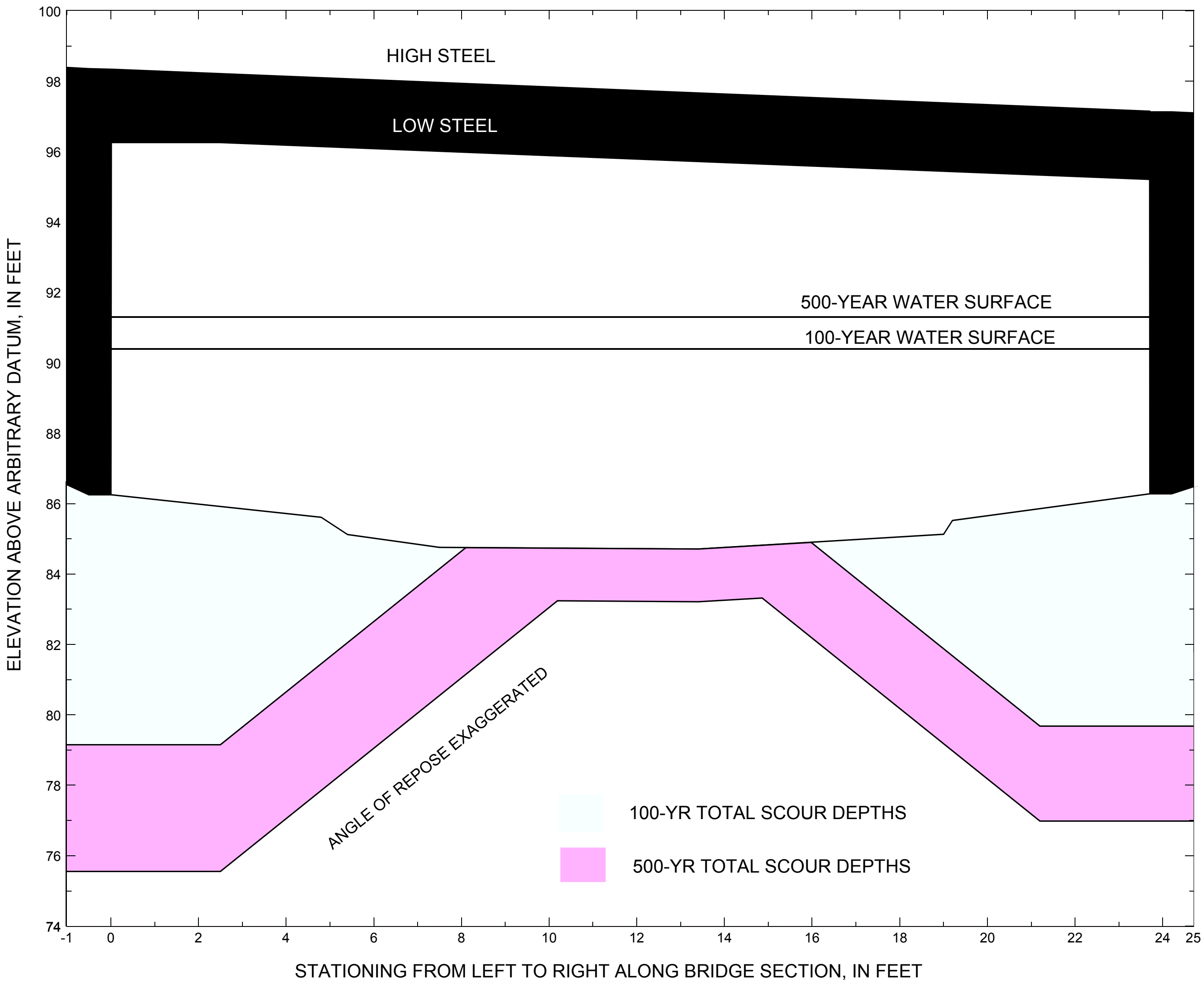

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRNATH00470031 on town highway 47, crossing Locust Creek, Barnard, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRNATH00470031 on Town Highway 47, crossing Locust Creek, Barnard, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat 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 1,200 cubic-feet per second											
Left abutment	0.0	1693.6	96.4	82	86.2	0.0	7.1	--	7.1	79.1	-3
Right abutment	23.7	1692.4	95.2	82	86.3	0.0	6.6	--	6.6	79.7	-2

