LEVEL II SCOUR ANALYSIS FOR BRIDGE 42 (BRIDTH00040042) on TOWN HIGHWAY 4, crossing DAILEY HOLLOW BROOK, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-243

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

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By SCOTT A. OLSON 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
Gordon P. Eaton, Director

For additional information
write to:

District Chief
U.S. Geological Survey
361 Commerce Way
Pembroke, NH 03275

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Denver, CO 80225

CONTENTS

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 42 (BRIDTH00040042) ON TOWN HIGHWAY 4, CROSSING DAILEY HOLLOW BROOK, BRIDGEWATER, VERMONT

By Scott A. Olson 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 BRIDTH00040042 on town highway 4 crossing Dailey Hollow Brook, 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 division of central Vermont in the town of Bridgewater. The 2.20-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the overbanks are covered by shrubs and trees except for the upstream right overbank where there is a house. Dailey Hollow Brook enters Dailey Hollow Branch at the downstream face of the bridge.

In the study area, Dailey Hollow Brook has an incised, sinuous channel with a slope of approximately 0.035 ft/ft. The channel top width and channel depth upstream of the bridge is 19 ft and 3 ft, respectively. Downstream of the bridge and the confluence the channel top width and channel depth is 39 ft and 2 ft respectively. The predominant channel bed material is cobble and gravel (D_{50} is 64.7 mm or 0.212 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 Brook is a 25-ft-long, one-lane bridge consisting of one 23-foot concrete span (Vermont Agency of Transportation, written communication, August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. Type-2 stone fill (less than 36 inches) exists along all four wingwalls, the downstream right road approach, and the channel banks in the immediate vicinity of the bridge. The channel is skewed approximately 20 degrees to the opening; the opening-skew-to-roadway is also 20 degrees. 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 modelled flows was 0.0 ft. Abutment scour ranged from 3.9 to 5.4 ft. with the worst-case abutment scour occurring 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). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

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 BRIDTH00040042 ***Stream*** Dailey Hollow Brook

County Windsor ***Road*** TH04 ***District*** 04

Description of Bridge

Bridge length 25 ***ft*** ***Bridge width*** 17.4 ***ft*** ***Max span length*** 23 ***ft***

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

Abutment type vertical ***Embankment type*** sloping on left

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

Description of stone fill Type-2 stone protects the wingwalls and the channel banks in the vicinity of the bridge. The downstream right road embankment is also protected with type-2 stone.

The abutments and wingwalls are concrete.

Brief description of piers/abutments

Y

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

There is a mild bend in the channel approach. Since the opening skew to roadway matches the skew of 20 degrees, the left abutment is impacted only slightly by flow.

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 with the banks upstream often undercut with many trees leaning towards the channel.

Describe any features near or at the bridge that may affect flow (include observation date) November 1, 1994. Dailey Hollow Brook empties into Dailey Hollow Branch immediately downstream of the bridge. Both streams are roughly the same size.

Description of the Geomorphic Setting

General topography The bridge is in a steep narrow valley with moderate relief.

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

Date of inspection 11/01/94

DS left: Steep high bank. A gravel road parallels the left bank.

DS right: Moderately sloping bank.

US left: Steep high bank. A gravel road parallels the left bank.

US right: High river bank with a flat narrow overbank to a steep valley wall.

Description of the Channel

Average top width 19 (US) ***ft*** ***Average depth*** 3.2 (US) ***ft***

Predominant bed material cobble/gravel ***Bank material*** cobble / gravel

High gradient, slightly sinuous stream with no flood plains.

Vegetative co 11/01/94

Forested.

DS left: Immediate banks have significant woody vegetation; grass on overbanks.

DS right: Forested.

US left: Immediate bank is grass; forested beyond.

US right:

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

11/01/94--None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 2.20 ***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.

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 805 ***ft³/s*** ***Q500*** 1,060 ***ft³/s***

Q100 and Q500 for Bridgewater bridge #42 were based on a drainage area relationship with Bridgewater bridge #30 which is on Dailey Hollow Branch. The Q100 for bridge #30 was taken from VTAOT files. The Q500 for bridge #30 was determined by a weighted average of numerous extrapolated empirical methods which were applicable to a stream with it's size drainage in this region(Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887; FEMA, 1980).

