LEVEL II SCOUR ANALYSIS FOR BRIDGE 45 (CHELTH00440045) on TOWN HIGHWAY 44, crossing the FIRST BRANCH WHITE RIVER, CHELSEA, VERMONT

U.S. Geological Survey
Open-File Report 96-241

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

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By JOSEPH D. AYOTTE and ROBERT E. HAMMOND

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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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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 45 (CHELTH00440045) ON TOWN HIGHWAY 44, CROSSING the FIRST BRANCH WHITE RIVER, CHELSEA, VERMONT

By Joseph D. Ayotte *and* Robert E. Hammond

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure CHELTH00440045 on town highway 44 crossing the First Branch White River, Chelsea, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Chelsea. The 32.5-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have low to moderate woody vegetation coverage except for the upstream right bank, which is grass covered. The immediate vicinity of the site is suburban and the overbank areas are occupied by houses, driveways, and lawn areas. The upstream right bank area is a dirt parking lot for a small auto repair garage.

In the study area, the First Branch White River has an incised, sinuous channel with a slope of approximately 0.003 ft/ft, an average channel top width of 41 ft and an average channel depth of 4 ft. The predominant channel bed material is gravel (D_{50} is 43.1 mm or 0.141 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 17, 1994, indicated that the reach was stable.

The town highway 44 crossing of the First Branch White River is a 31-ft-long, two-lane bridge consisting of one 27-foot clear-span concrete-encased steel beam deck superstructure (Vermont Agency of Transportation, written commun., August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is 5 degrees.

Both abutment footings were reported as exposed and the left abutment was reported to be undermined by 0.5 ft at the time of the Level I assessment. The only scour protection measure at the site was type-1 stone fill (less than 12 inches diameter) along the left abutment which was reported as failed. 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 0.4 to 5.1 ft. with the worst-case occurring at the 500-year discharge. Abutment scour ranged from 9.9 to 20.3 ft. The worst-case abutment scour also occurred at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled "Scour Results". Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). 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.

Chelsea, VT. Quadrangle, 1:24,000, 1981

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 CHELTH00440045 ***Stream*** First Branch White River

County Orange ***Road*** TH044 ***District*** 04

Description of Bridge

Bridge length 31 ***ft*** ***Bridge width*** 22.4 ***ft*** ***Max span length*** 27 ***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*** 11/17/94

Description of stone fill Type-1, along the left abutment reported as failed. No protection is reported along the right abutment.

Abutments and wingwalls are concrete. There is 0.5 ft of undermining of the left abutment.

Is bridge skewed to flood flow according to N ***survey?*** Y ***Angle*** 10

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	11/17/94	0	0
Level II	11/17/94	--	--

Potential for debris Low.

Describe any features near or at the bridge that may affect flow (include observation date) There is a small farm-type bridge several hundred feet DS of the bridge which may cause backwater; this structure was ignored for the analyses presented in this report (11/17/94.)

Description of the Geomorphic Setting

General topography The channel is located within a 1,000 foot-wide, 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 11/17/94

DS left: Wide flood plain.

DS right: Wide flood plain

US left: Wide flood plain

US right: Wide flood plain

Description of the Channel

Average top width 41 ***ft*** ***Average depth*** 4 ***ft***

Predominant bed material Gravel / Cobbles ***Bank material*** Stone walls

Sinuous but stable

with alluvial and man-made channel boundaries and a wide flood plain.

11/17/94

Vegetative co Brush and trees on bank with lawn and house overbank

DS left: Few trees and brush on bank with lawn and house overbank

DS right: Brush and some trees; dry wall, with dirt lot and house and garage

US left: Trees and brush on bank, gravel driveway overbank.

US right:

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

None as of 11/17/94

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 32.5 ***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***: The drainage area is largely rural but the site is located in a suburban area of the town of Chelsea

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 5,350 ***ft³/s*** ***Q500*** 6,900 ***ft³/s***

The 100- and 500-year discharges are based on several empirical methods (Talbot, 1887; Potter, 1957a & b; Johnson and Laraway, 1971, written commun.; Johnson and Tasker, 1974; Federal Highway Administration, 1983) and a drainage area relationship [(32.5/58.2)exp 0.7] with bridge number 46 in Chelsea. Bridge 46 on the First Branch White River in Chelsea had a drainage area 58.2 square miles and an estimated Q100 of 7,900 cfs. The discharge at bridge 46 was selected from a range of empirical methods applicable to a site in this region.

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 on DS right guard-rail footing (elev. 501.70 ft, arbitrary datum). RM2 is a chiseled X on top of the US end of the left abutment (elev. 500.55 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-60	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	12	1	Road Grade section
APPRO	50	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 analyses reported herein reflect 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 0.040 to 0.050, and overbank "n" values were 0.025 for driveways and lawn areas.

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 0.003 ft/ft which was estimated from the Flood Insurance Study for the town of Chelsea (FEMA, 1980).

