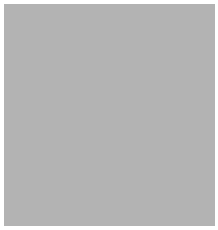
LEVEL II SCOUR ANALYSIS FOR BRIDGE 43 (BRIDTH00040043) on TOWN HIGHWAY 4, crossing DAILEY HOLLOW BRANCH, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-153



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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 43 (BRIDTH00040043) on TOWN HIGHWAY 4, crossing DAILEY HOLLOW BRANCH, BRIDGEWATER, VERMONT

By SCOTT A. OLSON

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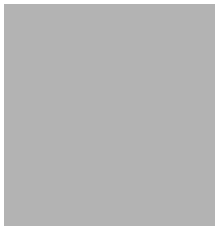

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VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

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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FIGURES

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 43 (BRIDTH00040043) ON TOWN HIGHWAY 4, CROSSING DAILEY HOLLOW BRANCH, BRIDGEWATER, VERMONT

By **Scott A. Olson**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00040043 on town highway 4 crossing Dailey Hollow Branch, Bridgewater, 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.

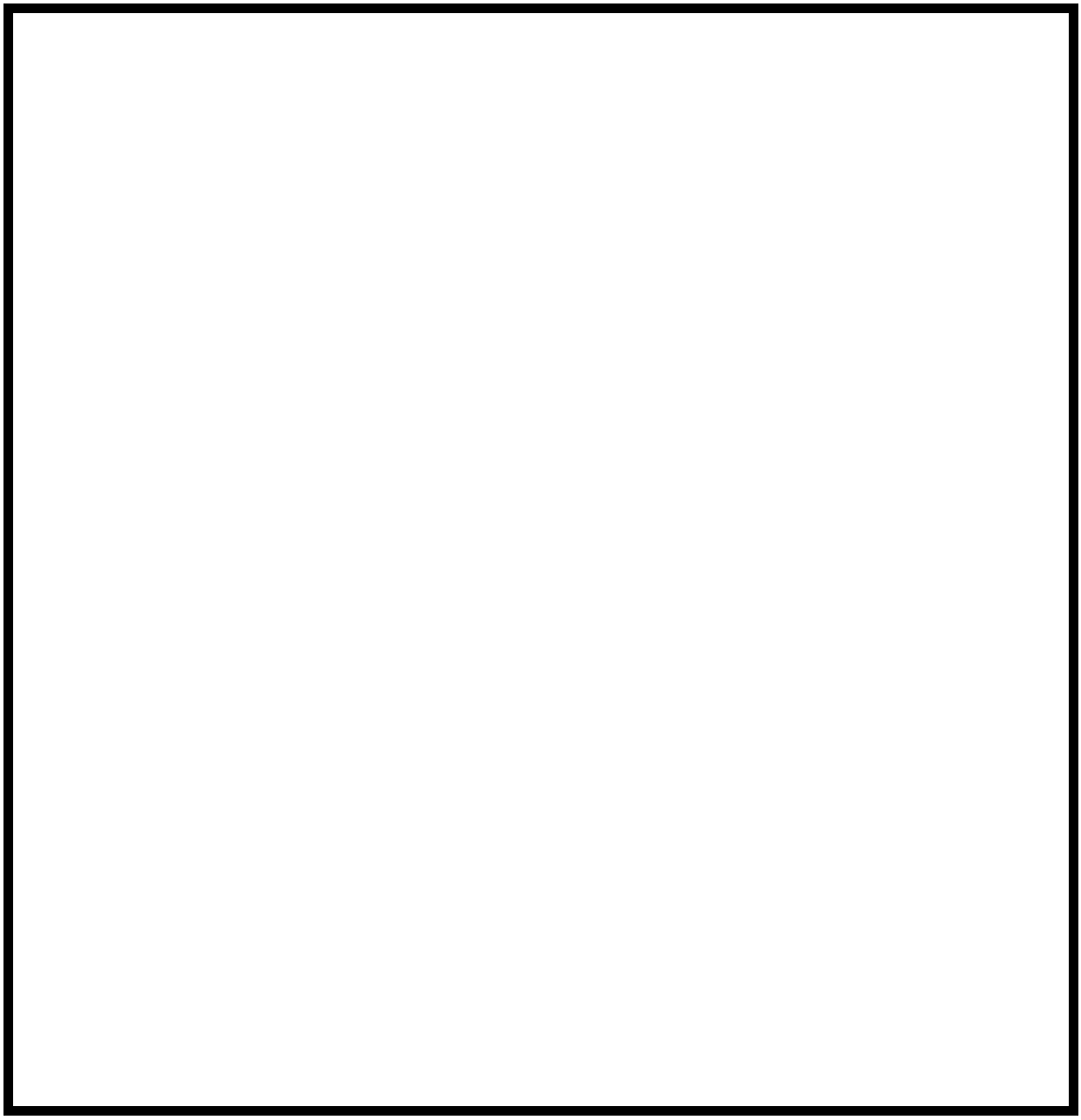
The site is in the Green Mountain physiographic province of central Vermont. The 9.80-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left and right banks are forested. Upstream of bridge 43, Town Highway 4 runs parallel to the left bank and DS of the bridge, parallel to the right bank.

