LEVEL II SCOUR ANALYSIS FOR BRIDGE 25 (BRNAVT00120025) on STATE HIGHWAY 12, crossing LOCUST CREEK, BARNARD, VERMONT

U.S. Geological Survey
Open-File Report 96-388

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

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By MICHAEL A. IVANOFF and MATTHEW A. WEBER

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
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Denver, CO 80225

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TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

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

OTHER ABBREVIATIONS

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

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

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

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 25 (BRNAVT00120025) ON STATE HIGHWAY 12, CROSSING LOCUST CREEK, BARNARD, VERMONT

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

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRNAVT00120025 on State Highway 12 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 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 division of central Vermont in the town of Barnard. The 11.6-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have woody vegetation coverage.

In the study area, Locust Creek has a sinuous channel with a slope of approximately 0.023 ft/ft, an average channel top width of 49 ft and an average channel depth of 4 ft. The predominant channel bed material is cobble (D_{50} is 109 mm or 0.359 ft). The geomorphic assessment at the time of the Level I and Level II site visits on September 23 and December 16, 1994, indicated that the reach was stable.

The State Highway 12 crossing of Locust Creek is a 41-ft-long, two-lane bridge consisting of one 39-foot concrete slab type superstructure (Vermont Agency of Transportation, written communication, August 23, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 30 degrees to the opening while the opening-skew-to-roadway is 45 degrees.

A scour hole 1 ft deeper than the mean thalweg depth was observed along a bedrock outcrop near the upstream left wingwall during the Level I assessment. The scour protection measures in place at the site are type-1 stone fill (less than 12 inches diameter) along the left abutment, upstream right bank, and both downstream banks; type-2 stone fill (less than 36 inches diameter) at the downstream side of the right road approach and upstream left bank; type-3 stone fill (less than 48 inches diameter) at the upstream end of the upstream right wingwall and downstream end of downstream left wingwall; type-5 (wall/ artificial levee) at the upstream end of the upstream 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 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 1.4 ft. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 8.5 to 20.9 ft. The worst-case abutment scour 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.

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 BRNAVT00120025 ***Stream*** Locust Creek

County Windsor ***Road*** VT 12 ***District*** 04

Description of Bridge

Bridge length 41 ***ft*** ***Bridge width*** 33 ***ft*** ***Max span length*** 39 ***ft***

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

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

Stone fill on abutment? Yes ***Date of inspection*** 9/23 &12/16/94

Description of stone fill type-1 along the left abutment, US right bank, and both DS banks; type-2 DS side of the right road approach and US left bank; type-3 US end of the US right wingwall and DS end of DS left wingwall; type-5 US end of the US left wingwall.

Abutments and wingwalls are concrete. There is a one foot deep scour hole along the right abutment.

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

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	09/23 & 12/16/94	0	0
Level II	09/23/94	--	--

Potential for debris Low

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

09/23 & 12/16/94 -- A gravel side bar under the bridge along the upstream half of the left abutment. Also, a bedrock outcrop upstream of the upstream left wingwall.

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 09/23 & 12/16/94

DS left: Steep channel bank to flood plain

DS right: Moderately sloped bank to flood plain

US left: Steep valley wall with gravel road parallel to the stream

US right: Moderately sloped overbank with town highway 29 parallel to the stream

Description of the Channel

Average top width 49 *ft* ***Average depth*** 4 *ft*

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

Sinuous but stable with semi-alluvial channel boundaries and a narrow flood plain US and wide DS flood plain.

9/23 & 12/16/94

Vegetative co Brush with pasture on the flood plain

DS left: Brush with pasture on the flood plain

DS right: Trees and brush

US left: Trees

US right:

Do banks appear stable? Y -

date of observation.