The surveyed approach section (APPRO) was used, as surveyed, at one bridge length upstream of the upstream bridge face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

The roadway section (RDWAY) was shortened to remove ineffective flow area caused by houses on all banks. The ends of the surveyed section were truncated at the surveyed ends of the exit (EXITX) section.

The incipient overtopping discharge was determined to be 2,080 ft^3/s

Bridge Hydraulics Summary

Average bridge embankment elevation 501.6 *ft*
Average low steel elevation 498.2 *ft*

100-year discharge 5,350 *ft³/s*
Water-surface elevation in bridge opening 498.3 *ft*
Road overtopping? Y *Discharge over road* 2,530 *ft³/s*
Area of flow in bridge opening 248 *ft²*
Average velocity in bridge opening 11.3 *ft/s*
Maximum WSPRO tube velocity at bridge 13.5 *ft/s*

Water-surface elevation at Approach section with bridge 504.1 *ft*
Water-surface elevation at Approach section without bridge 501.3 *ft*
Amount of backwater caused by bridge 2.8 *ft*

500-year discharge 6,900 *ft³/s*
Water-surface elevation in bridge opening 498.3 *ft*
Road overtopping? Y *Discharge over road* 3,870 *ft³/s*
Area of flow in bridge opening 248 *ft²*
Average velocity in bridge opening 11.7 *ft/s*
Maximum WSPRO tube velocity at bridge 14.0 *ft/s*

Water-surface elevation at Approach section with bridge 505.0 *ft*
Water-surface elevation at Approach section without bridge 502.1 *ft*
Amount of backwater caused by bridge 2.9 *ft*

Incipient overtopping discharge 2,080 *ft³/s*
Water-surface elevation in bridge opening 498.3 *ft*
Area of flow in bridge opening 248 *ft²*
Average velocity in bridge opening 8.4 *ft/s*
Maximum WSPRO tube velocity at bridge 10.0 *ft/s*

Water-surface elevation at Approach section with bridge 500.2 *ft*
Water-surface elevation at Approach section without bridge 498.8 *ft*
Amount of backwater caused by bridge 1.4 *ft*

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

The 100-year, 500-year and incipient road over-flow discharges resulted in submerged 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 these three discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). In this case, the 500-year discharge model resulted in the worst case contraction scour with a scour depth of 5.1 ft. The results of Laursen's clear-water contraction scour (Richardson and others, 1993, p. 35, equation 18) for the three events were also computed and can be found in appendix F. For contraction scour computations, the average depth in the contracted section (AREA/ TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour for both abutments at all modelled discharges was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Parameters 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	4.5	5.1	0.4
Depth to armoring	8.5	10.0	2.1
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	11.0	11.5	9.9
Right abutment	19.2	20.3	15.2
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	2.5	2.7	1.3
Right abutment	2.5	2.7	1.3
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