In the study area, Dailey Hollow Branch has an incised channel with a slope of approximately 0.02 ft/ft, an average channel top width of 63 ft and an average channel depth of 5 ft. The predominant channel bed materials are gravel and cobble (D_{50} is 77.0 mm or 0.253 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 1, 1994, indicated that the reach was stable.

The town highway 4 crossing of Dailey Hollow Branch is a 38-ft-long, one-lane bridge consisting of one 34-foot steel beam span with a timber deck (Vermont Agency of Transportation, written commun., August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 34 degrees to the opening while the opening-skew-to-roadway is 30 degrees.

The footings of both abutments are exposed and the left abutment has experienced some undermining. Abutments are not protected by stone fill. However, upstream and downstream wingwalls are protected by type-2 stone fill (less than 36 inches). Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

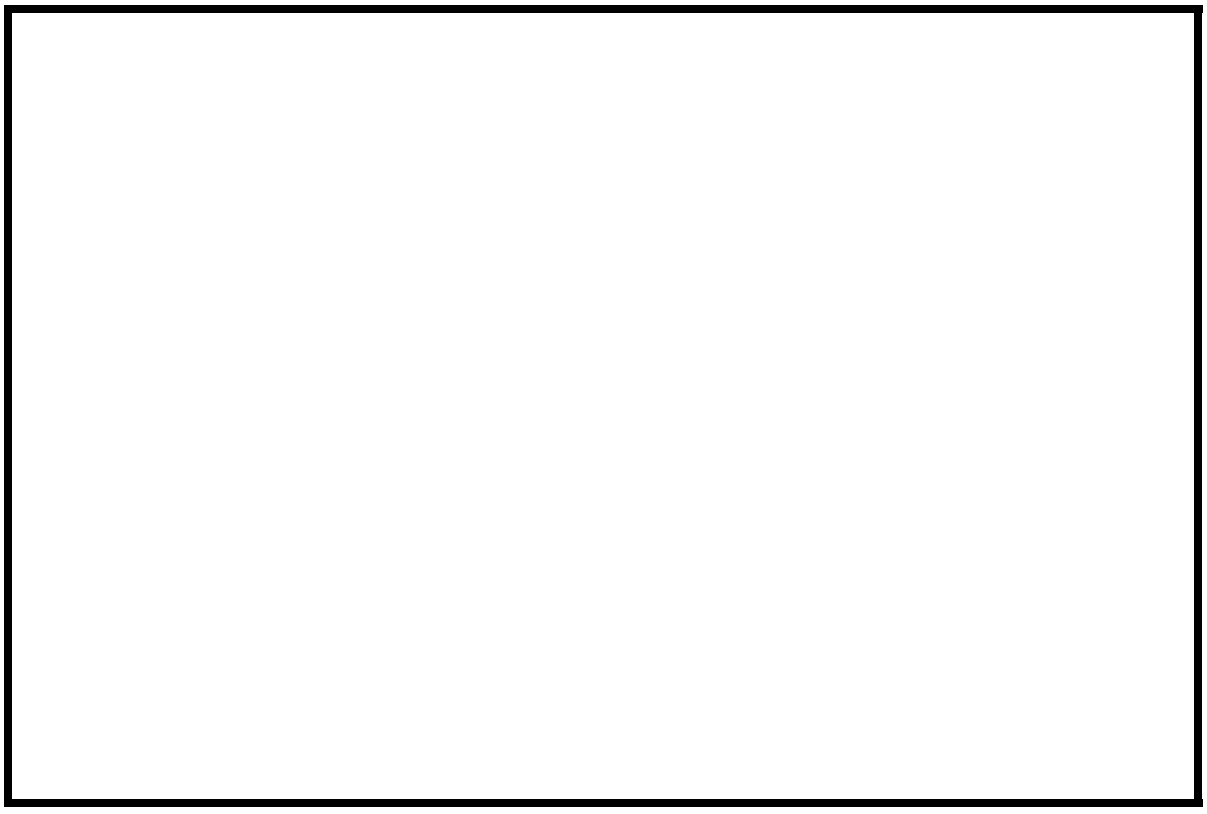


Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

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 BRIDTH00040043 ***Stream*** Dailey Hollow Branch

County Windsor ***Road*** TH004 ***District*** 04

Description of Bridge

Bridge length 38 ***ft*** ***Bridge width*** 14.3 ***ft*** ***Max span length*** 34 ***ft***

Alignment of bridge to road (on curve or straight) moderate S-curve

Abutment type vertical, concrete ***Embankment type*** sloping

Stone fill on abutment? no ***Date of inspection*** 11/01/94

Description of stone fill Type-2 on wingwalls, except downstream left, which has type-3 stone fill.