09/23 & 12/16/94 --

Bedrock outcrop upstream of the upstream left wingwall.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 11.6 ***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 No

Calculated Discharges

Q100 2,360 ***ft³/s*** ***Q500*** 3,070 ***ft³/s***

The 100- and 500-year discharges are based on a drainage area relationship [(11.6/11.5)exp 0.7] with bridge number 34 in Barnard. Bridge number 34 crosses Locust Creek upstream of this site and has flood frequency estimates available from the VTAOT database (VTAOT, written communication, May 4, 1995). The drainage area above bridge number 34 is 11.5 square miles.

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 in a chiseled square on top of the DS end of the right abutment (elev. 499.26 ft, arbitrary survey datum). RM2 is a chiseled X in a chiseled square on top of the US end of the left abutment (elev. 499.64 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT-	-58	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT-)
BRIDG	0	1	Bridge section
RDWAY	26	1	Road Grade section
APPR-	78	2	Modelled Approach section (Templated from APTEM)
APTEM	102	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). The analysis reported herein reflects conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. 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 0.054 to 0.062, and overbank "n" values ranged from 0.036 to 0.072.

Normal depth at the exit section (EXIT-) 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 0.023 ft/ft which was estimated from the topographic map (U.S. Geological Survey, 1980).

The surveyed approach section (APTEM) was moved along the approach channel slope (0.032 ft/ft) to establish the modelled approach section (APPR-), 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.

For the 100-year discharge, WSPRO assumes critical depth at the bridge section. Further analysis, in which the water surface is shown to pass through critical depth in the bridge, suggests the critical depth assumption at the bridge section is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.1 *ft*
Average low steel elevation 496.8 *ft*

100-year discharge 2,360 *ft^3/s*
Water-surface elevation in bridge opening 490.4 *ft*
Road overtopping? N *Discharge over road* -- *s*
Area of flow in bridge opening 163 *ft^2*
Average velocity in bridge opening 14.5 *ft/s*
Maximum WSPRO tube velocity at bridge 18.2 *ft/s*

Water-surface elevation at Approach section with bridge 495.9
Water-surface elevation at Approach section without bridge 492.5
Amount of backwater caused by bridge 3.4 *t*

500-year discharge 3,070 *ft^3/s*
Water-surface elevation in bridge opening 496.9 *ft*
Road overtopping? N *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 324 *ft^2*
Average velocity in bridge opening 9.4 *ft/s*
Maximum WSPRO tube velocity at bridge 11.8 */s*

Water-surface elevation at Approach section with bridge 498.9
Water-surface elevation at Approach section without bridge 493.4
Amount of backwater caused by bridge 5.5

Incipient overtopping discharge -- *ft^3/s*
Water-surface elevation in bridge opening -- *ft*
Area of flow in bridge opening -- *ft^2*
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 -- *t*

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.

The 500-year discharge resulted in unsubmerged orifice flow. 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). Therefore, contraction scour for the 500-year discharge was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). 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 discharge. 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.

The depth of streambed armoring computed for the 100 -year discharge suggests that contraction scour will not be limited by armoring.

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	1.4	0.0	--
Depth to armoring	36.8	1.1	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	8.5	12.3	--
Right abutment	18.2	20.9	--
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:			
Left abutment	2.7	2.4	--
Right abutment	2.7	2.4	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