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 1355 feet to the study's arbitrary datum to obtain VTAOT plans' datum (NAD27).

Description of reference marks used to determine USGS datum. RM1 is the center of a bronze disk on top of the downstream end of the right abutment (elev. 99.62 ft, arbitrary survey datum). RM2 is a chiseled X on the upstream end of the left abutment (elev. 99.23 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-45	1	Surveyed exit section downstream of the confluence of a Dailey Hollow Brook and Dailey Hollow Branch (this section modelled with the combined discharge).
EXIT2	-20	2	Exit section (templated from EXITX)
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	9	1	Road Grade section
APPRO	55	1	Approach section

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

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). 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 0.055 to 0.075, and overbank "n" values ranged from 0.055 to 0.105.

Since the confluence of Dailey Hollow Brook and Dailey Hollow Branch was at the immediate downstream face of the bridge, the exit section (EXITX) was surveyed just downstream of the confluence. Normal depth at the exit section (EXITX) was assumed and used as the starting water surface for the model. 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 0.0221 ft/ft which was determined from surveyed thalweg points downstream of the confluence.

The discharges used in the normal depth computations were 1,780 ft^3/s (100-year) and 2,260 ft^3/s (500-year), which are the estimated combined flow of the Dailey Hollow Brook and Dailey Hollow Branch. Both streams are assumed to peak at the same time since each has similar basin characteristics including drainage area. The 100-year discharge of Dailey Hollow Branch is from the VTAOT database (written communication, May 1995). The 500-year discharge for Dailey Hollow Branch was based on a drainage area relationship (2.2/2.5) with the study site.

The surveyed exit section was then used as a template and moved upstream in the model with a correction for the bed slope to a location one bridge length downstream of the bridge and the discharge was changed to only include the flows of Dailey Hollow Brook.

Bridge Hydraulics Summary

Average bridge embankment elevation 99.6 *ft*
Average low steel elevation 97.9 *ft*

100-year discharge 805 *ft^3/s*
Water-surface elevation in bridge opening 90.7 *ft*
Road overtopping? N *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 106 *ft^2*
Average velocity in bridge opening 7.6 *ft/s*
Maximum WSPRO tube velocity at bridge 9.5 *ft/s*

Water-surface elevation at Approach section with bridge 91.6 *ft*
Water-surface elevation at Approach section without bridge 91.8 *ft*
Amount of backwater caused by bridge -- *ft*

500-year discharge 1,060 *ft^3/s*
Water-surface elevation in bridge opening 91.5 *ft*
Road overtopping? N *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 121 *ft^2*
Average velocity in bridge opening 8.8 *ft/s*
Maximum WSPRO tube velocity at bridge 11.1 *ft/s*

Water-surface elevation at Approach section with bridge 92.6 *ft*
Water-surface elevation at Approach section without bridge 92.7 *ft*
Amount of backwater caused by bridge -- *ft*

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 -- *ft*
Water-surface elevation at Approach section without bridge -- *ft*
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 live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16,17). For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). 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	0.0	--
Clear-water scour	--	--	--
Depth to armoring	1.0	2.3	
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	4.3	5.4	--
Right abutment	3.9	5.0	--
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:			
Left abutment	1.1	1.5	--
Right abutment	1.1	1.5	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