Abutments are vertical and concrete. The left abutment is noted as having some undermining.

Is bridge skewed to flood flow according to N ***survey?*** Y ***Angle*** 34

Opening skew to roadway is 30 degrees.

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	11/01/94	0	0
Level II	11/01/94	--	--

Potential for debris Moderate potential for debris since the drainage area is forested. Low potential for accumulation at the bridge.

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

Description of the Geomorphic Setting

General topography The bridge is over a steep, upland, incised channel.

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

Date of inspection 11/01/94

DS left: steep valley wall

DS right: narrow terrace to steep valley wall

US left: narrow terrace to steep valley wall

US right: steep valley wall

Description of the Channel

Average top width 63 ***ft*** ***Average depth*** 5 ***ft***

Predominant bed material gravel and cobbles ***Bank material*** gravel/cobbles

Channel type (straight, sinuous, braided, irregular, etc.) Narrow, incised channel with only slight sinuosity.

Vegetative cover 11/01/94

DS left: forest

DS right: forest with gravel road parallel to channel

US left: forest with gravel road parallel to channel

US right: forest

Do banks appear stable? Y

If no, describe relative amount, type of instability and date of observation. 11/01/94--Both the US left and right banks are reported to have moderate fluvial erosion. The DS left and right banks are reported to have light fluvial erosion.

11/01/94--none.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 9.8 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
Green Mountain Prov.	100

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: None. Area is mostly forested high-elevation headwater drainage.

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 2150 ***ft³/s*** ***Q500*** 2900 ***ft³/s***

The Q100 is from VTAOT files (VTAOT, written commun. May, 1995). This discharge compared well to values determined by several different empirical methods. The Q500 was estimated from the comparison of several graphically extrapolated empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; 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 6 feet to USGS survey to obtain VTAOT plans' datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled 'X' in the top of the downstream end of the left abutment (elev. 500.05 feet, arbitrary datum). RM2 is a chiseled 'X' in the top of the upstream end of the right abutment (elev. 499.97 feet, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-73	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	11	1	Road Grade section
APPRO	50	2	Modelled Approach section (Templated from SURVA)
APTEM	118	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 0.050 to 0.060, and overbank "n" values ranged from 0.035 to 0.090.

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 0.020 ft/ft which was determined from surveyed water-surface points in the reach at the time of the field visit.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.027 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.

For the modeled discharges, the Froude number at the bridge section was 1.0. Further analysis suggests critical depth at the bridge section is a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.8 *ft*
Average low steel elevation 497.7 *ft*

100-year discharge 2150 ft^3/s
Water-surface elevation in bridge opening 490.8 *ft*
Road overtopping? N *Discharge over road* 0 *ft/s*
Area of flow in bridge opening 160 ft^2
Average velocity in bridge opening 13.5 *ft/s*
Maximum WSPRO tube velocity at bridge 17.3 *ft/s*

Water-surface elevation at Approach section with bridge 494.4
Water-surface elevation at Approach section without bridge 492.0
Amount of backwater caused by bridge 2.4 *ft*

500-year discharge 2900 ft^3/s
Water-surface elevation in bridge opening 492.0 *ft*
Road overtopping? N *Discharge over road* 0 *ft/s*
Area of flow in bridge opening 193 ft^2
Average velocity in bridge opening 15.0 *ft/s*
Maximum WSPRO tube velocity at bridge 19.4 *ft/s*

Water-surface elevation at Approach section with bridge 496.4
Water-surface elevation at Approach section without bridge 492.9
Amount of backwater caused by bridge 3.5

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 -- *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 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 at the right abutment 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 at the left abutment was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The varibles used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

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	1.7	2.7	--
Depth to armoring	31.2	48.0	--
Left overbank	--	--	--
Right overbank			
Local scour:			
Abutment scour	8.7	12.4	--
Left abutment	11.1	13.4	--
Right abutment			
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:	2.4	2.9	--
Left abutment	2.4	2.9	--
Right abutment	--	--	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2			