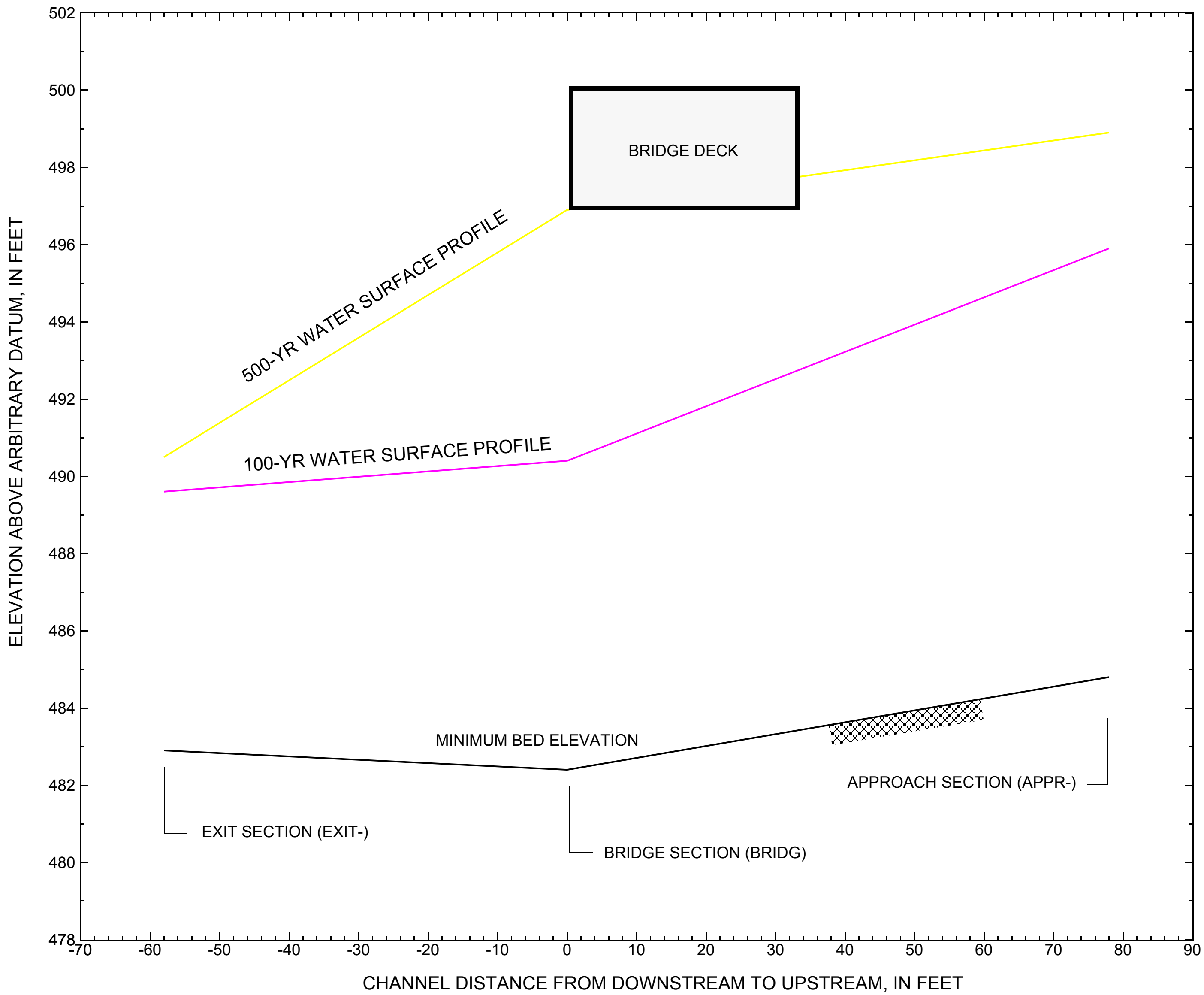

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRNAVT00120025 on State Highway 12, crossing Locust Creek, Barnard, Vermont.