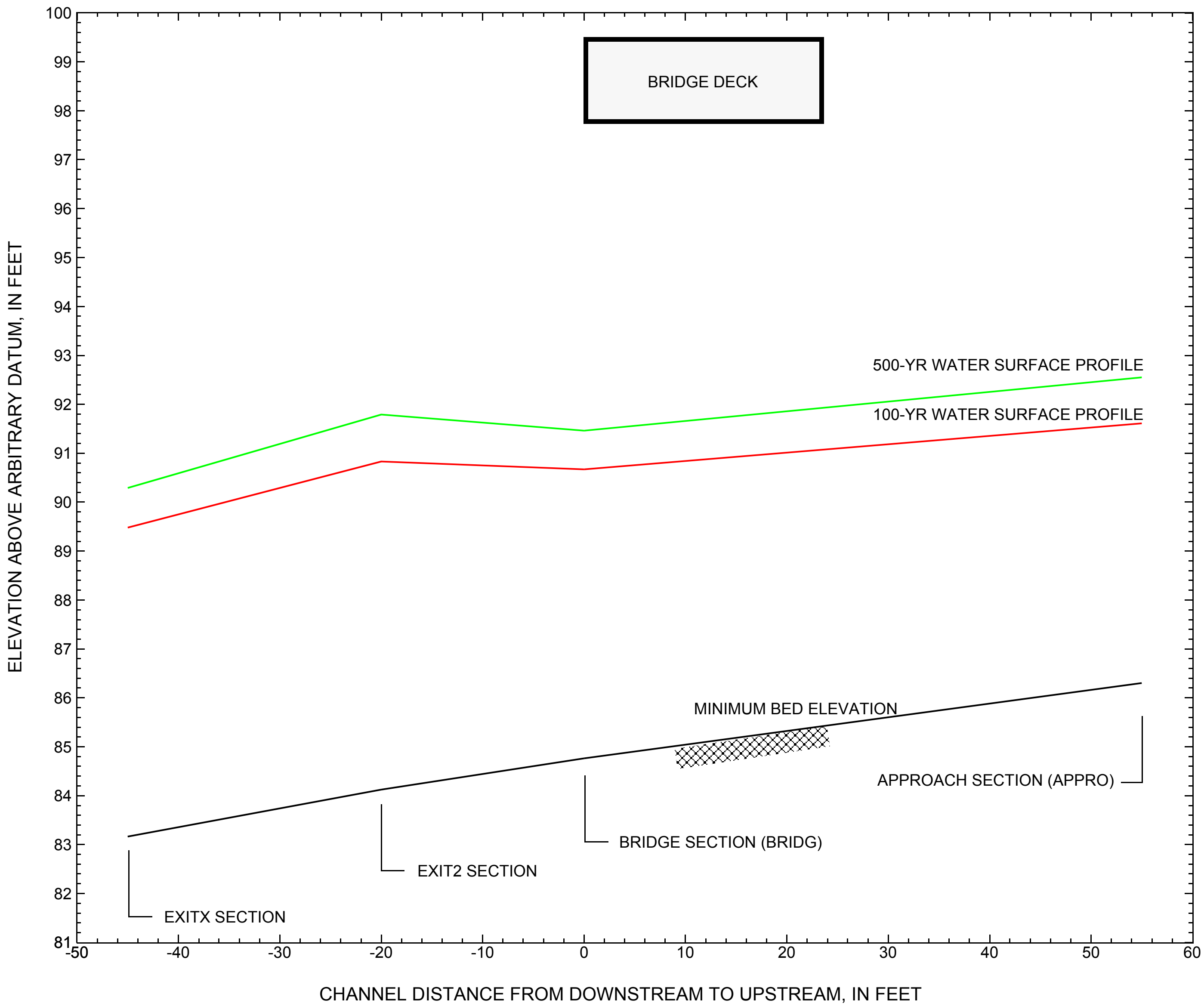

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00040042 on town highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.