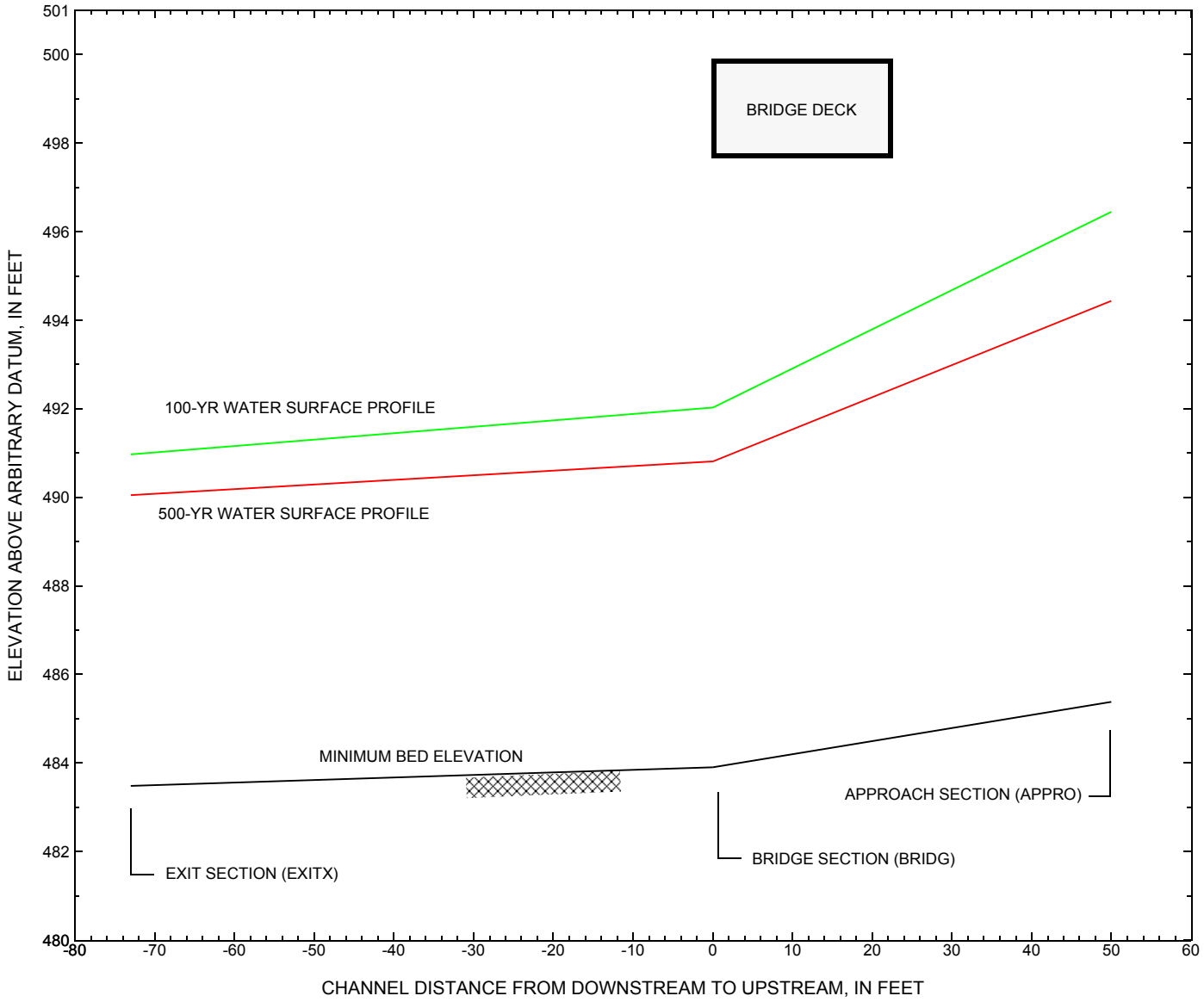


Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00040043 on town highway 4, crossing Dailey Hollow Branch, Bridgewater, Vermont.