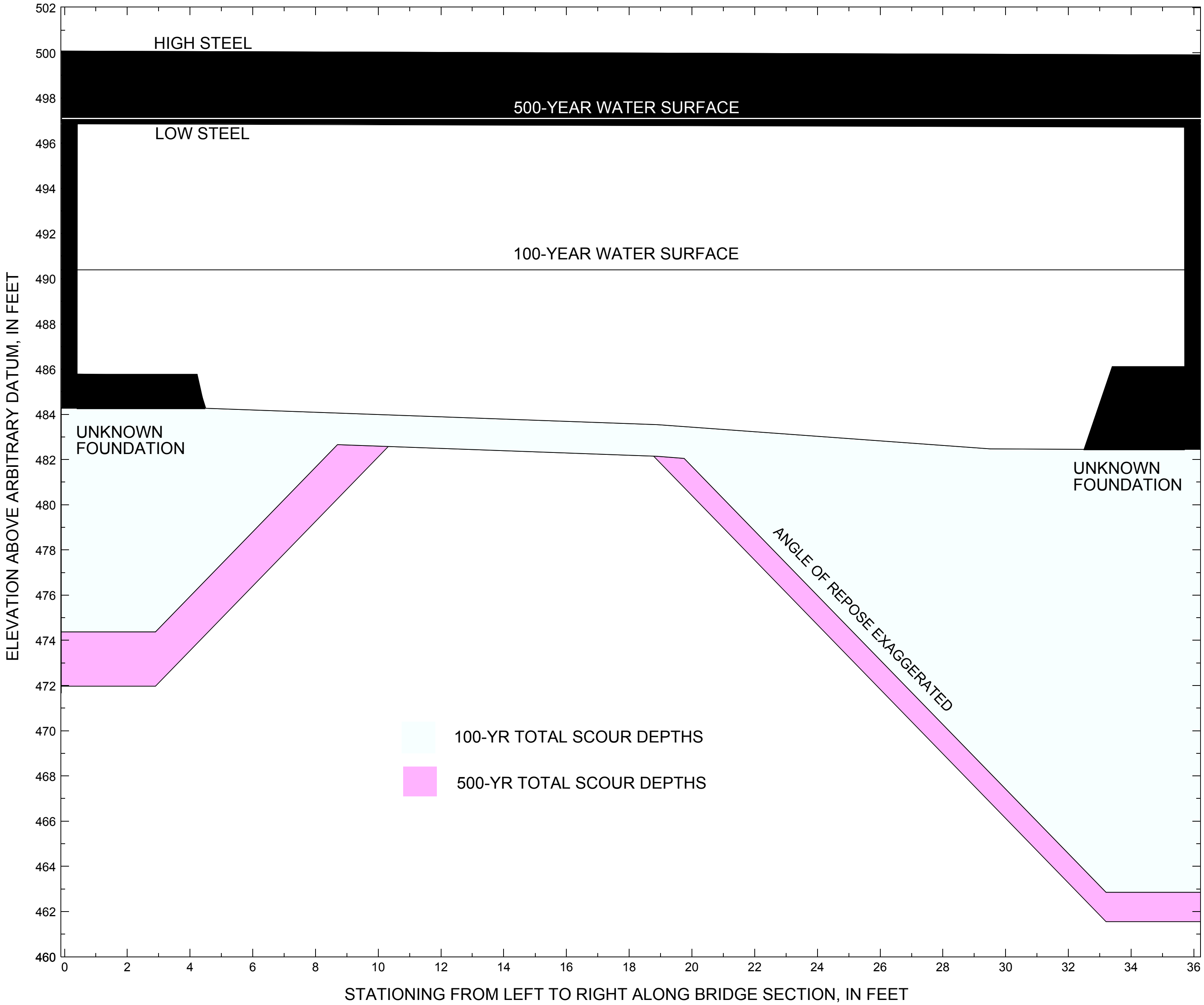

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRNAVT00120025 on State Highway 12, crossing Locust Creek, Barnard, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRNAVT00120025 on State Highway 12, crossing Locust Creek, Barnard, Vermont.

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

Description	Station[1]	VTAOT 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 2,360 cubic-feet per second											
Left abutment	0.0	--	496.9	--	484.3	1.4	8.5	--	9.9	474.4	--
Right abutment	35.7	--	496.7	--	482.4	1.4	18.2	--	19.6	462.8	--

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure BRNAVT00120025 on State Highway 12, crossing Locust Creek, Barnard, Vermont.