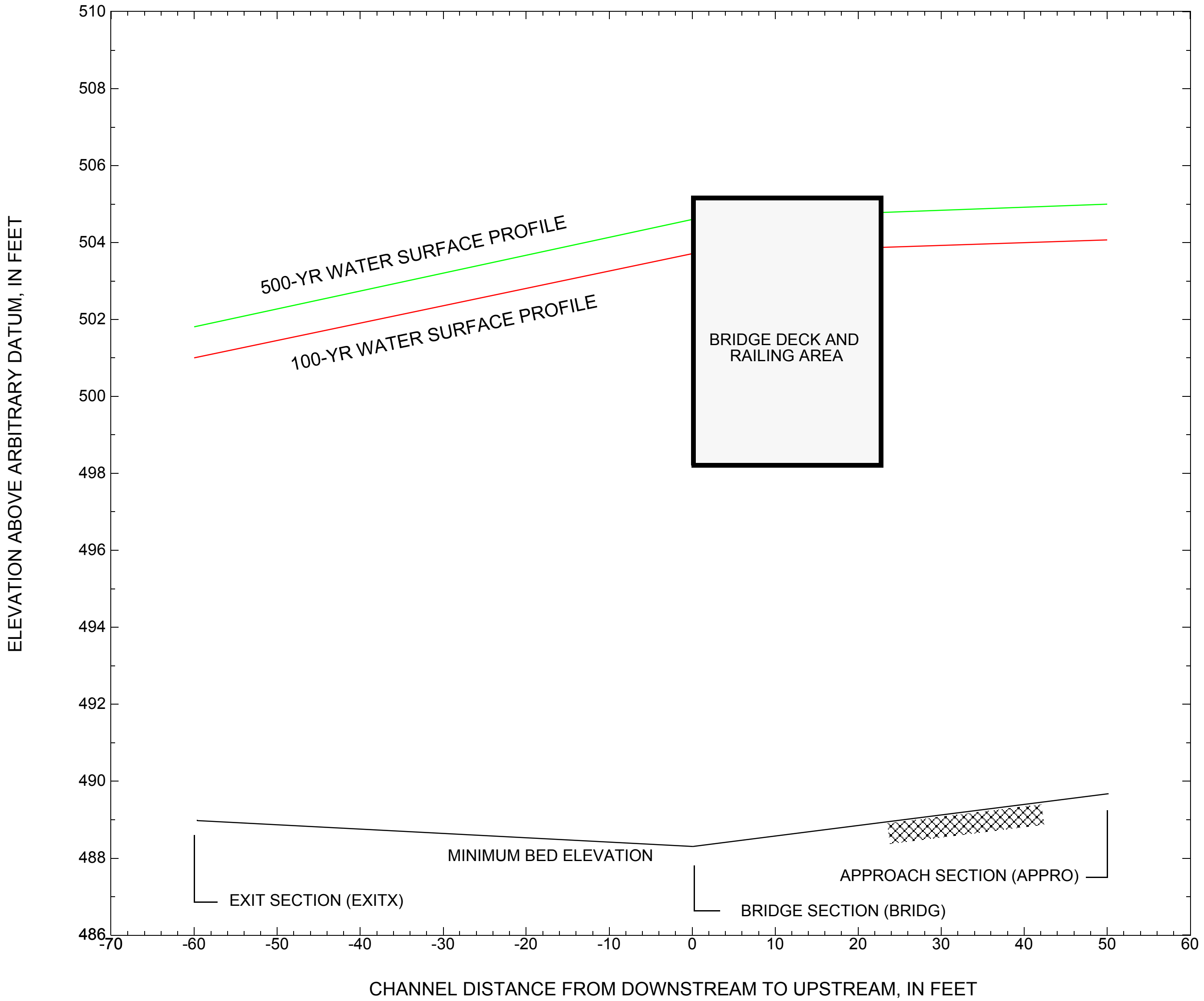

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CHELTH00440045 on town highway 44, crossing First Branch White River, Chelsea, Vermont.

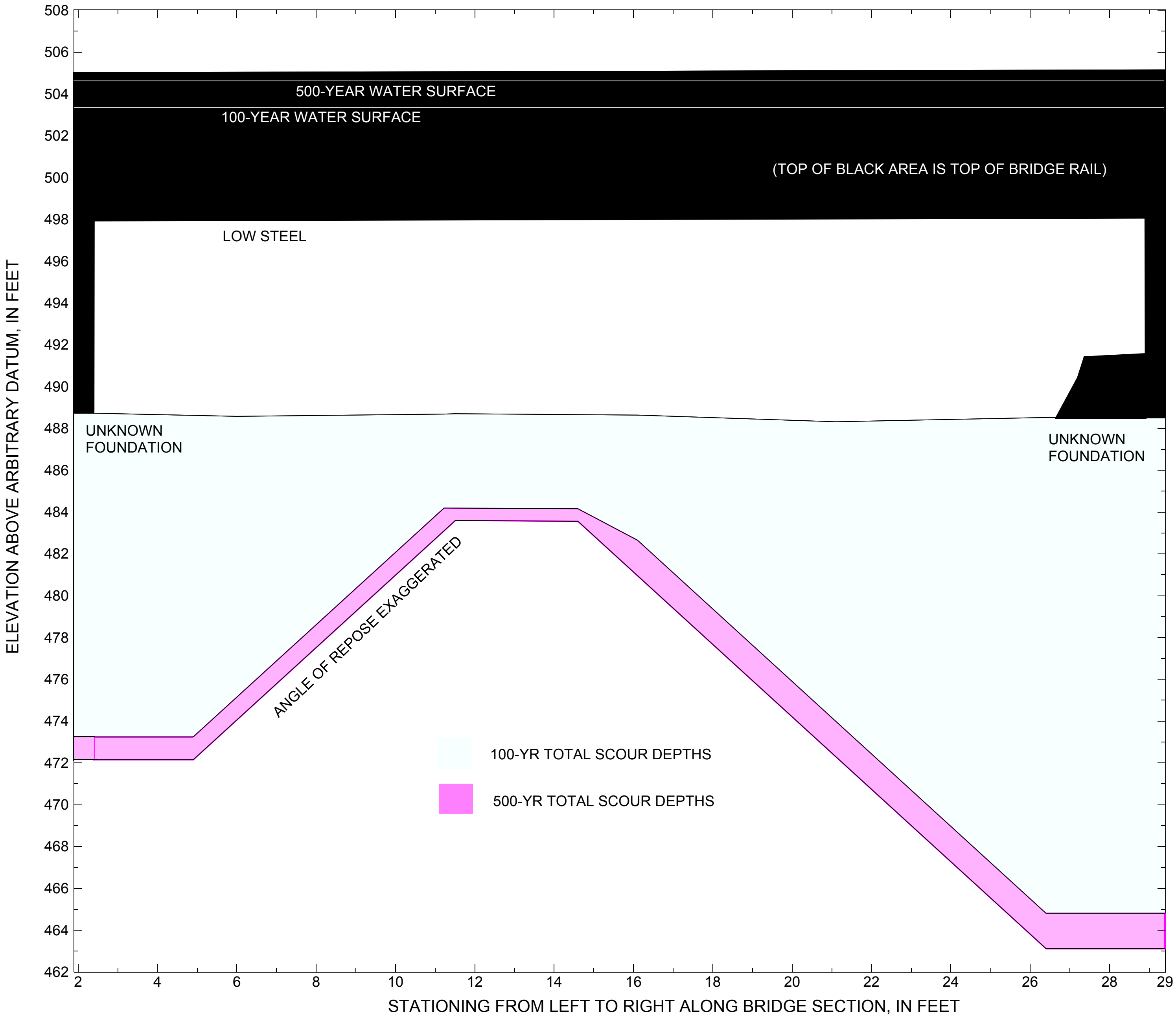

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure CHELTH00440045 on town highway 44, crossing First Branch White River, Chelsea, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CHELTH00440045 on Town Highway 44, crossing First Branch White River, Chelsea, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 5,350 cubic-feet per second											
Left abutment	2.4	--	498.3	--	488.8	4.5	11.0	--	15.5	473.3	--
Right abutment	28.9	--	498.2	--	488.5	4.5	19.2	--	23.7	464.8	--

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 CHELTH00440045 on Town Highway 44, crossing First Branch White River, Chelsea, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 6,900 cubic-feet per second											
Left abutment	2.4	--	498.3	--	488.8	5.1	11.5	--	16.6	472.2	--
Right abutment	28.9	--	498.2	--	488.5	5.1	20.3	--	25.4	463.1	--

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, 1981, Chelsea, 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 chel045.wsp
T2        Hydraulic analysis for structure CHELTH0440045    Date: 14-FEB-96
T3        chelsea br 45 crossing first br white river, town highway 44   JDA
*
Q           5350 6900 2080
SK          0.0030 0.0030 0.0030
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -60
GR          -62.0, 501.32    -10.9, 498.22     -2.6, 493.87      0.0, 490.58
GR            3.7, 489.73      7.7, 488.96     13.3, 489.35     21.9, 489.79
GR           30.4, 490.45     30.6, 490.63     37.4, 494.41     43.9, 496.66
GR          118.7, 498.95    119.0, 508
N           0.025        0.050        0.025
SA                 -10.9        43.9
*
XS   FULLV       0  * * *   0.0030
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0     498.2       5.0
*
*
GR            2.4, 498.31      2.5, 488.75      6.0, 488.58     11.6, 488.70
GR           16.1, 488.64     21.1, 488.32     26.5, 488.52     27.2, 490.94
GR           27.4, 492.13     28.8, 492.32     28.9, 498.17      2.4, 498.31
*
*         BRTYPE  BRWDTH    EMBSS   EMBELV   WWANGL
CD           4      24.4      2.7    500.7     67.8
N           0.040
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     12      22.4     1
*
*           Roadway included concrete bridge rails (-3.0, 501.56, -3.0, 505.01 and
*                                                    31.6, 505.21      31.6, 501.56)
*
GR         -62.0, 502.00     -47.2, 501.60     -3.0, 501.56     -3.0, 505.01
GR          31.6, 505.21      31.6, 501.56    113.2, 500.13    114.0, 508
*
AS   APPRO     50
GR          -29.5, 503.28    -12.1, 497.69     -3.3, 494.42      0.0, 490.67
GR            3.7, 490.01     11.2, 490.07     14.2, 489.67     25.8, 489.76
GR           29.9, 489.71     31.3, 490.78     39.4, 495.67     39.4, 495.67
GR           79.8, 498.29    109.2, 499.12    109.2, 508
*
N           0.050        0.025
SA                  39.4
*
HP 1 BRIDG  498.31 1 498.31
HP 2 BRIDG  498.31 * * 2803
HP 2 RDWAY  503.71 * * 2528
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HP 1 APPRO  504.07 1 504.07
HP 2 APPRO  504.07 * * 5350
*
HP 1 BRIDG  498.31 1 498.31
HP 2 BRIDG  498.31 * * 2909
HP 2 RDWAY  504.60 * * 3872
HP 1 APPRO  505.00 1 505.00
HP 2 APPRO  505.00 * * 6900
*
HP 1 BRIDG  498.31 1 498.31
HP 2 BRIDG  498.31 * * 2080
HP 1 APPRO  500.18 1 500.18
HP 2 APPRO  500.18 * * 2080
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. Geological Survey WSPRO Input File chel045.wsp
        Hydraulic analysis for structure CHELTH0440045    Date: 14-FEB-96
        chelsea br 45 crossing first br white river, town highway 44   JDA
           *** RUN DATE & TIME: 03-19-96  12:51
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     248.   21251.     0.    71.                          0.
   498.31          248.   21251.     0.    71.  1.00     2.    29.      0.
1
    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.31     2.4    28.9   247.7   21251.    2803.  11.32