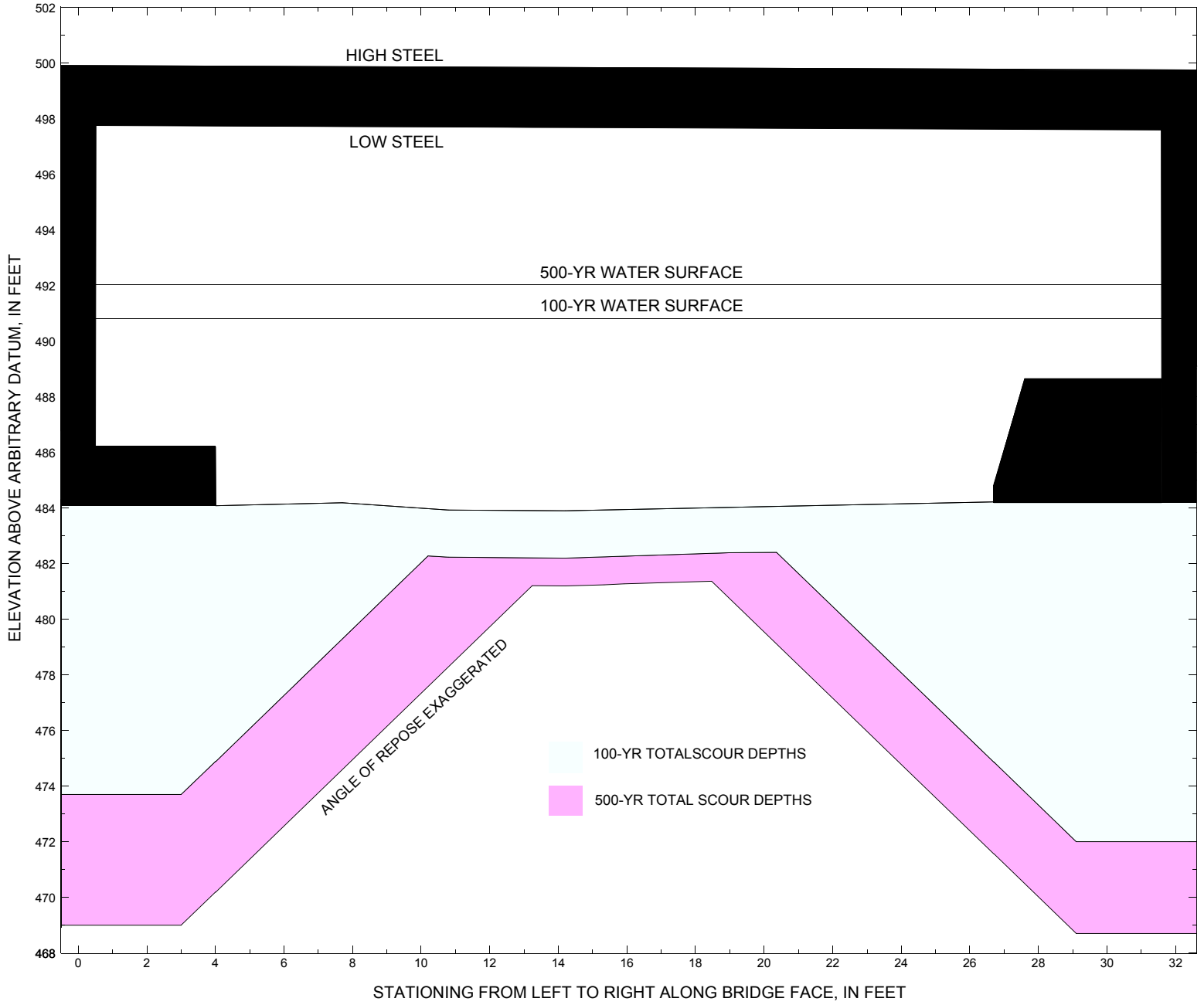


Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00040043 on town highway 4, crossing Dailey Hollow Branch, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00040043 on Town Highway 4, crossing Dailey Hollow Branch, Bridgewater, 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 2,150 cubic-feet per second											
Left abutment	0.0	503.7	497.80	484	484.1	1.7	8.7	--	10.4	473.7	-10
Right abutment	32.1	503.4	497.70	484	484.8	1.7	11.1	--	12.8	472.0	-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 BRIDTH00040043 on Town Highway 4, crossing Dailey Hollow Branch, Bridgewater, 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 2,900 cubic-feet per second											
Left abutment	0.0	503.7	497.80	484	484.1	2.7	12.4	--	15.1	469.0	-15
Right abutment	32.1	503.4	497.70	484	484.8	2.7	13.4	--	16.1	468.7	-15

[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, 1966, Plymouth, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Photoinspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
T2        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
T3        HYDRAULIC ANALYSIS OF BRID043    SAO
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q          2150 2900
SK         0.020 0.020
*
XS   EXITX    -73
GR          -73.0, 506.79    -49.1, 490.84     -9.4, 487.19      0.0, 484.43
GR            5.7, 483.98     12.6, 483.48     20.6, 484.29     22.9, 485.70
GR           30.7, 487.47     32.4, 489.59     48.0, 495.36     69.9, 496.26
GR           79.0, 495.49     88.9, 493.98    111.9, 507.50
N            0.090        0.060        0.035
SA                -9.4         48.0
*
XS   FULLV   0 * * * 0.006
*
BR   BRIDG   0 497.7 30
GR            0.0, 497.80      0.2, 486.19      4.0, 486.20      4.0, 484.08
GR            7.7, 484.19     10.8, 483.93     14.2, 483.90     19.0, 484.09
GR           26.7, 484.22     26.7, 484.84     27.6, 488.65     32.1, 488.63
GR           32.1, 497.70      0.0, 497.80
N            0.050
CD           1 31.9 * * 45 8.1
*
XR   RDWAY   11 14.3 2
GR          -117.4, 512.21   -100.7, 495.93    -86.0, 496.25    -51.1, 497.99
GR            0.0, 499.96     32.6, 499.70     90.5, 498.11    121.4, 507.22
*
XT   APTEM   118
GR          -105.3, 506.38    -82.5, 496.40    -69.9, 497.61    -56.2, 495.80
GR            -9.7, 493.92     -5.9, 490.07      0.0, 487.77      5.3, 487.33
GR            10.9, 487.21     17.8, 487.56     27.1, 488.20     35.8, 492.79
GR            39.8, 501.15
*
AS   APPRO    50
GT           -1.83
N            0.040        0.060
SA                -9.7
*
HP 1 BRIDG    490.81 1 490.81
HP 2 BRIDG    490.81 * * 2150
HP 1 APPRO    494.44 1 494.44
HP 2 APPRO    494.44 * * 2150
*
HP 1 BRIDG    492.03 1 492.03
HP 2 BRIDG    492.03 * * 2900
HP 1 APPRO    496.45 1 496.45
HP 2 APPRO    496.45 * * 2900
*
EX
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     159.   11892.    28.    40.                       2172.
   490.81          159.   11892.    28.    40.  1.00     0.    32.   2172.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       490.81     0.1    32.1   159.5   11892.    2150.  13.48