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 BRNATH00470031 on Town Highway 47, crossing Locust Creek, Barnard, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 1,600 cubic-feet per second											
Left abutment	0.0	1693.6	96.4	82	86.2	1.5	9.2	--	10.7	75.5	-7
Right abutment	23.7	1692.4	95.2	82	86.3	1.5	7.8	--	9.3	77.0	-5

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

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APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File brna031.wsp
T2        Hydraulic analysis for structure BRNATH00470031   Date: 31-JAN-96
T3        Town Highway 47 crossing of Locust Creek, Barnard, VT             EMB
Q          1200.0,   1600.0
SK         0.0060,   0.0060
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -36
GR          -41.7, 103.09    -24.0,  93.93     -8.7,  87.37      0.0,  85.40
GR            6.7,  84.47     16.2,  84.84     20.9,  85.29     34.0,  88.06
GR           41.1,  91.01     70.8,  94.40    122.9,  96.63
N           0.060
*
XS   FULLV      0  * * *   0.0125
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0      95.8      15.0
GR            0.0,  96.39      0.0,  86.25      4.8,  85.61      5.4,  85.12
GR            7.5,  84.76     13.4,  84.71     19.0,  85.13     19.2,  85.52
GR           23.7,  86.28     23.7,  95.20      0.0,  96.39
*
*           BRTYPE  BRWDTH
CD             1      23.7
N           0.045
*
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     12      17.5     2
GR          -76.9, 103.54    -31.6, 100.31      0.0,  98.34     25.9,  97.16
GR           83.3,  96.13    136.8,  96.65
BP           1.1
*
XT   APTEM     59
GR          -96.1, 101.06    -46.1,  98.51    -41.3,  95.96    -24.7,  95.18
GR          -10.4,  94.16      0.0,  89.24      7.5,  86.32     10.4,  85.88
GR           13.0,  85.45     16.1,  85.92     17.0,  86.28     18.3,  86.68
GR           21.4,  87.57     24.5,  90.21     34.2,  94.54     66.5,  94.57
GR           92.5,  95.23    109.2,  99.08
*
AS   APPRO     47
GT           -0.35
N           0.060
*
HP 1 BRIDG    90.42 1  90.42
HP 2 BRIDG    90.42 * * 1200
HP 1 APPRO    91.70 1  91.70
HP 2 APPRO    91.70 * * 1200
*
HP 1 BRIDG    91.26 1  91.26
HP 2 BRIDG    91.26 * * 1600
HP 1 APPRO    93.17 1  93.17
HP 2 APPRO    93.17 * * 1600
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

```
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V042094           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

           *** RUN DATE & TIME: 02-14-96  12:54

   T1        U.S. Geological Survey WSPRO Input File brna031.wsp
   T2        Hydraulic analysis for structure BRNATH00470031   Date: 31-JAN-96
   T3        Town Highway 47 crossing of Locust Creek, Barnard, VT             EMB

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

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      118      9321     23     32                         1513
     90.42           118      9321     23     32  1.00      0     24     1513
1
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
         90.42     0.0    23.7   117.6    9321.    1200.  10.20

 X STA.         0.0        2.6        4.1        5.4        6.5        7.4
   A(I)             10.7        6.8        6.2        5.5        5.2
   V(I)             5.61       8.81       9.70      10.84      11.46

 X STA.         7.4        8.3        9.2       10.1       11.0       11.9
   A(I)              5.0        4.9        4.8        4.8        4.8
   V(I)            11.92      12.24      12.38      12.51      12.49

 X STA.        11.9       12.7       13.6       14.5       15.4       16.4
   A(I)              4.8        4.8        4.8        5.0        5.1
   V(I)            12.54      12.53      12.48      11.97      11.87

 X STA.        16.4       17.3       18.4       19.7       21.2       23.7
   A(I)              5.2        5.4        6.3        6.7       10.7
   V(I)            11.58      11.07       9.50       8.90       5.61
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      47.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      135      7920     35     37                         1521
     91.70           135      7920     35     37  1.00     -5     29     1521
1
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      47.

          WSEL     LEW     REW    AREA        K        Q    VEL
         91.70    -5.9    28.6   135.4    7920.    1200.   8.86

 X STA.        -5.9        1.3        3.6        5.2        6.5        7.6
   A(I)             12.4        8.6        7.2        6.6        6.1
   V(I)             4.83       6.98       8.29       9.08       9.83

 X STA.         7.6        8.6        9.5       10.4       11.3       12.1
   A(I)              5.9        5.6        5.4        5.4        5.3
   V(I)            10.22      10.75      11.06      11.15      11.25

 X STA.        12.1       12.9       13.7       14.6       15.4       16.4
   A(I)              5.2        5.2        5.4        5.5        5.7
   V(I)            11.56      11.52      11.20      10.87      10.55

 X STA.        16.4       17.4       18.5       19.9       21.6       28.6
   A(I)              6.0        6.3        7.0        7.9       12.7
   V(I)            10.04       9.53       8.61       7.57       4.72
1
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      137     11591     23     33                         1899
     91.26           137     11591     23     33  1.00      0     24     1899
1
```

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

          WSEL     LEW     REW    AREA        K        Q    VEL
         91.26     0.0    23.7   136.9   11591.    1600.  11.69


 X STA.        0.0        2.6        4.1        5.4        6.4        7.4
   A(I)            13.0        7.8        7.2        6.4        6.0
   V(I)            6.16      10.23      11.06      12.52      13.30

 X STA.        7.4        8.3        9.2       10.1       11.0       11.9
   A(I)             5.8        5.7        5.5        5.5        5.5
   V(I)           13.85      14.01      14.47      14.63      14.61

 X STA.       11.9       12.7       13.6       14.5       15.4       16.4
   A(I)             5.5        5.5        5.6        5.7        5.8
   V(I)           14.49      14.48      14.41      14.08      13.73

 X STA.       16.4       17.3       18.4       19.7       21.1       23.7
   A(I)             6.0        6.5        7.2        7.7       13.0
   V(I)           13.37      12.40      11.14      10.35       6.15
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      47.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      191     12517     41     45                         2339
     93.17           191     12517     41     45  1.00     -8     32     2339
1
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      47.

          WSEL     LEW     REW    AREA        K        Q    VEL
         93.17    -9.0    31.9   190.9   12517.    1600.   8.38

 X STA.       -9.0       -0.4        2.1        4.0        5.5        6.8
   A(I)            17.6       11.8       10.3        9.1        8.8
   V(I)            4.56       6.77       7.77       8.76       9.14

 X STA.        6.8        8.0        9.0       10.0       11.0       12.0
   A(I)             8.3        7.8        7.5        7.5        7.4
   V(I)            9.62      10.30      10.61      10.73      10.84

 X STA.       12.0       12.9       13.8       14.7       15.7       16.8
   A(I)             7.3        7.3        7.5        7.8        8.0
   V(I)           11.00      10.93      10.62      10.29      10.04

 X STA.       16.8       18.0       19.3       20.9       23.0       31.9
   A(I)             8.4        8.9        9.9       11.8       18.1
   V(I)            9.55       8.99       8.07       6.79       4.43
1
   *
   EX

 +++ BEGINNING PROFILE CALCULATIONS --   2

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

 EXITX:XS   ******    -16      244  0.38 *****   91.24   88.68    1200   90.87
       -35 ******     41    15487  1.00 ***** *******    0.42    4.93

 FULLV:FV       36    -15      230  0.42  0.23   91.50 *******    1200   91.08
         0     36     40    14271  1.00  0.02    0.00    0.46    5.22
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

  ===125 FR# EXCEEDS FNTEST AT SECID “APPRO”:  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.93      91.21      91.00

  ===110 WSEL NOT FOUND AT SECID “APPRO”:  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    90.58     100.71    0.50

  ===115 WSEL NOT FOUND AT SECID “APPRO”:  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    90.58     100.71      91.00

  ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             “APPRO”     KRATIO =  0.47
```

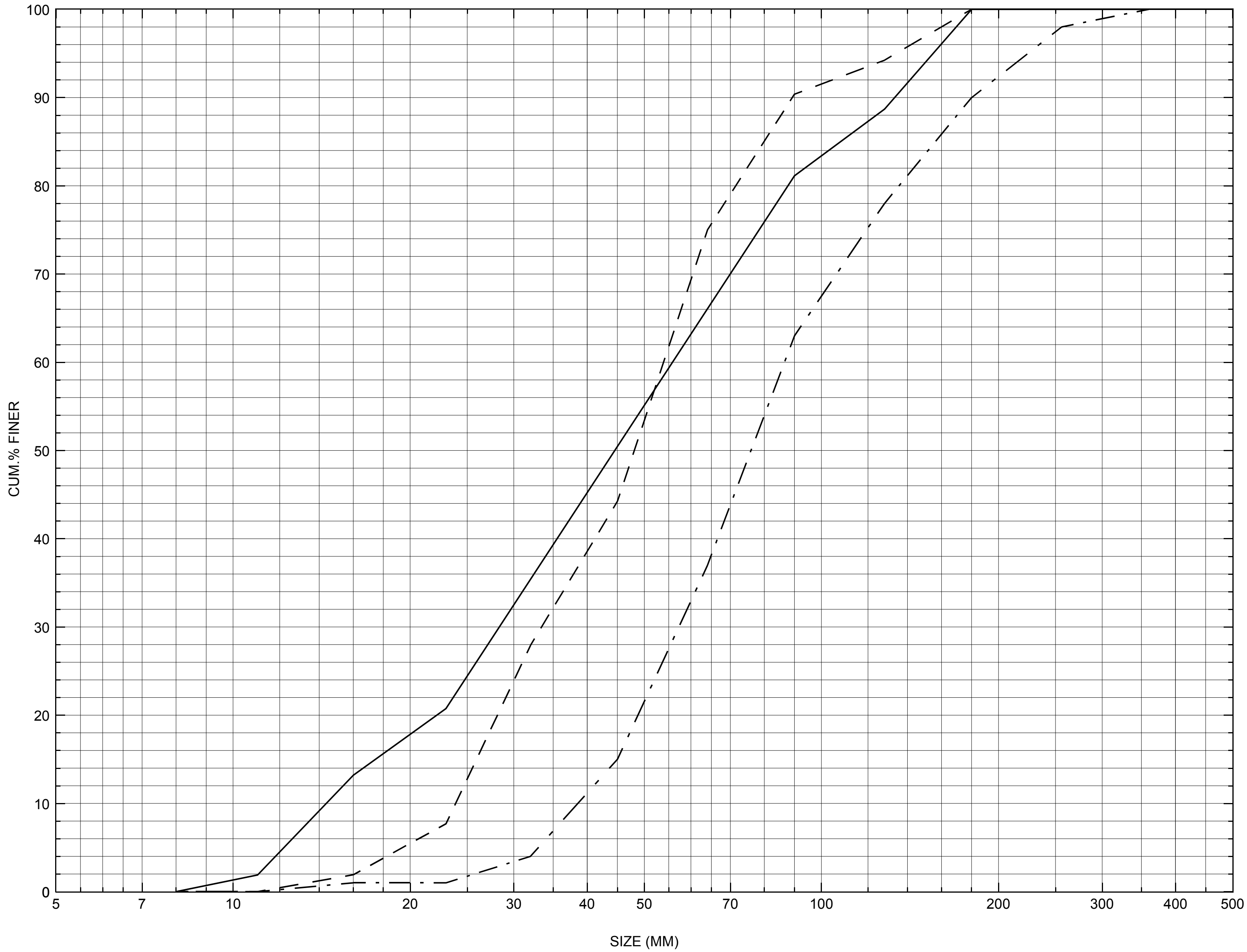
```
APPRO:AS       47     -4      119  1.59  0.71   92.79   91.00    1200   91.20
        47     47     28     6653  1.00  0.58    0.00    0.93   10.10
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

            <<<<<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       36      0      118  1.62  0.39   92.04   89.70    1200   90.42
         0     36     24     9333  1.00  0.40   -0.01    0.79   10.19

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******   95.80 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD    EGL     ERR       Q    WSEL
   RDWAY:RG      12.        <<<<<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       23     -5      136  1.22  0.49   92.92   91.00    1200   91.70
        47     23     29     7932  1.00  0.39   -0.02    0.79    8.85

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.269  0.000    8608.     0.    24.    91.04

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -36.   -17.    41.   1200.   15487.     244.    4.93   90.87
   FULLV:FV       0.   -16.    40.   1200.   14271.     230.    5.22   91.08
   BRIDG:BR       0.     0.    24.   1200.    9333.     118.   10.19   90.42
   RDWAY:RG      12.**************      0.******************    2.00********
   APPRO:AS      47.    -6.    29.   1200.    7932.     136.    8.85   91.70

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       0.    24.    8608.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS     88.68    0.42   84.47  103.09************  0.38   91.24   90.87
   FULLV:FV  ********    0.46   84.92  103.54  0.23  0.02  0.42   91.50   91.08
   BRIDG:BR     89.70    0.79   84.71   96.39  0.39  0.40  1.62   92.04   90.42
   RDWAY:RG  ****************   96.13  103.54*********************************
   APPRO:AS     91.00    0.79   85.10  100.71  0.49  0.39  1.22   92.92   91.70


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

EXITX:XS   ******    -18      310  0.41 *****   92.34   89.29    1600   91.93
       -35 ******     49    20641  1.00 ***** *******    0.43    5.16

FULLV:FV       36    -18      294  0.46  0.23   92.59 *******    1600   92.13
         0     36     47    19367  1.00  0.02    0.00    0.45    5.45
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.91      92.18      91.88

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    91.63     100.71    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    91.63     100.71      91.88

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.48

APPRO:AS       47     -6      152  1.72  0.67   93.89   91.88    1600   92.17
        47     47     30     9250  1.00  0.63    0.00    0.91   10.52
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
```

WSPRO OUTPUT FILE (continued)

```
           <<<<<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       36      0      137  2.12  0.39   93.39   90.62    1600   91.26
         0      36     24    11598  1.00  0.67    0.01    0.84   11.69

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******   95.80 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
    RDWAY:RG      12.        <<<<<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       23     -8      191  1.09  0.42   94.26   91.88    1600   93.17
        47      24     32    12507  1.00  0.45    0.00    0.68    8.39

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.353  0.000   13029.     0.    24.    92.68

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

   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -36.   -19.    49.   1600.   20641.     310.    5.16   91.93
    FULLV:FV       0.   -19.    47.   1600.   19367.     294.    5.45   92.13
    BRIDG:BR       0.     0.    24.   1600.   11598.     137.   11.69   91.26
    RDWAY:RG      12.**************       0.******************    2.00********
    APPRO:AS      47.    -9.    32.   1600.   12507.     191.    8.39   93.17

     XSID:CODE   XLKQ   XRKQ       KQ
    APPRO:AS       0.    24.   13029.

  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
    EXITX:XS     89.29    0.43   84.47  103.09************  0.41    92.34   91.93
    FULLV:FV  ********    0.45   84.92  103.54  0.23  0.02  0.46    92.59   92.13
    BRIDG:BR     90.62    0.84   84.71   96.39  0.39  0.67  2.12    93.39   91.26
    RDWAY:RG  ****************   96.13  103.54**********************************
    APPRO:AS     91.88    0.68   85.10  100.71  0.42  0.45  1.09    94.26   93.17
   ER

1  NORMAL  END  OF  WSPRO  EXECUTION.
```

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 BRNATH00470031, in Barnard, Vermont.

APPENDIX D:

HISTORICAL DATA FORM