 X STA.         2.4        4.8        6.2        7.4        8.6        9.8
   A(I)            22.3       13.6       12.1       11.3       11.1
   V(I)            6.29      10.34      11.58      12.40      12.61

 X STA.         9.8       10.9       12.1       13.2       14.3       15.4
   A(I)            10.8       10.9       10.6       10.5       10.5
   V(I)           12.93      12.82      13.25      13.40      13.39

 X STA.        15.4       16.5       17.6       18.6       19.7       20.8
   A(I)            10.5       10.6       10.4       10.6       10.9
   V(I)           13.32      13.25      13.48      13.18      12.84

 X STA.        20.8       21.9       23.1       24.4       25.8       28.9
   A(I)            10.9       11.6       12.4       13.4       22.8
   V(I)           12.88      12.09      11.32      10.45       6.16
1
    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      12.

         WSEL     LEW     REW    AREA        K        Q    VEL
       503.71   -62.0   113.6   356.8   36627.    2528.   7.08

 X STA.       -62.0      -50.0      -40.9      -32.1      -23.5      -14.7
   A(I)            22.5       19.1       18.6       18.4       18.7
   V(I)            5.61       6.63       6.78       6.87       6.76

 X STA.       -14.7       35.6       47.3       54.1       60.4       66.2
   A(I)            33.8       27.3       16.9       16.3       15.9
   V(I)            3.74       4.64       7.48       7.78       7.95

 X STA.        66.2       71.8       77.0       82.0       86.8       91.3
   A(I)            15.6       15.2       14.7       14.8       14.2
   V(I)            8.09       8.33       8.61       8.55       8.91

 X STA.        91.3       95.6       99.8      103.9      108.2      113.6
   A(I)            14.1       13.9       13.9       14.7       18.3
   V(I)            8.96       9.10       9.07       8.58       6.90
1
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     702.   93208.    69.    75.                      12717.
             2     444.   86771.    70.    75.                       6358.
   504.07         1146.  179979.   139.   150.  1.12   -30.   109.  17695.
1
    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

         WSEL     LEW     REW    AREA        K        Q    VEL
       504.07   -29.5   109.2  1146.2  179979.    5350.   4.67

 X STA.       -29.5       -4.8        2.2        6.9       11.2       15.4
   A(I)           119.2       81.1       65.7       61.6       59.0
   V(I)            2.24       3.30       4.07       4.34       4.53

 X STA.        15.4       19.3       23.1       27.0       31.0       36.5
   A(I)            56.8       54.7       55.1       56.8       64.7
   V(I)            4.71       4.89       4.85       4.71       4.13

 X STA.        36.5       42.3       47.1       52.3       58.0       64.0
   A(I)            51.3       38.9       40.3       41.5       42.1
   V(I)            5.21       6.87       6.65       6.44       6.35
```

```
 X STA.        64.0       71.0       78.6       87.3       96.7      109.2
   A(I)            46.1       46.2       49.7       51.2       64.1
   V(I)            5.80       5.79       5.38       5.23       4.17
1
   *
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     248.   21251.     0.    71.                           0.
    498.31          248.   21251.     0.    71.  1.00     2.    29.      0.
1
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        498.31     2.4    28.9   247.7   21251.    2909.  11.74

 X STA.         2.4        4.8        6.2        7.4        8.6        9.8
   A(I)            22.3       13.6       12.1       11.3       11.1
   V(I)            6.53      10.73      12.02      12.87      13.09

 X STA.         9.8       10.9       12.1       13.2       14.3       15.4
   A(I)            10.8       10.9       10.6       10.5       10.5
   V(I)           13.42      13.31      13.76      13.90      13.89

 X STA.        15.4       16.5       17.6       18.6       19.7       20.8
   A(I)            10.5       10.6       10.4       10.6       10.9
   V(I)           13.83      13.75      13.99      13.68      13.33

 X STA.        20.8       21.9       23.1       24.4       25.8       28.9
   A(I)            10.9       11.6       12.4       13.4       22.8
   V(I)           13.36      12.55      11.74      10.85       6.39
1
     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      12.

          WSEL     LEW     REW    AREA        K        Q    VEL
        504.60   -62.0   113.7   482.3   59153.    3872.   8.03

 X STA.       -62.0      -51.3      -42.9      -35.1      -27.2      -19.2
   A(I)            29.2       25.0       23.4       24.0       24.2
   V(I)            6.62       7.74       8.26       8.06       8.00

 X STA.       -19.2      -11.4       41.4       49.4       55.9       62.0
   A(I)            23.5       56.0       26.5       22.1       21.4
   V(I)            8.23       3.46       7.31       8.75       9.03

 X STA.        62.0       67.8       73.4       78.7       83.8       88.7
   A(I)            20.9       20.8       20.4       20.0       19.6
   V(I)            9.28       9.32       9.49       9.69       9.88