X STA.          0.1        3.7        5.7        7.0        8.3        9.4
  A(I)             14.0       11.0        7.8        7.1        6.8
  V(I)             7.67       9.79      13.79      15.06      15.80

X STA.          9.4       10.6       11.6       12.7       13.7       14.8
  A(I)              6.6        6.4        6.3        6.2        6.2
  V(I)            16.17      16.86      17.05      17.23      17.22

X STA.         14.8       15.8       16.9       18.0       19.1       20.2
  A(I)              6.2        6.2        6.5        6.5        6.7
  V(I)            17.22      17.33      16.64      16.58      16.06

X STA.         20.2       21.5       22.7       24.2       25.8       32.1
  A(I)              7.1        7.4        8.2        9.4       16.7
  V(I)            15.11      14.59      13.05      11.45       6.42

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      66.    2983.    50.    50.                        434.
             2     349.   30563.    47.    53.                       5380.
   494.44          415.   33547.    97.   103.  1.10   -60.    37.   4642.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

         WSEL     LEW     REW    AREA        K        Q    VEL
       494.44   -59.8    37.5   415.1   33547.    2150.   5.18

X STA.        -59.8      -20.7       -7.2       -3.3       -0.8        1.3
  A(I)             43.0       32.3       24.6       19.8       17.8
  V(I)             2.50       3.33       4.36       5.44       6.05

X STA.          1.3        3.3        5.2        7.0        8.8       10.6
  A(I)             17.1       16.8       16.4       16.3       16.4
  V(I)             6.30       6.41       6.55       6.60       6.57

X STA.         10.6       12.4       14.3       16.2       18.1       20.1
  A(I)             16.1       16.5       16.8       16.8       17.2
  V(I)             6.66       6.52       6.39       6.39       6.25

X STA.         20.1       22.2       24.4       26.8       29.9       37.5
  A(I)             17.6       18.8       19.0       23.4       32.5
  V(I)             6.12       5.70       5.65       4.59       3.31
```

WSPRO OUTPUT FILE (continued)

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     193.   15753.    28.    43.                       2897.
   492.03          193.   15753.    28.    43.  1.00     0.    32.   2897.

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       492.03     0.1    32.1   193.3   15753.    2900.  15.00

X STA.          0.1        3.6        5.6        7.1        8.3        9.5
  A(I)             17.4       13.3        9.7        8.6        8.2
  V(I)             8.34      10.89      14.91      16.78      17.62

X STA.          9.5       10.7       11.8       12.9       13.9       15.0
  A(I)             8.0        7.8        7.5        7.5        7.5
  V(I)            18.07      18.60      19.21      19.41      19.42

X STA.         15.0       16.1       17.1       18.3       19.4       20.6
  A(I)             7.5        7.5        7.8        7.8        8.1
  V(I)            19.32      19.42      18.64      18.54      17.94

X STA.         20.6       21.8       23.1       24.6       26.2       32.1
  A(I)             8.4        8.9        9.9       11.3       20.6
  V(I)            17.32      16.37      14.63      12.83       7.04

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     201.   14075.    77.    78.                       1838.
             2     444.   44549.    48.    55.                       7665.
   496.45          645.   58624.   125.   133.  1.07   -87.    38.   8043.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

         WSEL     LEW     REW    AREA        K        Q    VEL
       496.45   -86.8    38.4   645.2   58624.    2900.   4.49

X STA.        -86.8      -49.6      -35.5      -24.6      -15.8       -7.6
  A(I)             59.0       42.6       38.4       34.6       37.5
  V(I)             2.46       3.40       3.77       4.19       3.86

X STA.         -7.6       -3.3       -0.5        2.0        4.4        6.7
  A(I)             34.6       28.3       26.4       25.3       24.9
  V(I)             4.20       5.13       5.49       5.74       5.83

X STA.          6.7        8.9       11.2       13.4       15.8       18.2
  A(I)             24.8       24.9       25.1       25.6       25.7
  V(I)             5.85       5.82       5.78       5.65       5.65

X STA.         18.2       20.7       23.4       26.3       29.7       38.4
  A(I)             26.8       27.9       29.9       32.7       50.2
  V(I)             5.41       5.19       4.86       4.43       2.89
```