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

Description	Station[1]	VTAOT 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 3,070 cubic-feet per second											
Left abutment	0.0	--	496.9	--	484.3	0.0	12.3	--	12.3	472.0	--
Right abutment	35.7	--	496.7	--	482.4	0.0	20.9	--	20.9	461.5	--

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

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U.S. Geological Survey, 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 brna025.wsp
T2        CREATED ON 13-DEC-95 FOR BRIDGE BRNAVT00120025 USING FILE brna025.dca
T3        Hydraulic analysis for BRNA025  TS
*
Q          2360 3070
SK         0.023 0.023
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXIT-    -58
GR          -95.3, 504.87    -80.9, 500.14    -72.7, 500.26    -57.0, 500.54
GR          -39.2, 500.22    -35.2, 499.31    -12.1, 490.72     -7.6, 489.13
GR           -6.0, 487.24      0.0, 484.57      1.5, 483.48     13.3, 482.95
GR           19.2, 483.13     22.6, 483.80     24.4, 484.63     31.3, 485.88
GR           40.6, 486.93     47.1, 489.19     56.5, 493.49    105.0, 495.68
GR          162.7, 497.61    172.4, 497.86
N           0.041        0.062        0.036
SA                  -39.2        56.5
*
XS   FULLV      0  * * *   0.0159
*
BR   BRIDG     0 496.8 45
GR            0.0, 496.87      0.4, 485.78      3.7, 485.70      4.3, 485.16
GR            4.5, 484.27     18.9, 483.54     29.5, 482.47     32.5, 482.45
GR           33.2, 485.30     33.4, 486.10     35.7, 486.12     35.7, 496.68
GR            0.0, 496.87
N             0.054
CD           1 58.9 * * 55 1.1
*
XR   RDWAY     26 33 1
GR         -115.8, 504.87   -101.4, 500.14    -93.2, 500.26    -77.5, 500.54
GR          -54.0, 500.51      0.0, 500.17     18.9, 499.98     36.7, 499.81
GR          102.4, 500.26    224.5, 502.50    350.9, 507.21
*
XT   APTEM     102
GR          -49.9, 512.59    -26.6, 495.77    -18.3, 496.05    -12.5, 495.75
GR           -6.9, 490.75     -1.3, 487.24      0.0, 486.22      8.7, 485.92
GR           11.0, 485.61     20.8, 486.56     29.1, 487.38     33.8, 488.67
GR           41.4, 490.08     63.2, 492.07     84.8, 500.02     90.7, 500.47
GR          196.6, 502.59
*
AS   APPR-   78
GT          -0.77
N           0.058        0.072
SA                  84.8
*
HP 1 BRIDG   490.39 1 490.39
HP 2 BRIDG   490.39 * * 2360
HP 1 APPR-   495.94 1 495.94
HP 2 APPR-   495.94 * * 2360
*
HP 1 BRIDG   496.87 1 496.87
HP 2 BRIDG   496.87 * * 3070
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
      U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brna025.wsp
      CREATED ON 13-DEC-95 FOR BRIDGE BRNAVT00120025 USING FILE brna025.dca
      Hydraulic analysis for BRNA025  TS
         *** RUN DATE & TIME: 02-26-96  08:26
  CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     163.   11876.    25.    38.                       2360.
 490.39          163.   11876.    25.    38.  1.00     0.    36.   2360.

HP 2 BRIDG   490.39 * * 2360

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

       WSEL     LEW     REW    AREA        K        Q    VEL
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X STA.        0.2        4.8        7.0        8.8       10.5       12.1
  A(I)           15.4        9.3        8.3        7.7        7.1
  V(I)           7.65      12.65      14.24      15.38      16.58

X STA.       12.1       13.6       15.0       16.4       17.8       19.2
  A(I)            6.9        6.8        6.8        6.5        6.6
  V(I)          17.02      17.45      17.44      18.08      17.89

X STA.       19.2       20.5       21.8       23.1       24.4       25.7
  A(I)            6.5        6.6        6.6        6.5        6.8
  V(I)          18.21      17.86      17.95      18.11      17.33

X STA.       25.7       27.0       28.3       29.8       31.4       35.7
  A(I)            7.0        7.4        8.1        9.4       16.8
  V(I)          16.80      15.91      14.65      12.56       7.03

HP 1 APPR-   495.94 1 495.94

  CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR-;  SRD =      78.

   WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
           1     639.   53475.   104.   109.                       8998.
 495.94          639.   53475.   104.   109.  1.00   -28.    76.   8998.

HP 2 APPR-   495.94 * * 2360

  VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR-;  SRD =      78.

      WSEL     LEW     REW    AREA        K        Q    VEL
     495.94   -27.9    75.8   638.9   53475.    2360.   3.69

X STA.      -27.9       -2.4        1.5        4.5        7.1        9.6
  A(I)           64.3       39.0       31.5       28.5       26.7
  V(I)           1.83       3.02       3.75       4.15       4.42

X STA.        9.6       12.0       14.3       16.7       19.1       21.5
  A(I)           26.7       25.0       25.2       24.8       25.0
  V(I)           4.43       4.72       4.69       4.76       4.72

X STA.       21.5       24.0       26.6       29.4       32.5       36.2
  A(I)           25.1       25.2       26.2       27.3       29.2
  V(I)           4.70       4.68       4.50       4.33       4.05

X STA.       36.2       40.4       45.4       51.2       58.4       75.8
  A(I)           30.3       32.8       34.8       39.0       52.5
  V(I)           3.90       3.60       3.39       3.03       2.25

HP 1 BRIDG   496.87 1 496.87
```

```
  CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     324.   23461.     0.    76.                     ********
   496.87          324.   23461.     0.    76.  1.00     0.    36.********

  HP 2 BRIDG   496.87 * * 3070

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      496.87     0.0    35.7   323.7   23461.    3070.   9.48

X STA.         0.0         4.0         6.2         8.0         9.7        11.3
  A(I)            30.3        18.9        16.4        14.8        14.4
  V(I)            5.06        8.12        9.35       10.37       10.63

X STA.        11.3        12.8        14.3        15.7        17.1        18.5
  A(I)            14.0        13.6        13.2        13.1        13.2
  V(I)           10.98       11.32       11.65       11.73       11.67

X STA.        18.5        19.9        21.3        22.7        24.1        25.5
  A(I)            13.1        13.2        13.0        13.4        13.8
  V(I)           11.72       11.61       11.77       11.47       11.14

X STA.        25.5        26.9        28.4        29.9        31.8        35.7
  A(I)            14.2        14.6        15.7        18.8        32.1
  V(I)           10.80       10.54        9.78        8.15        4.78

  HP 1 APPR-   498.91 1 498.91

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR-;  SRD =      78.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     965.   98251.   116.   122.                      15801.
   498.91          965.   98251.   116.   122.  1.00   -32.    84.  15801.

  HP 2 APPR-   498.91 * * 3070

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR-;  SRD =      78.

        WSEL     LEW     REW    AREA        K        Q    VEL
      498.91   -32.0    83.9   965.0   98251.    3070.   3.18

X STA.       -32.0        -8.0        -2.2         1.6         4.7         7.7
  A(I)            90.3        58.5        48.8        43.0        41.2
  V(I)            1.70        2.62        3.15        3.57        3.73

X STA.         7.7        10.6        13.3        16.1        19.0        21.9
  A(I)            39.7        38.0        38.3        38.5        37.7
  V(I)            3.87        4.04        4.01        3.99        4.08

X STA.        21.9        24.9        28.0        31.3        35.1        39.3
  A(I)            38.6        38.9        40.1        42.9        43.9
  V(I)            3.97        3.94        3.83        3.58        3.50

X STA.        39.3        44.1        49.5        55.6        62.6        83.9
  A(I)            46.0        49.2        52.0        55.9        83.6
  V(I)            3.34        3.12        2.95        2.75        1.84
```

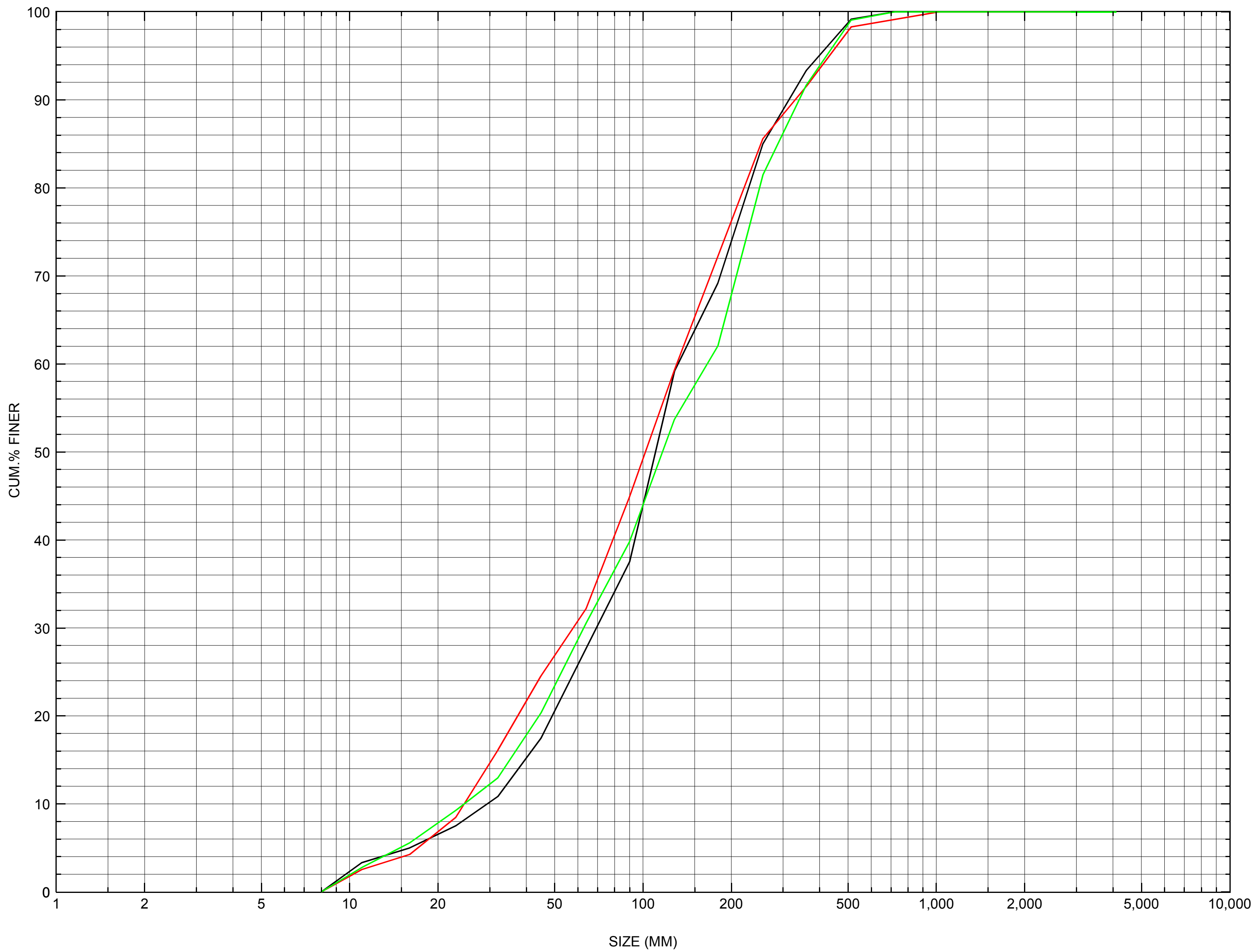
```
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXIT-:XS   ******    -9.     250.  1.39 *****  491.03  488.93   2360.  489.64
      -58. ******    48.   15549.  1.00 ***** *******    0.80    9.45

FULLV:FV      58.   -10.     279.  1.11  1.14  492.18 *******   2360.  491.06
        0.    58.    49.   18175.  1.00  0.00    0.01    0.69    8.45
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR-:AS      78.   -10.     340.  0.75  1.04  493.21 *******   2360.  492.46
       78.    78.    66.   23075.  1.00  0.00    0.00    0.58    6.95
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"     Q,CRWS =    2360.     490.39

            <<<<<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.     163.  3.25 *****  493.65  490.39   2360.  490.39
        0.    58.    36.   11887.  1.00 ***** *******    1.00   14.46

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  496.80 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      26.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR-:AS      19.   -28.     639.  0.21  0.18  496.15  490.90   2360.  495.94
       78.    21.    76.   53480.  1.00  2.32    0.01    0.26    3.69

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.533  0.200   42718.    -3.    32.   495.85

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT-:XS     -58.    -9.    48.   2360.   15549.     250.    9.45  489.64
   FULLV:FV       0.   -10.    49.   2360.   18175.     279.    8.45  491.06
   BRIDG:BR       0.     0.    36.   2360.   11887.     163.   14.46  490.39
   RDWAY:RG      26.**************      0.******************    1.00********
   APPR-:AS      78.   -28.    76.   2360.   53480.     639.    3.69  495.94

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR-:AS      -3.    32.   42718.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT-:XS    488.93    0.80  482.95  504.87************  1.39  491.03  489.64
   FULLV:FV  ********    0.69  483.87  505.79  1.14  0.00  1.11  492.18  491.06
   BRIDG:BR    490.39    1.00  482.45  496.87************  3.25  493.65  490.39
   RDWAY:RG  ****************  499.81  507.21**********************************
   APPR-:AS    490.90    0.26  484.84  511.82  0.18  2.32  0.21  496.15  495.94
```

WSPRO OUTPUT FILE (continued)

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

EXIT-:XS   ******   -12.     302.  1.61 *****  492.12  489.75   3070.  490.51
      -58. ******    50.   20234.  1.00 ***** *******    0.81   10.18

FULLV:FV      58.   -13.     336.  1.30  1.15  493.28 *******   3070.  491.97
        0.    58.    51.   23485.  1.00  0.00    0.00    0.71    9.15
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR-:AS      78.   -11.     415.  0.85  1.01  494.28 *******   3070.  493.43
       78.    78.    69.   31122.  1.00  0.00    0.00    0.57    7.39
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   491.65     497.69     497.85     496.80

 ===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.     324.  1.38 *****  498.25  491.62   3050.  496.87
        0. ******    36.   23461.  1.00 ***** *******    0.55    9.42

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.453 ******  496.80 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      26.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR-:AS      19.   -32.     965.  0.16  0.09  499.07  491.63   3070.  498.91
       78.    21.    84.   98288.  1.00  2.38   -0.01    0.19    3.18

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q         K     AREA     VEL    WSEL
   EXIT-:XS     -58.   -12.    50.   3070.   20234.     302.   10.18  490.51
   FULLV:FV       0.   -13.    51.   3070.   23485.     336.    9.15  491.97
   BRIDG:BR       0.     0.    36.   3050.   23461.     324.    9.42  496.87
   RDWAY:RG      26.**************      0.******************    1.00********
   APPR-:AS      78.   -32.    84.   3070.   98288.     965.    3.18  498.91

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT-:XS    489.75    0.81  482.95  504.87************  1.61  492.12  490.51
   FULLV:FV  ********    0.71  483.87  505.79  1.15  0.00  1.30  493.28  491.97
   BRIDG:BR    491.62    0.55  482.45  496.87************  1.38  498.25  496.87
   RDWAY:RG  ****************  499.81  507.21************  0.11  500.64********
   APPR-:AS    491.63    0.19  484.84  511.82  0.09  2.38  0.16  499.07  498.91
```

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 BRNAVT00120025, in Barnard, Vermont.

APPENDIX D:

HISTORICAL DATA FORM