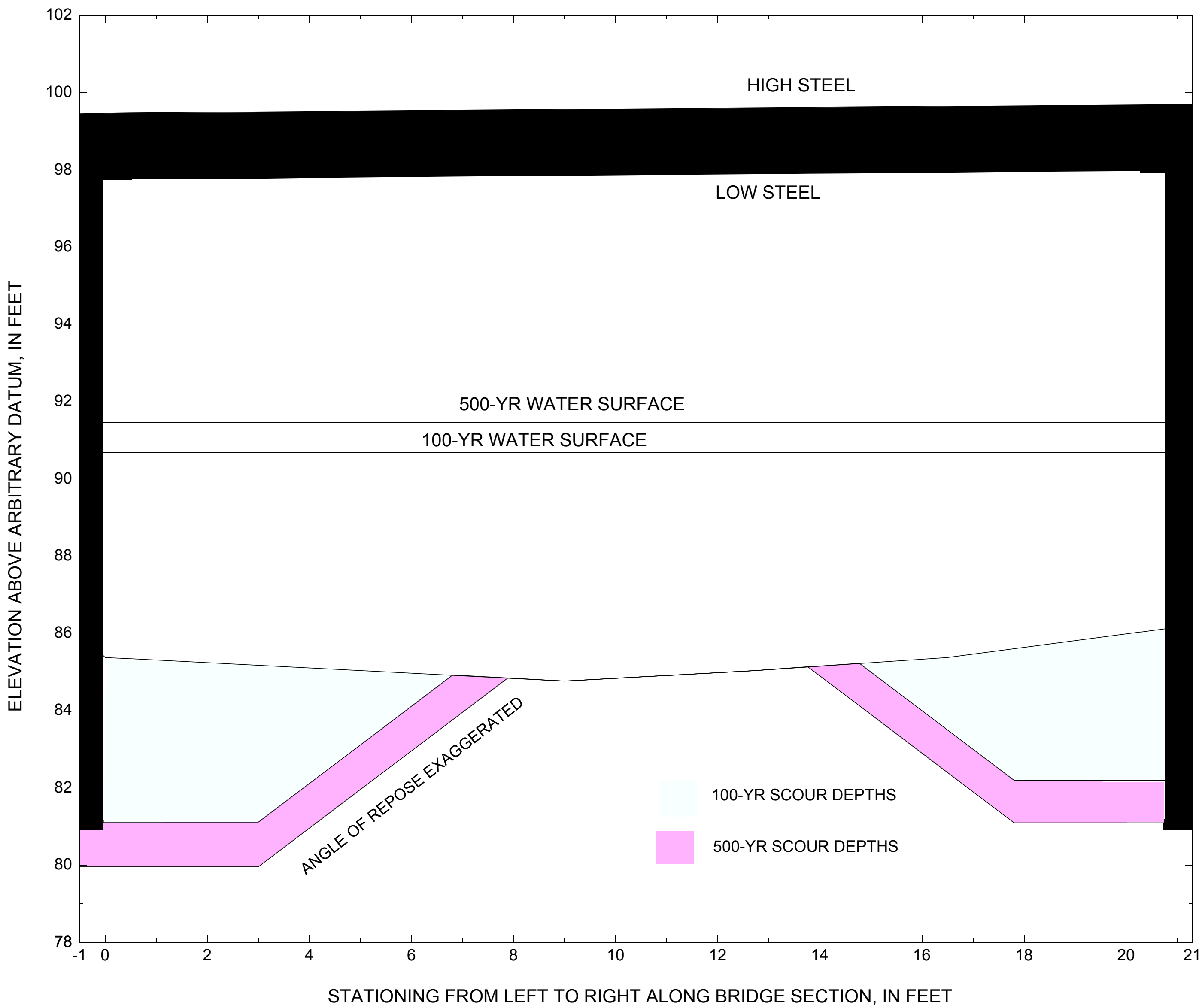

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00040042 on town highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00040042 on Town Highway 4, crossing Dailey Hollow Brook, 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 1,780 cubic-feet per second											
Left abutment	0.0	1452.4	97.66	81	85.4	0.0	4.3	--	4.3	81.1	0
Right abutment	20.8	1452.8	98.13	81	86.1	0.0	3.9	--	3.9	82.2	1

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 BRIDTH00040042 on Town Highway 4, crossing Dailey Hollow Brook, 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 2,260 cubic-feet per second											
Left abutment	0.0	1452.4	97.66	81	85.4	0.0	5.4	--	5.4	80.0	-1
Right abutment	20.8	1452.8	98.13	81	86.1	0.0	5.0	--	5.0	81.1	0

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 brid042.wsp
T2        CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
T3        HYDRAULIC ANALYSIS OF BRID042     SAO
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1780 2260
SK          0.0221 0.0221
*
XS   EXITX   -45
GR          -80.1, 105.48    -59.4, 100.61    -51.6,  99.61    -33.0,  99.51
GR          -13.3,  95.49     -4.0,  87.28      0.0,  85.36      6.3,  84.67
GR           12.7,  84.11     18.0,  83.16     21.8,  83.37     25.8,  84.15
GR           34.7,  86.56     36.7,  89.67     46.7,  93.13     72.5,  94.40
GR           85.9,  96.11    133.0,  98.27    143.9, 103.36
N            0.055        0.062        0.060
SA                 -13.3        46.7
*
XS   EXIT2  -20 * * * 0.0385
*
Q           805 1060
*
XS   FULLV   0 * * * 0.0385
*
BR   BRIDG   0 97.9 20
GR            0.0,  97.66      0.1,  85.37      4.3,  85.11      9.0,  84.76
GR           12.7,  85.03     16.5,  85.37     20.6,  86.12     20.8,  98.13
GR            0.0,  97.66
N            0.055
CD           1 35.5 * * 55 8.8
*
XR   RDWAY    9 17.4 2
GR          -78.2, 103.19    -64.3, 100.12    -50.9, 101.09    -33.4, 100.21
GR            0.0,  99.35     21.3,  99.80     56.9, 100.25    100.0, 101.67
*
AS   APPRO     55 * 1
GR          -48.5, 106.21    -31.8, 101.52     -4.0,  93.73      0.0,  90.43
GR            3.9,  87.49      6.2,  87.03      7.3,  86.30      9.3,  86.33
GR           10.8,  86.75     13.6,  86.95     15.7,  87.00     18.8,  90.69
GR           23.8,  92.50     27.7,  94.01     32.4,  99.50     44.2, 100.11
GR           80.5, 102.23     86.9, 106.85
N            0.105        0.075        0.072
SA                  -4.0        32.4
*
HP 1 BRIDG    90.67 1 90.67
HP 2 BRIDG    90.67 * * 805
HP 1 APPRO    91.61 1 91.61
HP 2 APPRO    91.61 * * 805
*
HP 1 BRIDG    91.46 1 91.46
HP 2 BRIDG    91.46 * * 1060
HP 1 APPRO    92.55 1 92.55
HP 2 APPRO    92.55 * * 1060
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
        CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
        HYDRAULIC ANALYSIS OF BRID042     SAO
           *** RUN DATE & TIME: 10-03-95  10:46
    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     106.    6736.    19.    29.                        1399.
    90.67          106.    6736.    19.    29.  1.00     0.    21.   1399.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        90.67     0.1    20.7   105.6    6736.     805.   7.62

X STA.         0.1        2.1        3.3        4.4        5.3        6.2
  A(I)            10.4        6.1        5.4        5.0        4.6
  V(I)            3.88       6.63       7.49       8.11       8.75

X STA.         6.2        7.0        7.8        8.6        9.3       10.1
  A(I)             4.5        4.4        4.3        4.2        4.2
  V(I)            8.99       9.22       9.44       9.47       9.54

X STA.        10.1       10.9       11.7       12.5       13.3       14.2
  A(I)             4.3        4.2        4.4        4.4        4.5
  V(I)            9.44       9.54       9.20       9.21       9.00

X STA.        14.2       15.1       16.0       17.1       18.4       20.7
  A(I)             4.7        4.8        5.4        5.8       10.2
  V(I)            8.56       8.37       7.39       6.89       3.96

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      55.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2      78.    3165.    23.    26.                         813.
    91.61           78.    3165.    23.    26.  1.00    -1.    21.    813.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      55.
         WSEL     LEW     REW    AREA        K        Q    VEL
        91.61    -1.4    21.3    77.6    3165.     805.  10.37

X STA.        -1.4        2.7        4.0        4.9        5.7        6.5
  A(I)             6.9        4.7        3.9        3.6        3.5
  V(I)            5.82       8.58      10.36      11.18      11.58

X STA.         6.5        7.2        7.8        8.3        8.9        9.5
  A(I)             3.4        3.1        3.0        3.0        3.0
  V(I)           11.96      12.82      13.25      13.43      13.47