WSPRO OUTPUT FILE (continued)

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57

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

EXITX:XS   ******   -41.     252.  1.39 *****  491.44  489.54   2150.  490.05
      -73. ******    34.   15193.  1.23 ***** *******    0.90    8.52

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

FULLV:FV      73.   -50.     349.  0.76  1.00  492.43 *******   2150.  491.67
        0.    73.    37.   22260.  1.28  0.00    0.00    0.61    6.16
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      50.   -10.     236.  1.29  0.63  493.32 *******   2150.  492.03
       50.    50.    36.   16580.  1.00  0.26    0.00    0.71    9.09
         <<<<<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      73.     0.     160.  2.82  1.87  493.64  490.79   2150.  490.81
        0.    73.    32.   11900.  1.00  0.33    0.00    0.99   13.47

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.70 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      11.        <<<<<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      18.   -60.     415.  0.46  0.22  494.90  490.89   2150.  494.44
       50.    19.    37.   33536.  1.10  1.04    0.01    0.46    5.18

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.304  0.161   28036.    -2.    30.   494.29

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -73.   -41.    34.   2150.   15193.     252.    8.52  490.05
   FULLV:FV       0.   -50.    37.   2150.   22260.     349.    6.16  491.67
   BRIDG:BR       0.     0.    32.   2150.   11900.     160.   13.47  490.81
   RDWAY:RG      11.**************      0.******************    2.00********
   APPRO:AS      50.   -60.    37.   2150.   33536.     415.    5.18  494.44

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      -2.    30.   28036.
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS     489.54    0.90  483.48  507.50************  1.39  491.44  490.05
   FULLV:FV   ********    0.61  483.92  507.94  1.00  0.00  0.76  492.43  491.67
   BRIDG:BR     490.79    0.99  483.90  497.80  1.87  0.33  2.82  493.64  490.81
   RDWAY:RG   ***************** 495.93  512.21**********************************
   APPRO:AS     490.89    0.46  485.38  504.55  0.22  1.04  0.46  494.90  494.44
```

WSPRO OUTPUT FILE (continued)

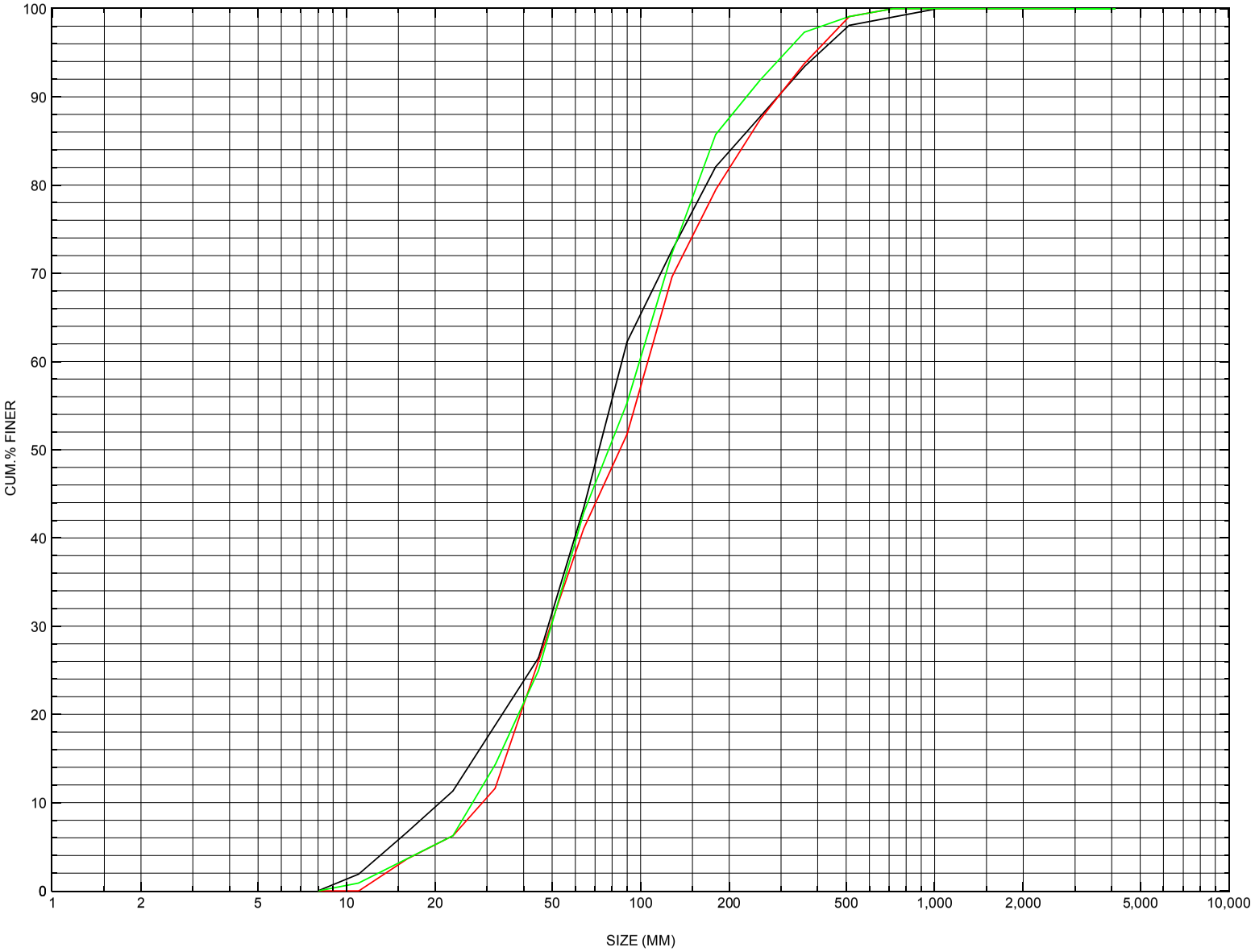
```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
        CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
        HYDRAULIC ANALYSIS OF BRID043    SAO
           *** RUN DATE & TIME: 09-13-95  13:57