 X STA.        88.7       93.5       98.2      102.8      107.4      113.7
   A(I)            19.6       19.4       19.6       19.9       26.6
   V(I)            9.88       9.97       9.87       9.71       7.27
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     766.  106928.    69.    76.                       14497.
              2     509.  108027.    70.    76.                        7802.
    505.00         1275.  214955.   139.   151.  1.14   -30.   109.  20573.
1
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

          WSEL     LEW     REW    AREA        K        Q    VEL
        505.00   -29.5   109.2  1275.2  214955.    6900.   5.41

 X STA.       -29.5       -6.0        1.7        6.7       11.3       15.8
   A(I)           130.1       92.5       75.2       69.2       67.2
   V(I)            2.65       3.73       4.59       4.98       5.13

 X STA.        15.8       19.9       24.0       28.2       32.8       39.6
   A(I)            62.8       63.7       63.2       66.9       77.7
   V(I)            5.49       5.42       5.46       5.16       4.44

 X STA.        39.6       44.3       49.2       54.3       60.1       66.1
   A(I)            42.3       43.5       44.1       47.0       46.7
   V(I)            8.16       7.93       7.83       7.34       7.39
```

WSPRO OUTPUT FILE (continued)

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 X STA.        66.1       72.8       80.3       88.5       97.2      109.2
   A(I)            49.7       51.6       54.0       55.6       72.3
   V(I)            6.94       6.68       6.39       6.20       4.77
1
   *
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     248.   21251.     0.    71.                          0.
    498.31          248.   21251.     0.    71.  1.00     2.    29.      0.
1
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        498.31     2.4    28.9   247.7   21251.    2080.   8.40

 X STA.         2.4        4.8        6.2        7.4        8.6        9.8
   A(I)            22.3       13.6       12.1       11.3       11.1
   V(I)            4.67       7.67       8.59       9.20       9.36

 X STA.         9.8       10.9       12.1       13.2       14.3       15.4
   A(I)            10.8       10.9       10.6       10.5       10.5
   V(I)            9.59       9.51       9.84       9.94       9.93

 X STA.        15.4       16.5       17.6       18.6       19.7       20.8
   A(I)            10.5       10.6       10.4       10.6       10.9
   V(I)            9.89       9.83      10.00       9.78       9.53

 X STA.        20.8       21.9       23.1       24.4       25.8       28.9
   A(I)            10.9       11.6       12.4       13.4       22.8
   V(I)            9.56       8.97       8.40       7.75       4.57
1
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

      WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
              1     449.   49171.    59.    64.                       7014.
              2     173.   18614.    70.    71.                       1541.
    500.18          622.   67785.   129.   135.  1.00   -20.   109.   7741.
1
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.

          WSEL     LEW     REW    AREA        K        Q    VEL
        500.18   -19.9   109.2   621.6   67785.    2080.   3.35

 X STA.       -19.9       -1.3        2.7        5.9        8.8       11.5
   A(I)            59.4       38.2       32.0       29.5       27.7
   V(I)            1.75       2.72       3.25       3.53       3.76

 X STA.        11.5       14.1       16.7       19.1       21.6       24.0
   A(I)            27.2       26.7       25.8       25.4       25.4
   V(I)            3.82       3.90       4.04       4.09       4.10

 X STA.        24.0       26.4       28.9       31.7       35.7       42.0
   A(I)            25.3       25.3       28.2       32.0       32.5
   V(I)            4.12       4.11       3.68       3.25       3.20

 X STA.        42.0       48.0       55.0       64.5       78.6      109.2
   A(I)            24.9       26.2       30.3       34.1       45.7
   V(I)            4.18       3.97       3.43       3.05       2.28
1
   EX

 +++ BEGINNING PROFILE CALCULATIONS --   3
  XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
         SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

 EXITX:XS   ******   -57.     806.  0.71 *****  501.71  499.29   5350.  501.00
       -60. ******   119.   97596.  1.03 ***** *******    0.56    6.64

 FULLV:FV      60.   -57.     811.  0.70  0.18  501.91 *******   5350.  501.21
         0.    60.   119.   98430.  1.03  0.00    0.02    0.55    6.60
          <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS      50.   -23.     772.  0.76  0.15  502.09 *******   5350.  501.33
        50.    50.   109.   95098.  1.02  0.03    0.00    0.51    6.93
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         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   501.21     498.20

            <<<<<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      60.     2.     248.  1.99 *****  500.30  495.90   2803.  498.31
        0. ******    29.   21251.  1.00 ***** *******    0.65   11.32

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   6.  0.800  0.000  498.20 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG      12.    28.  0.02  0.38  504.43    0.00   2528.  503.71

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    838.    59.   -62.    -3.   2.2   2.1   7.6   6.8   2.8   3.0
   RT:   1690.    82.    32.   114.   3.6   2.9   8.6   7.2   3.6   3.0

===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                             WSEL,YLT,YRT =   504.07      503.3      508.0

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

APPRO:AS      26.   -30.    1147.  0.38  0.14  504.45  499.25   5350.  504.07
       50.    31.   109.  180090.  1.12  0.00    0.00    0.30    4.67

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -60.   -57.   119.   5350.   97596.     806.    6.64  501.00
   FULLV:FV       0.   -57.   119.   5350.   98430.     811.    6.60  501.21
   BRIDG:BR       0.     2.    29.   2803.   21251.     248.   11.32  498.31
   RDWAY:RG      12.*******   838.   2528.*****************    1.00  503.71
   APPRO:AS      50.   -30.   109.   5350.  180090.    1147.    4.67  504.07

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
   EXITX:XS    499.29    0.56  488.96  508.00************  0.71  501.71  501.00
   FULLV:FV  ********    0.55  489.14  508.18  0.18  0.00  0.70  501.91  501.21
   BRIDG:BR    495.90    0.65  488.32  498.31************  1.99  500.30  498.31
   RDWAY:RG  ****************  500.13  508.00  0.02******  0.38  504.43  503.71
   APPRO:AS    499.25    0.30  489.67  508.00  0.14  0.00  0.38  504.45  504.07
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS      Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -62.     952.  0.85 *****  502.66  499.95   6900.  501.81
      -60. ******   119.  125956.  1.04 ***** *******    0.57    7.25

 ===140 AT SECID "FULLV":  END OF CROSS SECTION EXTENDED VERTICALLY.
                             WSEL,YLT,YRT =   502.00     501.50     508.18

FULLV:FV      60.   -62.     953.  0.84  0.18  502.84 *******   6900.  502.00
        0.    60.   119.  126117.  1.04  0.00    0.00    0.57    7.24
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      50.   -26.     871.  1.02  0.16  503.09 *******   6900.  502.07
       50.    50.   109.  115135.  1.05  0.09   -0.01    0.56    7.92
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   502.00     498.20

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>
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WSPRO OUTPUT FILE (continued)

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

BRIDG:BR      60.     2.     248.  2.14 *****  500.45  496.08   2909.  498.31
        0. ******    29.   21251.  1.00 ***** *******    0.68   11.74

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   6.  0.800  0.000  498.20 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      12.    28.  0.03  0.52  505.49   -0.02   3872.  504.60

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   1361.    59.   -62.    -3.   3.0   3.0   9.0   7.8   3.9   3.1
   RT:   2511.    82.    32.   114.   4.5   3.7   9.9   8.2   4.6   3.1

===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                             WSEL,YLT,YRT =   505.00      503.3      508.0

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

APPRO:AS      26.   -30.    1275.  0.52  0.17  505.52  499.90   6900.  505.00
       50.    32.   109.  214922.  1.14  0.00   -0.02    0.34    5.41

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ****** ********

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -60.   -62.   119.   6900.  125956.     952.    7.25  501.81
   FULLV:FV       0.   -62.   119.   6900.  126117.     953.    7.24  502.00
   BRIDG:BR       0.     2.    29.   2909.   21251.     248.   11.74  498.31
   RDWAY:RG      12.*******  1361.   3872.*****************    1.00  504.60
   APPRO:AS      50.   -30.   109.   6900.  214922.    1275.    5.41  505.00

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  **********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    499.95    0.57  488.96  508.00************  0.85  502.66  501.81
   FULLV:FV  ********    0.57  489.14  508.18  0.18  0.00  0.84  502.84  502.00
   BRIDG:BR    496.08    0.68  488.32  498.31************  2.14  500.45  498.31
   RDWAY:RG  ***************  500.13  508.00  0.03******  0.52  505.49  504.60
   APPRO:AS    499.90    0.34  489.67  508.00  0.17  0.00  0.52  505.52  505.00
 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL

EXITX:XS   ******   -13.     405.  0.44 *****  498.79  494.79   2080.  498.35
      -60. ******    99.   37955.  1.06 ***** *******    0.49    5.14

FULLV:FV      60.   -13.     408.  0.43  0.18  498.99 *******   2080.  498.56
        0.    60.   100.   38246.  1.07  0.00    0.02    0.49    5.10
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      50.   -15.     445.  0.35  0.13  499.12 *******   2080.  498.77
       50.    50.    97.   42711.  1.04  0.00    0.00    0.42    4.67
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   498.56     498.20

            <<<<<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      60.     2.     248.  1.10 *****  499.41  494.63   2082.  498.31
        0. ******    29.   21251.  1.00 ***** *******    0.48    8.41

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   3.  0.800  0.000  498.20 ****** ****** ******
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     XSID:CODE     SRD    FLEN     HF    VHD      EGL      ERR        Q    WSEL
    RDWAY:RG      12.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

 APPRO:AS      26.    -20.      622.  0.17  0.08  500.35  494.93   2080.  500.18
        50.    28.    109.    67765.  1.00  0.00    0.00    0.27    3.35

        M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      ****** ****** ******** ****** ******   500.15

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -60.   -13.    99.   2080.   37955.     405.    5.14  498.35
    FULLV:FV       0.   -13.   100.   2080.   38246.     408.    5.10  498.56
    BRIDG:BR       0.     2.    29.   2082.   21251.     248.    8.41  498.31
    RDWAY:RG      12.**************      0.       0.       0.    1.00********
    APPRO:AS      50.   -20.   109.   2080.   67765.     622.    3.35  500.18

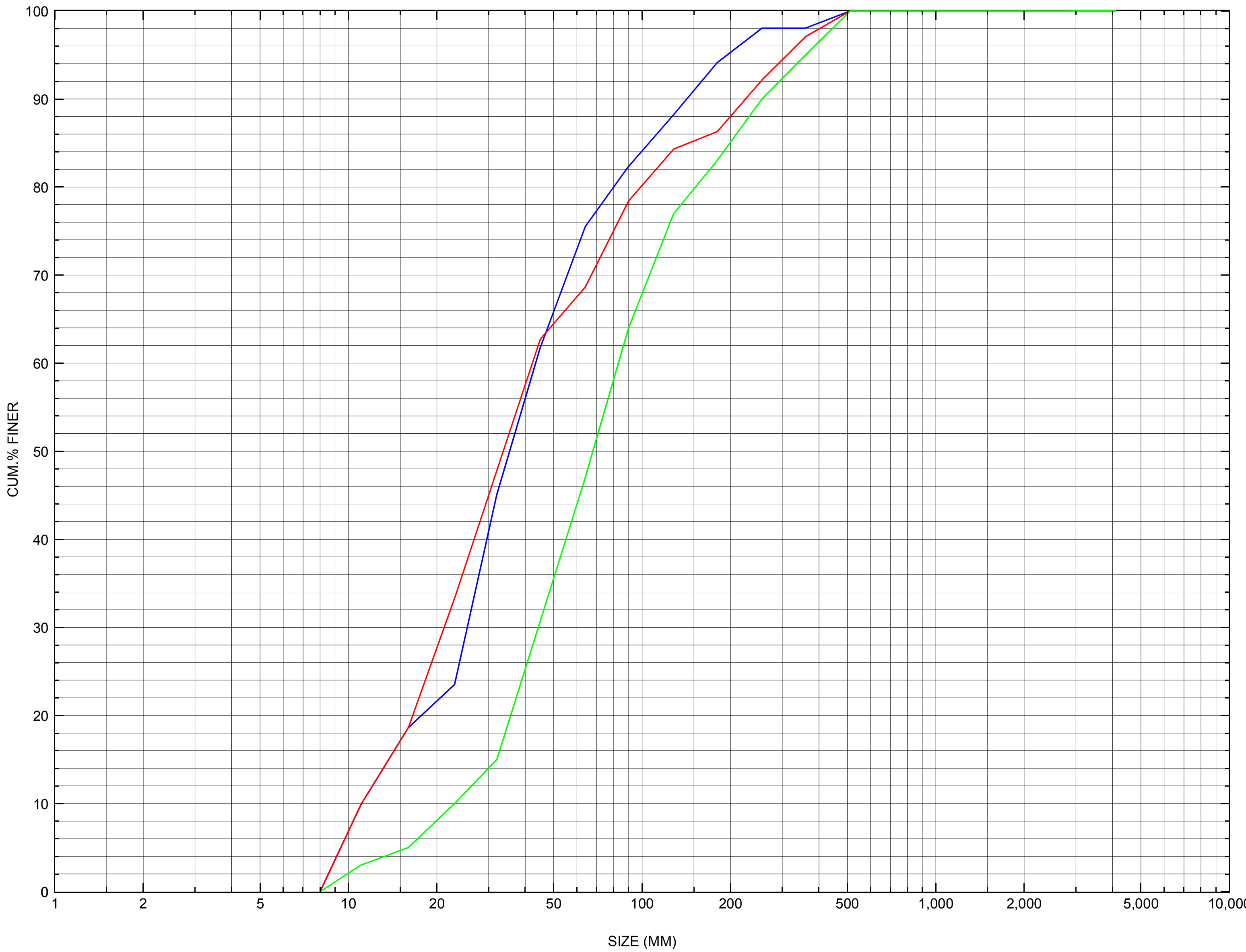
     XSID:CODE   XLKQ   XRKQ       KQ
    APPRO:AS  ***********************
  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
    EXITX:XS    494.79    0.49  488.96  508.00************  0.44  498.79  498.35
    FULLV:FV  ********    0.49  489.14  508.18  0.18  0.00  0.43  498.99  498.56
    BRIDG:BR    494.63    0.48  488.32  498.31************  1.10  499.41  498.31
    RDWAY:RG  ****************  500.13  508.00************  0.17  500.33********
    APPRO:AS    494.93    0.27  489.67  508.00  0.08  0.00  0.17  500.35  500.18
   ER

1  NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure CHELTH00440045, in Chelsea, Vermont.

APPENDIX D:

HISTORICAL DATA FORM