X STA.         9.5       10.1       10.7       11.3       12.0       12.7
  A(I)             3.0        3.1        3.2        3.2        3.2
  V(I)           13.29      12.91      12.62      12.39      12.44

X STA.        12.7       13.4       14.2       15.1       16.1       21.3
  A(I)             3.5        3.6        4.0        4.8        7.8
  V(I)           11.49      11.08      10.16       8.35       5.16
```

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        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
        CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
        HYDRAULIC ANALYSIS OF BRID042     SAO
           *** RUN DATE & TIME: 10-03-95  10:46
    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     121.    8151.    19.    31.                       1714.
    91.46          121.    8151.    19.    31.  1.00     0.    21.   1714.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
        91.46     0.1    20.7   120.9    8151.    1060.  8.77

X STA.         0.1        2.2        3.4        4.4        5.4        6.2
  A(I)            12.2        7.1        6.1        5.6        5.2
  V(I)            4.35       7.43       8.67       9.39      10.15

X STA.         6.2        7.1        7.8        8.6        9.4       10.1
  A(I)             5.1        4.9        4.8        4.8        4.8
  V(I)           10.44      10.73      10.99      11.05      11.12

X STA.        10.1       10.9       11.7       12.5       13.3       14.2
  A(I)             4.8        4.8        4.9        4.9        5.1
  V(I)           11.03      11.13      10.72      10.71      10.45

X STA.        14.2       15.1       16.0       17.1       18.4       20.7
  A(I)             5.2        5.6        6.0        7.1       11.8
  V(I)           10.19       9.45       8.78       7.48       4.50

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      55.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             2     101.    4430.    26.    31.                       1115.
    92.55          101.    4430.    26.    31.  1.00    -3.    24.   1115.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      55.
         WSEL     LEW     REW    AREA        K        Q    VEL
        92.55    -2.6    23.9   100.8    4430.    1060.  10.52

X STA.        -2.6        2.1        3.5        4.5        5.4        6.2
  A(I)             8.9        6.1        4.9        4.7        4.3
  V(I)            5.95       8.71      10.86      11.37      12.36

X STA.         6.2        6.9        7.6        8.2        8.8        9.4
  A(I)             4.2        4.1        3.9        3.8        3.8
  V(I)           12.51      12.85      13.70      13.88      13.91

X STA.         9.4       10.1       10.8       11.5       12.2       12.9
  A(I)             3.9        4.0        4.0        4.2        4.3
  V(I)           13.58      13.16      13.24      12.69      12.44

X STA.        12.9       13.7       14.6       15.5       16.9       23.9
  A(I)             4.5        4.7        5.3        6.7       10.4
  V(I)           11.69      11.23       9.99       7.86       5.09
```

```
         U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
        CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
        HYDRAULIC ANALYSIS OF BRID042     SAO
           *** RUN DATE & TIME: 10-03-95  10:46

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

EXITX:XS   ******    -6.     193.  1.32 *****   90.80   88.71   1780.   89.48
      -45. ******    37.   11969.  1.00 ***** *******    0.77    9.23

EXIT2:XS      25.    -7.     210.  0.23  0.26   91.06 *******    805.   90.83
      -20.    25.    37.   13506.  1.00  0.00    0.00    0.31    3.84

FULLV:FV      20.    -6.     178.  0.32  0.09   91.19 *******    805.   90.87
        0.    20.    36.   10656.  1.00  0.04    0.00    0.39    4.51
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.91      91.84      91.59

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =    90.37     106.85    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =    90.37     106.85      91.59

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.32

APPRO:AS      55.    -2.      83.  1.46  0.97   93.31   91.59    805.   91.85
       55.    55.    22.    3454.  1.00  1.14    0.01    0.91    9.69
         <<<<<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      20.     0.     106.  0.91  0.29   91.57   88.99    805.   90.67
        0.    20.    21.    6728.  1.00  0.22    0.00    0.58    7.63

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******   97.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      20.    -1.      78.  1.67  1.20   93.28   91.59    805.   91.61
       55.    20.    21.    3165.  1.00  0.51    0.00    0.99   10.37

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.130  0.000    3341.    -1.    20.    89.18

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -45.    -6.    37.   1780.   11969.     193.    9.23   89.48
   EXIT2:XS     -20.    -7.    37.    805.   13506.     210.    3.84   90.83
   FULLV:FV       0.    -6.    36.    805.   10656.     178.    4.51   90.87
   BRIDG:BR       0.     0.    21.    805.    6728.     106.    7.63   90.67
   RDWAY:RG       9.**************      0.******************     2.00********
   APPRO:AS      55.    -1.    21.    805.    3165.      78.   10.37   91.61

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL     WSEL
   EXITX:XS     88.71    0.77   83.16  105.48************  1.32    90.80    89.48
   EXIT2:XS  ********    0.31   84.12  106.44  0.26  0.00  0.23    91.06    90.83
   FULLV:FV  ********    0.39   84.89  107.21  0.09  0.04  0.32    91.19    90.87
   BRIDG:BR     88.99    0.58   84.76   98.13  0.29  0.22  0.91    91.57    90.67
   RDWAY:RG ****************   99.35  103.19**********************************
   APPRO:AS     91.59    0.99   86.30  106.85  1.20  0.51  1.67    93.28    91.61
```

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
        CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
        HYDRAULIC ANALYSIS OF BRID042     SAO
           *** RUN DATE & TIME: 10-03-95  10:46

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

EXITX:XS   ******    -7.     229.  1.52 *****   91.80   89.40   2260.   90.29
      -45. ******    38.   15189.  1.00 ***** *******    0.78    9.88

EXIT2:XS      25.    -8.     254.  0.27  0.26   92.06 *******   1060.   91.79
      -20.    25.    40.   17513.  1.00  0.00   -0.01    0.32    4.17

FULLV:FV      20.    -7.     220.  0.36  0.09   92.19 *******   1060.   91.83
        0.    20.    38.   14404.  1.00  0.05    0.00    0.38    4.82
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.89     92.75      92.40

 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =    91.33     106.85    0.50

 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    91.33     106.85      92.40

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  0.33

APPRO:AS      55.    -3.     106.  1.56  0.91   94.30   92.40   1060.   92.74
       55.    55.    24.    4724.  1.00  1.20    0.00    0.90   10.01
         <<<<<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      20.     0.     121.  1.20  0.26   92.65   89.74   1060.   91.46
        0.    20.    21.    8142.  1.00  0.33    0.00    0.62    8.77

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******   97.90 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       9.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      20.    -3.     101.  1.72  1.03   94.27   92.40   1060.   92.55
       55.    20.    24.    4437.  1.00  0.60    0.01    0.95   10.51

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.241  0.000    4842.    -1.    20.    90.40

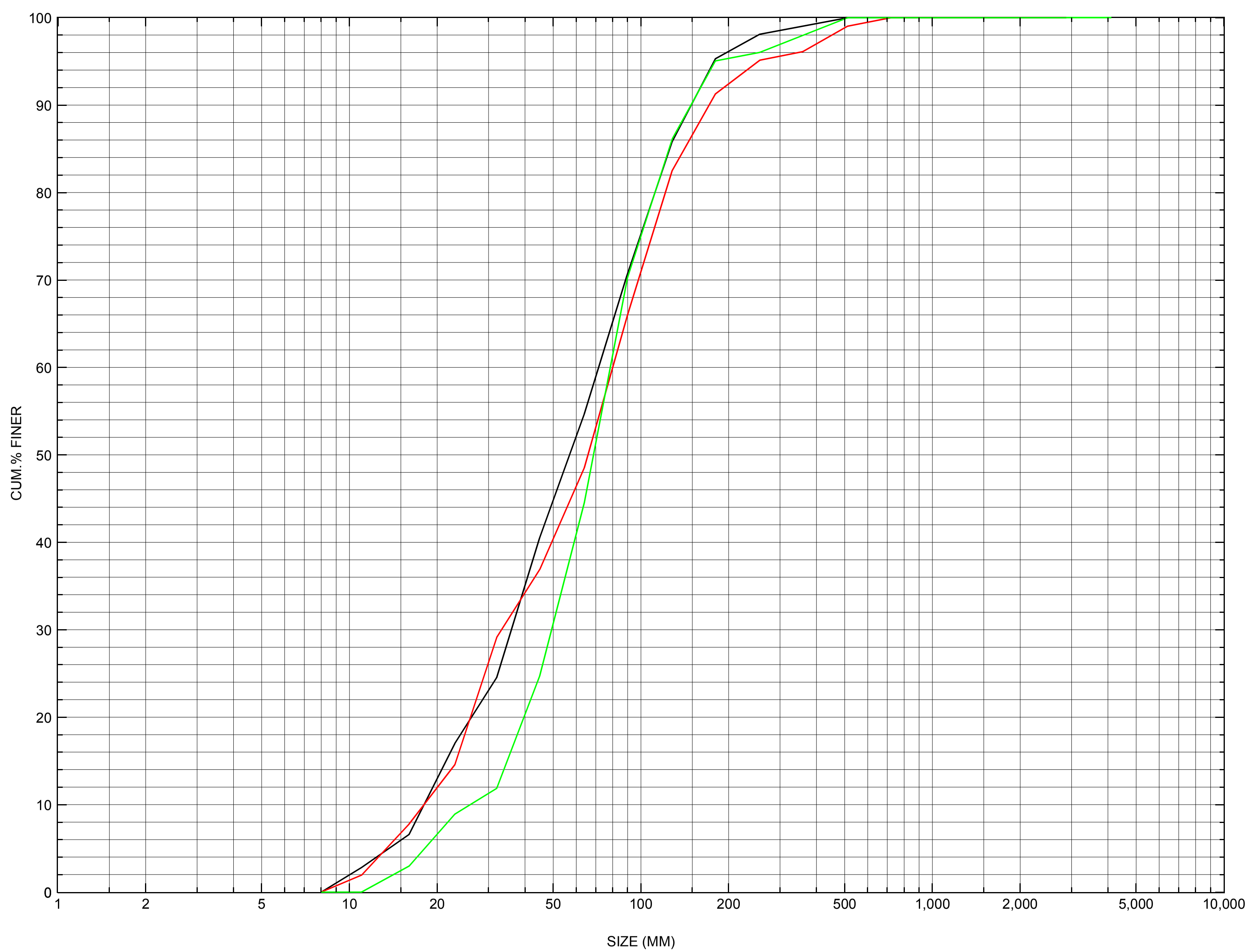
                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

   FIRST USER DEFINED TABLE.
     XSID:CODE    SRD     LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -45.     -7.    38.   2260.   15189.     229.    9.88   90.29
    EXIT2:XS     -20.     -8.    40.   1060.   17513.     254.    4.17   91.79
    FULLV:FV       0.     -7.    38.   1060.   14404.     220.    4.82   91.83
    BRIDG:BR       0.      0.    21.   1060.    8142.     121.    8.77   91.46
    RDWAY:RG       9.**************      0.*****************     2.00********
    APPRO:AS      55.     -3.    24.   1060.    4437.     101.   10.51   92.55

 SECOND USER DEFINED TABLE.
     XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
    EXITX:XS      89.40    0.78   83.16  105.48************  1.52   91.80   90.29
    EXIT2:XS   ********    0.32   84.12  106.44  0.26  0.00  0.27   92.06   91.79
    FULLV:FV   ********    0.38   84.89  107.21  0.09  0.05  0.36   92.19   91.83
    BRIDG:BR      89.74    0.62   84.76   98.13  0.26  0.33  1.20   92.65   91.46
    RDWAY:RG   ****************   99.35  103.19*********************************
    APPRO:AS      92.40    0.95   86.30  106.85  1.03  0.60  1.72   94.27   92.55
```

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 BRIDTH00040042, in Bridgewater, Vermont.

APPENDIX D:

HISTORICAL DATA FORM