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

EXITX:XS   ******   -49.     326.  1.58 *****  492.55  490.51   2900.  490.97
      -73. ******    36.   20498.  1.28 ***** *******    0.91    8.89

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "FULLV"     KRATIO =  1.45

FULLV:FV      73.   -51.     438.  0.87  1.01  493.55 *******   2900.  492.68
        0.    73.    40.   29789.  1.27  0.00   -0.01    0.60    6.62
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.88     492.94     491.86

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   492.18     504.55    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   492.18     504.55     491.86

APPRO:AS      50.   -31.     288.  1.64  0.65  494.59  491.86   2900.  492.94
       50.    50.    37.   21684.  1.04  0.39    0.00    0.88   10.08
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   496.45       0.00     492.03     495.93

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                  WS,QBO,QRD =   501.20         0.      2900.

 ===280 REJECTED FLOW CLASS 4 SOLUTION.

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

 ===250 INSUFFICIENT HEAD FOR PRESSURE FLOW.
                        YU/Z,WSIU,WS = 1.08     498.63     498.66

 ===270 REJECTED 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      73.     0.     193.  3.50  1.90  495.53  484.10   2900.  492.03
        0.    73.    32.   15764.  1.00  0.50    0.00    1.00   15.00

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  497.70 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      11.        <<<<<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      18.   -87.     645.  0.34  0.17  496.79  491.86   2900.  496.45
       50.    19.    38.   58617.  1.07  1.08    0.00    0.36    4.50

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.526  0.317   40023.    -3.    29.   496.36

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

WSPRO OUTPUT FILE (continued)

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

         U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
         CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
         HYDRAULIC ANALYSIS OF BRID043    SAO
            *** RUN DATE & TIME: 09-13-95  13:57
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -73.   -49.    36.   2900.   20498.     326.    8.89  490.97
    FULLV:FV       0.   -51.    40.   2900.   29789.     438.    6.62  492.68
    BRIDG:BR       0.     0.    32.   2900.   15764.     193.   15.00  492.03
    RDWAY:RG      11.**************      0.******************    2.00********
    APPRO:AS      50.   -87.    38.   2900.   58617.     645.    4.50  496.45

     XSID:CODE   XLKQ   XRKQ       KQ
    APPRO:AS      -3.    29.   40023.
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

         U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid043.wsp
         CREATED ON 01-SEP-95 FOR BRIDGE BRIDTH00040043 USING FILE brid043.dca
         HYDRAULIC ANALYSIS OF BRID043    SAO
            *** RUN DATE & TIME: 09-13-95  13:57
  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
    EXITX:XS     490.51    0.91  483.48  507.50************  1.58  492.55  490.97
    FULLV:FV   ********    0.60  483.92  507.94  1.01  0.00  0.87  493.55  492.68
    BRIDG:BR     484.10    1.00  483.90  497.80  1.90  0.50  3.50  495.53  492.03
    RDWAY:RG   ***************  495.93  512.21************  0.15  498.79********
    APPRO:AS     491.86    0.36  485.38  504.55  0.17  1.08  0.34  496.79  496.45
```

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 BRIDTH00040043, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM