LEVEL II SCOUR ANALYSIS FOR BRIDGE 34 (RANDTH00660034) on TOWN HIGHWAY 66, crossing the SECOND BRANCH WHITE RIVER, RANDOLPH, VERMONT

U.S. Geological Survey
Open-File Report 96-236

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

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By SCOTT A. OLSON and JOSEPH D. AYOTTE

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Pembroke, New Hampshire

1996

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

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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 34 (RANDTH00660034) ON TOWN HIGHWAY 66, CROSSING THE SECOND BRANCH WHITE RIVER, RANDOLPH, VERMONT

By **Scott A. Olson and Joseph D. Ayotte**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure RANDTH00660034 on town highway 66 crossing the Second Branch White River, Randolph, 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 Randolph. The 51.3-mi^2 drainage area is in a predominantly rural basin. In the vicinity of the study site, the left and right banks are covered by fields with some brush on the upstream left and downstream right banks and with row crops on the downstream left overbank.

In the study area, the Second Branch White River has a sinuous channel with a slope of approximately 0.002 ft/ft, an average channel top width of 60 ft and an average channel depth of 7 ft. The predominant channel bed material is sand (D_{50} is 1.34 mm or 0.0044 ft). The geomorphic assessment at the time of the Level I and Level II site visit on August 11, 1994, indicated that the reach was laterally unstable. Channel scour is evident along the left half of the channel from about 30 feet upstream to about 20 feet downstream of the bridge. There is a cut bank with block failures along the left bank upstream of the bridge further indicating instability of the stream reach.

The town highway 66 crossing of the Second Branch White River is a 57-ft-long, one-lane covered bridge consisting of one 45-foot span (Vermont Agency of Transportation, written communication, July 29, 1994). The bridge is supported by vertical, concrete abutments with one wingwall on the upstream left side. The base of the left abutment was protected by type-1 stone fill (less than 12 inches diameter). The channel is skewed approximately 40 degrees to the opening while the opening-skew-to-roadway is 45 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 aggradation or degradation; 2) contraction scour (due to reduction in flow area caused by 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 scour depths for contraction and local scour and a summary of the results follows.

Contraction scour for all modelled flows ranged from 6.3 ft to 7.8 ft and the worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 7.9 ft to 20.3 ft and the worst-case abutment scour occurred at the 500-year discharge. Scour depths and depths to armoring are summarized on p. 14 in the section titled "Scour Results". Scour elevations, based on the calculated depths are presented in tables 1 and 2; a graph of the scour elevations is presented in figure 8 Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

For all scour presented in this report, "the scour depths adopted [by VTAOT] may differ from the equation values based on engineering judgement" (Richardson and others, 1993, p. 21, 27). 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, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results.

Randolph Center, VT. Quadrangle, 1:24,000, 1981
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 RANDTH00660034 ***Stream*** Second Branch White River

County Orange ***Road*** TH066 ***District*** 04

Description of Bridge

Bridge length 57 ***ft*** ***Bridge width*** 12.0 ***ft*** ***Max span length*** 45 ***ft***

Alignment of bridge to road (on curve or straight) left approach is curved

Abutment type laid-up stone ***Embankment type*** vertical

Stone fill on abutment? on left ***Date of inspection*** 08/11/94

Description of stone fill type I stone fill along base of left abutment, some of which has slumped into the channel.

Brief description of piers/abutments Abutments are stone with one wing wall on the upstream left bank

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

The skew angle of the stream to the bridge is up to 30 degrees. Opening skew to roadway is 10 degrees and the left abutment is attacked at approximately 40 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	08/11/94	0	0
Level II	same	-	-

Potential for debris High, due to trees on the unstable banks.

Describe any features near or at the bridge that may affect flow (include observation date) August 11, 1994: Some minor debris existed in the bridge opening blocking an insignificant percentage of the opening. The left abutment protrudes into the low-water channel. This is a covered bridge, thus flow over the bridge deck does not occur

Description of the Geomorphic Setting

General topography The bridge is in an approximately 200-300 ft-wide, flat valley over a very sinuous stream.

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

Date of inspection 08/11/94

DS left: moderate flood plain to steep valley wall

DS right: moderately steep valley wall

US left: moderate flood plain to steep valley wall

US right: flood plain to moderately steep valley wall

Description of the Channel

Average top width 60 ***ft*** ***Average depth*** 6.5 ***ft***

Predominant bed material sand and gravel ***Bank material*** sand

sinuous, with moderately wide flood plains. It is alluvial and laterally unstable

08/11/94

Vegetative co row crops with some brush on immediate banks

DS left: scattered brush in an otherwise open field

DS right: brush on immediate banks changing to forest at the valley wall

US left: pasture

US right:

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

08/11/94--Moderate fluvial erosion has occurred on the upstream left bank due to flow impact. Light fluvial erosion was observed on the downstream right bank.

On 08/11/94, there was a minor amount of debris near the downstream end of the left abutment.

The left abutment protrudes into the low-water channel.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 51.3 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

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

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

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

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 7,660 ***ft³/s*** ***Q500*** 10,800 ***ft³/s***

The 100- and 500-yr discharges were determined from a drainage area relationship with an upstream site. The upstream site had a drainage area of 46 square miles and a 100-yr discharge, determined from a previous study by VTAOT, of 7100 cfs (Landry, D., oral communication, March 1995). The 500-yr discharge at the upstream site was found by graphically extrapolating flood frequency estimates determined in the previous study. Incipient road overflow discharge was determined to be 2,750 cfs.

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 N/A

Description of reference marks used to determine USGS datum. RM1 is a chiseled square in the top of the uppermost stone of the left abutment on the downstream side of the bridge; the arbitrary elevation is 499.52 feet, arbitrary datum.

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	0	1	Exit section
FULLV	57	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	57	1	Bridge section
RDWAY	65	1	Road Grade section
APPRO	124	2	Approach section (as surveyed at SRD=83)

[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 0.030 to 0.038, and overbank "n" values were 0.036.

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 0.0038 ft/ft which was measured from water surface profiles for the Second Branch White River in the Flood Insurance Study for the Town of Randolph (Federal Emergency Management Agency, 1991).

The surveyed approach section was moved 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.

Bridge Hydraulics Summary

Average bridge embankment elevation 501.3 *ft*
Average low steel elevation 498.4 *ft*

100-year discharge 7660 *ft³/s*
Water-surface elevation in bridge opening 498.6 *ft*
Road overtopping? Y *Discharge over road* 4170 *ft³/s*
Area of flow in bridge opening 295 *ft²*
Average velocity in bridge opening 11.8 *ft/s*
Maximum WSPRO tube velocity at bridge 14.5 *ft/s*

Water-surface elevation at Approach section with bridge 505.1
Water-surface elevation at Approach section without bridge 502.0
Amount of backwater caused by bridge 3.1 *ft*

500-year discharge 10800 *ft³/s*
Water-surface elevation in bridge opening 498.6 *ft*
Road overtopping? Y *Discharge over road* 7300 *ft³/s*
Area of flow in bridge opening 295 *ft²*
Average velocity in bridge opening 11.9 *ft/s*
Maximum WSPRO tube velocity at bridge 14.6 *ft/s*

Water-surface elevation at Approach section with bridge 506.5
Water-surface elevation at Approach section without bridge 503.6
Amount of backwater caused by bridge 2.9

Incipient overtopping discharge 2,750 *ft³/s*
Water-surface elevation in bridge opening 498.6 *ft*
Area of flow in bridge opening 295 *ft²*
Average velocity in bridge opening 9.3 *ft/s*
Maximum WSPRO tube velocity at bridge 11.4 *ft/s*

Water-surface elevation at Approach section with bridge 500.8
Water-surface elevation at Approach section without bridge 499.0
Amount of backwater caused by bridge 1.8 *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) for the 100-year, 500-year, and incipient road-overflow discharges. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour. The 100-year, 500-year and incipient road-overflow discharges resulted in submerged orifice flow. The results of Chang's contraction scour (Richardson and others, 1995, p. 145-146) for all the modeled events were also computed and can be found in appendix F. Because the Chang equation for pressure-flow scour was derived solely with data for clear-water scour, it is not currently understood how well it would predict in live-bed conditions. Therefore, although pressure flow conditions exist for all of the modelled flows, the reported scour depths were computed using Laursen's live-bed contraction scour equation.

Abutment scour 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. Variables for the HIRE 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.

It should be noted that the worst-case contraction scour and total scour resulted from the 100-yr event.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	7.8	6.3	6.9
Clear-water scour	--	--	--
Depth to armoring	--	--	--
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	10.1	11.0	7.9
Right abutment	18.7–	20.3-	11.4-
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	2.9	2.9	1.3
Right abutment	2.9	2.9	1.3
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

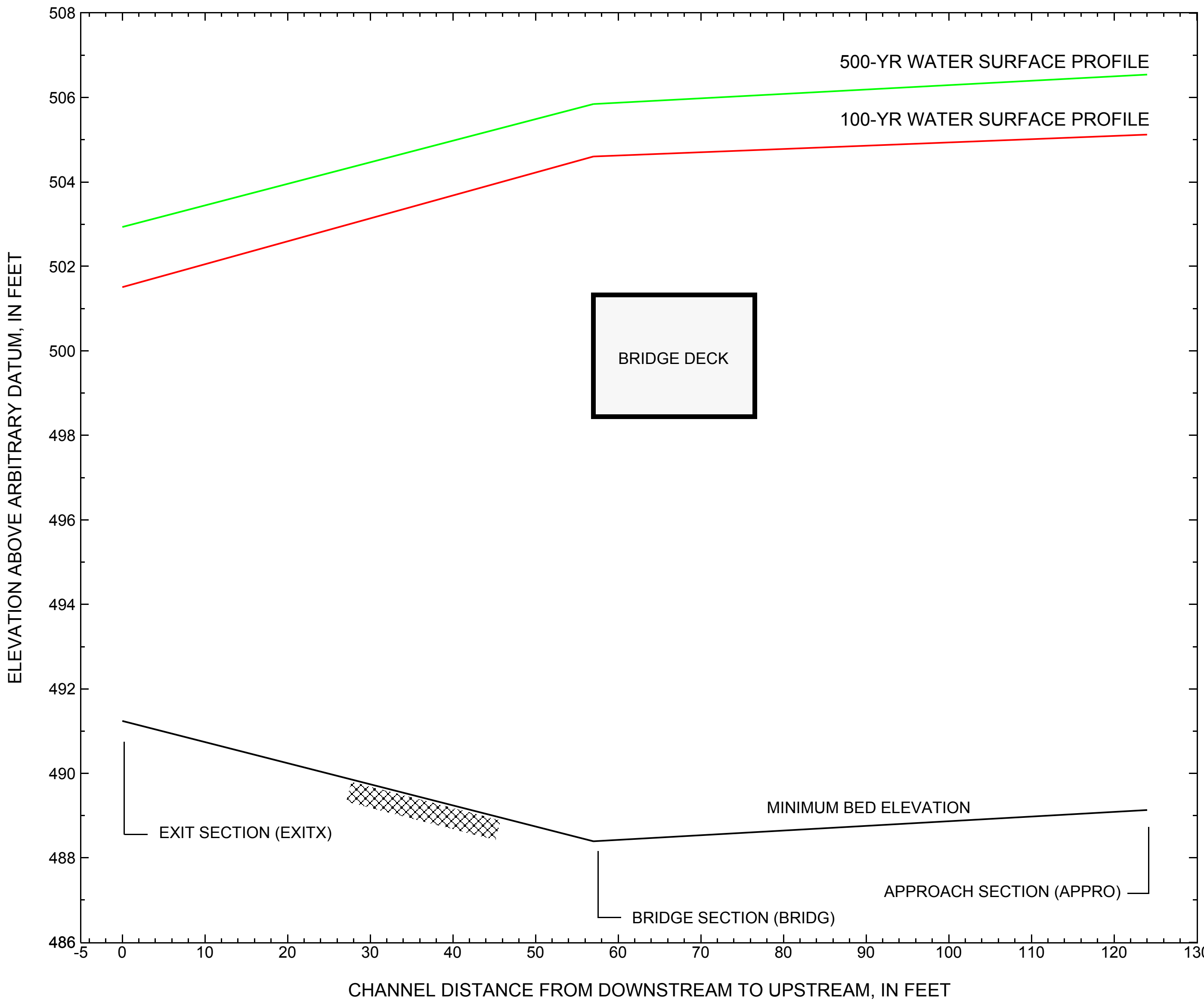

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure RANDTH00660034 on town highway 66, crossing the Second Branch White River, Randolph, Vermont.

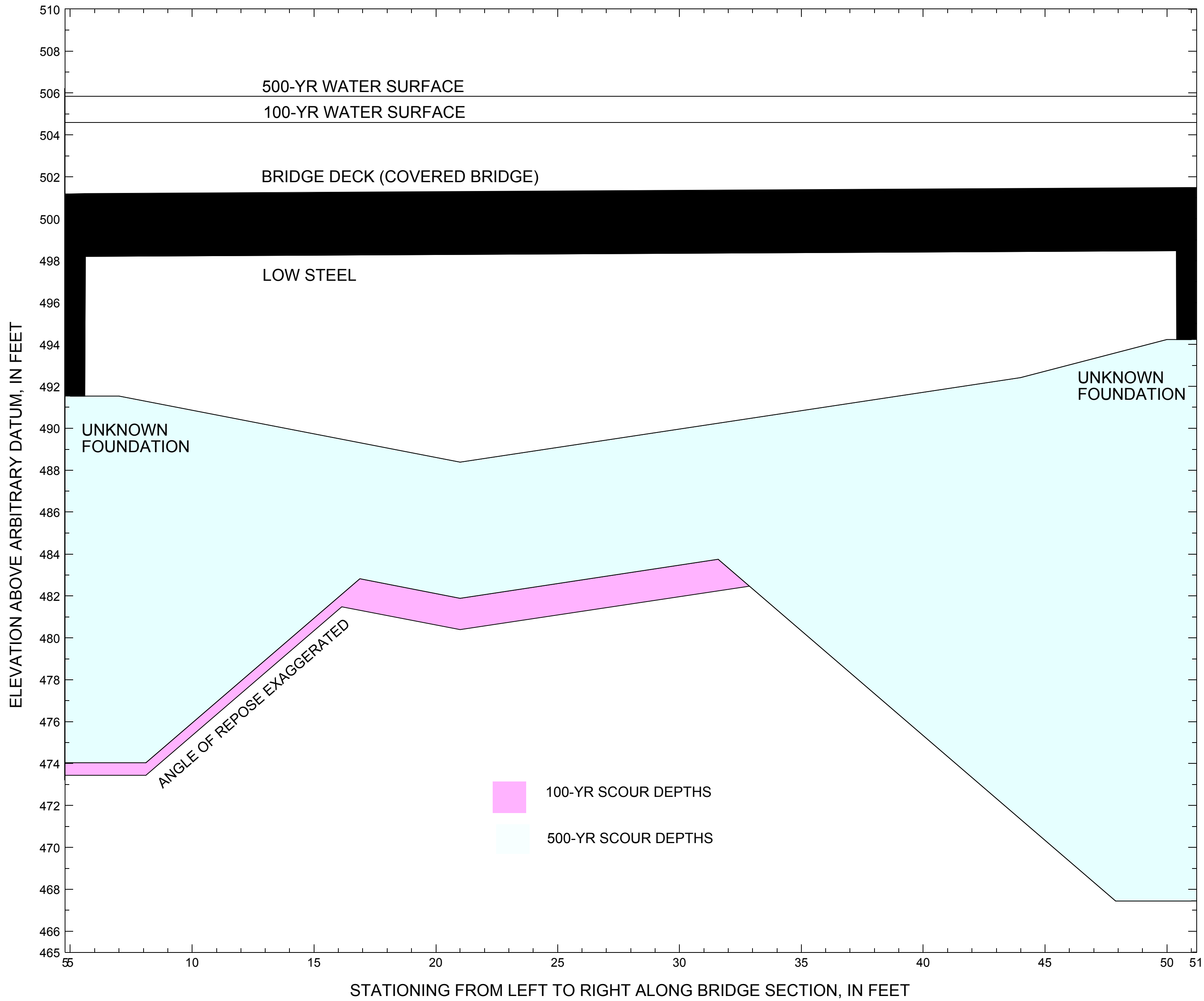

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure RANDTH00660034 on town highway 66, crossing the Second Branch White River, Randolph, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure RANDTH00660034 on Town Highway 66, crossing the Second Branch White River, Randolph, 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 7,660 cubic-feet per second											
Left abutment	5	--	498.1	--	491.5	7.8	10.1	--	17.9	473.6	--
Right abutment	51	--	498.6	--	494.2	7.8	18.7	--	26.5	467.7	--

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 RANDTH00660034 on Town Highway 66, crossing the Second Branch White River, Randolph, 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 10,800 cubic-feet per second											
Left abutment	5	--	498.1	--	491.5	6.3	11.0	--	17.3	474.2	--
Right abutment	51	--	498.6	--	494.2	6.3	20.3	--	26.6	467.6	--

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

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Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

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U.S. Geological Survey, 1981, Randolph Center, 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 rand034.wsp
T2        CREATED ON 28-MAR-95 FOR BRIDGE RANDTH0066034
T3        SECOND BRANCH WHITE RIVER, TH 66, Town of RANDOLPH
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
J1         * * 0.001
*
Q          7660 10800 2749
SK         0.0038 0.0038 0.0038
*
XS   EXITX     0
GR          -150., 504.58    -119., 502.11    -113., 498.45     -93., 498.31
GR           -64., 497.69     -22., 496.77     -13., 498.01      -4., 495.71
GR             0., 491.77      25., 491.81      33., 491.24      43., 491.94
GR            52., 496.77      68., 500.82      88., 506.91
N             0.036       0.038
SA                 -13.
*
XS   FULLV    57
*
BR   BRIDG    57 498.4 30
GR             5., 498.09       7., 491.54      21., 488.39      44., 492.42
GR            50., 494.24      51., 498.65       5., 498.09
CD            1 20.8 * * 10 6
N             0.030
*
XR   RDWAY    65 12.7 2 * 20
GR          -116., 506.39    -100., 501.73     -74., 501.08     -49., 500.88
GR           -14., 500.78       5., 501.13      5., 512.          60., 512.
GR           60., 501.55      139., 503.31    183., 504.51      199., 506.90
GR           214., 512.29
BP           5
*
*            station 286 was based on slope between stations 182 and 236
*
AS   APPRO     124
GR          -115., 507.86    -103., 503.28     -85., 499.57     -53., 498.48
GR           -31., 498.80     -10., 497.87       0., 490.92       8., 489.60
GR            15., 489.13      24., 490.03      32., 492.21      40., 492.23
GR            45., 496.45      78., 497.85     152., 500.02     182., 502.54
GR           236., 504.84     286., 506.97
N             0.036        0.033        0.036
SA                 -10.          45.
BP         -10
*
HP 1 APPRO 505.12 1 505.12
HP 2 APPRO 505.12 * * 7660
HP 2 RDWAY 504.60 * * 4168
HP 1 BRIDG 498.65 1 498.65
HP 2 BRIDG 498.65 * * 3491
*
HP 1 APPRO 506.54 1 506.54
HP 2 APPRO 506.54 * * 10800
HP 2 RDWAY 505.84 * * 7305
HP 1 BRIDG 498.65 1 498.65
HP 2 BRIDG 498.65 * * 3503
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE rand034.wsp
        CREATED ON 28-MAR-95 FOR BRIDGE RANDTH0066034
        SECOND BRANCH WHITE RIVER, TH 66, Town of RANDOLPH
           *** RUN DATE & TIME: 07-06-95  10:09
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     551.  71832.    98.    99.                        7421.
             2     745. 182183.    55.    59.                       15571.
             3     914. 104958.   198.   198.                       11156.
   505.12         2210. 358972.   350.   356.  1.42  -108.   243.  26394.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
         WSEL     LEW     REW    AREA        K        Q    VEL
       505.12  -107.8   242.6  2210.4  358972.    7660.   3.47
X STA.      -107.8      -68.5      -48.2      -28.1      -10.0       -0.8
  A(I)           167.1      130.7      129.1      124.0       96.8
  V(I)            2.29       2.93       2.97       3.09       3.96

X STA.        -0.8        4.3        8.8       12.9       16.9       21.2
  A(I)            73.1       68.5       65.5       63.5       66.2
  V(I)            5.24       5.59       5.85       6.04       5.79

X STA.        21.2       25.6       30.6       36.3       43.2       56.9
  A(I)            67.0       70.2       73.5       84.4      116.8
  V(I)            5.72       5.46       5.21       4.54       3.28

X STA.        56.9       72.5       91.1      113.4      142.3      242.6
  A(I)           122.5      133.1      146.5      167.6      244.4
  V(I)            3.13       2.88       2.61       2.29       1.57

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      65.
         WSEL     LEW     REW    AREA        K        Q    VEL
       504.60  -109.9   183.6   555.1   42582.    4168.   7.51
X STA.      -109.9      -93.1      -84.5      -76.9      -69.8      -63.2
  A(I)            32.5       25.5       24.0       23.2       22.5
  V(I)            6.42       8.17       8.69       8.97       9.27

X STA.       -63.2      -56.5      -50.2      -44.0      -37.9      -31.8
  A(I)            22.6       22.1       21.6       21.4       21.5
  V(I)            9.24       9.45       9.66       9.73       9.68

X STA.       -31.8      -25.8      -19.8      -13.9       -6.9        1.1
  A(I)            21.4       21.5       21.1       24.7       27.1
  V(I)            9.75       9.70       9.89       8.42       7.69

X STA.         1.1       68.5       81.3       96.9      118.0      183.6
  A(I)            36.5       32.7       35.2       39.5       58.7
  V(I)            5.71       6.37       5.92       5.28       3.55

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     295.  32380.     0.    89.                            0.
   498.65          295.  32380.     0.    89.  1.00     5.    51.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.65     5.0    51.0   294.6   32380.    3491.  11.85
X STA.         5.0       10.0       12.4       14.5       16.3       18.0
  A(I)            23.4       15.8       14.7       13.7       13.0
  V(I)            7.46      11.01      11.89      12.77      13.39

X STA.        18.0       19.5       21.0       22.4       23.9       25.4
  A(I)            12.5       12.4       12.0       12.3       12.3
  V(I)           13.95      14.03      14.51      14.24      14.17

X STA.        25.4       27.1       28.7       30.5       32.4       34.5
  A(I)            12.7       12.7       13.1       13.5       13.9
  V(I)           13.77      13.76      13.31      12.89      12.53

X STA.        34.5       36.7       39.1       41.9       45.0       51.0
  A(I)            14.3       15.2       16.1       16.9       24.1
  V(I)           12.23      11.49      10.87      10.35       7.26
```

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE rand034.wsp
        CREATED ON 28-MAR-95 FOR BRIDGE RANDTH0066034
        SECOND BRANCH WHITE RIVER, TH 66, Town of RANDOLPH
           *** RUN DATE & TIME: 07-06-95  10:09
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     693.  102409.   102.   103.                       10264.
             2     823.  215097.    55.    59.                       18081.
             3    1218.  152702.   231.   231.                       15879.
   506.54         2734.  470208.   387.   393.  1.39  -112.   276.  34974.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
         WSEL     LEW     REW    AREA        K        Q    VEL
       506.54  -111.5   275.9  2734.3  470208.   10800.   3.95
X STA.      -111.5      -72.3      -52.3      -33.6      -15.7       -2.9
  A(I)           197.3      154.7      147.8      144.2      127.8
  V(I)            2.74       3.49       3.65       3.75       4.23

X STA.        -2.9        3.2        8.3       13.1       17.7       22.4
  A(I)            93.6       84.4       81.0       79.6       80.3
  V(I)            5.77       6.40       6.67       6.78       6.73

X STA.        22.4       27.6       33.6       39.9       51.8       66.7
  A(I)            85.0       87.8       89.9      130.7      141.2
  V(I)            6.36       6.15       6.00       4.13       3.82

X STA.        66.7       84.1      103.8      127.6      157.1      275.9
  A(I)           152.9      162.1      180.8      199.7      313.6
  V(I)            3.53       3.33       2.99       2.70       1.72

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      65.
         WSEL     LEW     REW    AREA        K        Q    VEL
       505.84  -114.1   191.9   840.3   79326.    7305.   8.69
X STA.      -114.1      -93.9      -84.5      -76.1      -68.3      -60.7
  A(I)            51.2       38.8       36.2       34.9       34.7
  V(I)            7.13       9.41      10.08      10.45      10.54

X STA.       -60.7      -53.3      -46.1      -39.0      -31.9      -24.9
  A(I)            34.1       33.5       33.3       33.0       33.1
  V(I)           10.72      10.90      10.98      11.07      11.02

X STA.       -24.9      -18.0      -10.8       -2.6       65.6       76.8
  A(I)            32.9       33.9       37.9       56.7       42.2
  V(I)           11.11      10.76       9.64       6.45       8.65

X STA.        76.8       89.2      103.5      121.2      143.6      191.9
  A(I)            44.3       46.8       51.9       56.2       74.6
  V(I)            8.24       7.81       7.03       6.49       4.89

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     295.   32380.     0.    89.                           0.
   498.65          295.   32380.     0.    89.  1.00     5.    51.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.65     5.0    51.0   294.6   32380.    3503.  11.89
X STA.         5.0       10.0       12.4       14.5       16.3       18.0
  A(I)            23.4       15.8       14.7       13.7       13.0
  V(I)            7.49      11.05      11.93      12.81      13.43

X STA.        18.0       19.5       21.0       22.4       23.9       25.4
  A(I)            12.5       12.4       12.0       12.3       12.3
  V(I)           13.99      14.08      14.56      14.29      14.22

X STA.        25.4       27.1       28.7       30.5       32.4       34.5
  A(I)            12.7       12.7       13.1       13.5       13.9
  V(I)           13.82      13.81      13.36      12.94      12.57

X STA.        34.5       36.7       39.1       41.9       45.0       51.0
  A(I)            14.3       15.2       16.1       16.9       24.1
  V(I)           12.27      11.52      10.91      10.38       7.28
```

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE rand034.wsp
        CREATED ON 28-MAR-95 FOR BRIDGE RANDTH0066034
        SECOND BRANCH WHITE RIVER, TH 66, Town of RANDOLPH
           *** RUN DATE & TIME: 07-06-95  10:09
    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     162.  10639.    81.    81.                        1301.
             2     509.  96608.    55.    59.                        8798.
             3     266.  19013.   117.   117.                        2274.
   500.83          937. 126260.   253.   257.  1.58   -91.   162.   8150.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =     124.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.83   -91.1   161.6   937.2  126260.    2749.   2.93
X STA.       -91.1      -34.4       -5.5       -0.2        3.2        6.1
  A(I)           102.8       79.8       42.3       34.0       31.4
  V(I)            1.34       1.72       3.25       4.05       4.38

X STA.         6.1        8.9       11.4       13.9       16.3       18.9
  A(I)            30.5       29.3       28.8       28.3       28.6
  V(I)            4.51       4.69       4.78       4.87       4.80

X STA.        18.9       21.4       24.1       27.1       30.6       34.5
  A(I)            28.7       29.8       30.7       33.0       34.0
  V(I)            4.79       4.61       4.47       4.16       4.04

X STA.        34.5       38.5       45.2       62.1       88.0      161.6
  A(I)            34.4       46.2       67.8       81.2      115.8
  V(I)            4.00       2.98       2.03       1.69       1.19

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     295.  32380.     0.    89.                           0.
   498.65          295.  32380.     0.    89.  1.00     5.    51.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =      57.
         WSEL     LEW     REW    AREA        K        Q    VEL
       498.65     5.0    51.0   294.6   32380.    2749.   9.33
X STA.         5.0       10.0       12.4       14.5       16.3       18.0
  A(I)            23.4       15.8       14.7       13.7       13.0
  V(I)            5.88       8.67       9.37      10.05      10.54

X STA.        18.0       19.5       21.0       22.4       23.9       25.4
  A(I)            12.5       12.4       12.0       12.3       12.3
  V(I)           10.98      11.05      11.43      11.21      11.16

X STA.        25.4       27.1       28.7       30.5       32.4       34.5
  A(I)            12.7       12.7       13.1       13.5       13.9
  V(I)           10.85      10.83      10.48      10.15       9.87

X STA.        34.5       36.7       39.1       41.9       45.0       51.0
  A(I)            14.3       15.2       16.1       16.9       24.1
  V(I)            9.63       9.04       8.56       8.15       5.71
```

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

EXITX:XS   ******  -118.     992.  1.01 *****  502.51  500.21   7660.  501.51
        0. ******    70.  124244.  1.09 ***** *******    0.62    7.72

FULLV:FV      57.  -119.    1054.  0.88  0.20  502.72 *******   7660.  501.84
       57.    57.    71.  135805.  1.07  0.00    0.01    0.56    7.27
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      67.   -97.    1241.  0.90  0.16  502.89 *******   7660.  501.99
      124.    67.   175.  176026.  1.52  0.01    0.00    0.63    6.17
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   501.84     498.40

            <<<<<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      57.     5.     295.  2.18 *****  500.83  497.14   3491.  498.65
       57. ******    51.   32380.  1.00 ***** *******    0.83   11.85

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   611.800  0.000  498.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      65.    54.  0.02  0.27  505.36    0.00   4168.  504.60

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   2836.   108.  -110.     5.   3.8   3.4   9.5   7.8   4.1   3.1
   RT:   1332.   116.    60.   184.   3.0   1.6   7.2   7.0   2.4   3.1

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

APPRO:AS      46.  -108.    2210.  0.27  0.14  505.38  500.69   7660.  505.12
      124.    53.   243.  358876.  1.42  0.00    0.00    0.29    3.47

       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       0.  -118.    70.   7660.  124244.     992.    7.72  501.51
   FULLV:FV      57.  -119.    71.   7660.  135805.    1054.    7.27  501.84
   BRIDG:BR      57.     5.    51.   3491.   32380.     295.   11.85  498.65
   RDWAY:RG      65.******* 2836.   4168.*****************    2.00  504.60
   APPRO:AS     124.  -108.   243.   7660.  358876.    2210.    3.47  505.12

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    500.21    0.62  491.24  506.91************  1.01  502.51  501.51
   FULLV:FV  ********    0.56  491.24  506.91  0.20  0.00  0.88  502.72  501.84
   BRIDG:BR    497.14    0.83  488.39  498.65************  2.18  500.83  498.65
   RDWAY:RG  ****************  500.78  512.29  0.02******  0.27  505.36  504.60
   APPRO:AS    500.69    0.29  489.13  507.86  0.14  0.00  0.27  505.38  505.12
```

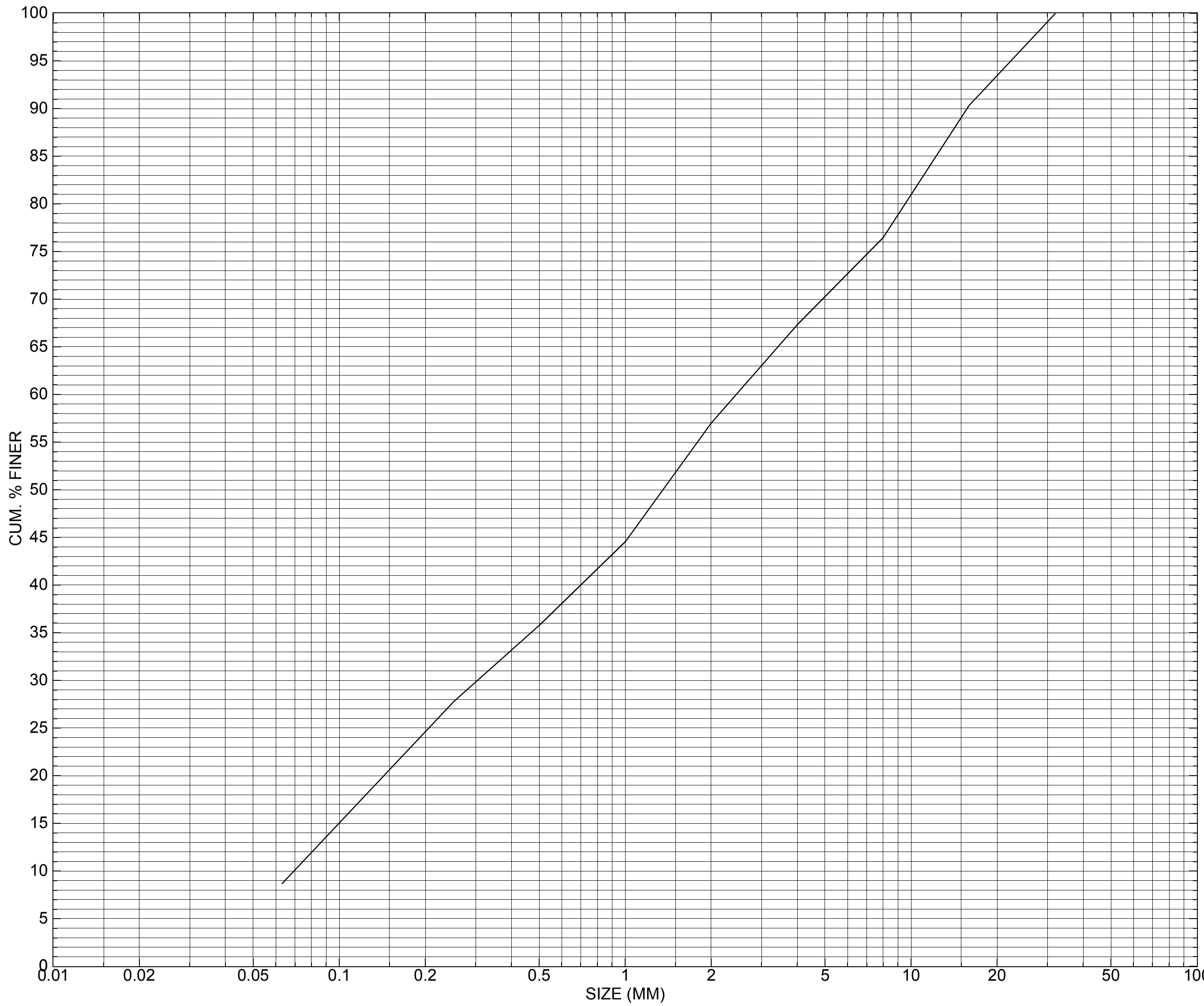
WSPRO OUTPUT FILE (continued)

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

EXITX:XS   ******  -129.    1269.  1.20 *****  504.13  501.22  10800.  502.93
        0. ******    75.  175193.  1.06 ***** *******    0.62    8.51

FULLV:FV      57.  -133.    1337.  1.08  0.20  504.34 *******  10800.  503.26
       57.    57.    76.  187985.  1.06  0.00    0.01    0.58    8.08
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      67.  -104.    1704.  0.92  0.16  504.50 *******  10800.  503.59
      124.    67.   207.  259277.  1.47  0.00    0.00    0.58    6.34
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   503.26     498.40

            <<<<<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      57.     5.     295.  2.20 *****  500.85  497.16   3503.  498.65
       57. ******    51.   32380.  1.00 ***** *******    0.83   11.89

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  498.40 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      65.    54.  0.03  0.34  506.85    0.00   7305.  505.84

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   4495.   112.  -114.     5.   5.1   4.5  11.0   9.0   5.5   3.1
   RT:   2810.   124.    60.   192.   4.3   2.7   9.1   8.3   3.7   3.1

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

APPRO:AS      46.  -112.    2734.  0.34  0.18  506.88  501.75  10800.  506.54
      124.    55.   276.  470221.  1.39  0.00    0.00    0.31    3.95

       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       0.  -129.    75.  10800.  175193.    1269.    8.51  502.93
   FULLV:FV      57.  -133.    76.  10800.  187985.    1337.    8.08  503.26
   BRIDG:BR      57.     5.    51.   3503.   32380.     295.   11.89  498.65
   RDWAY:RG      65.******* 4495.   7305.*****************    2.00  505.84
   APPRO:AS     124.  -112.   276.  10800.  470221.    2734.    3.95  506.54

SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    501.22    0.62  491.24  506.91************  1.20  504.13  502.93
   FULLV:FV  ********    0.58  491.24  506.91  0.20  0.00  1.08  504.34  503.26
   BRIDG:BR    497.16    0.83  488.39  498.65************  2.20  500.85  498.65
   RDWAY:RG  ****************  500.78  512.29  0.03******  0.34  506.85  505.84
   APPRO:AS    501.75    0.31  489.13  507.86  0.18  0.00  0.34  506.88  506.54
```

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

EXITX:XS   ******  -113.     448.  0.72 *****  499.21  496.53   2749.  498.49
        0. ******    59.   44586.  1.22 ***** *******    0.74    6.13

FULLV:FV      57.  -114.     509.  0.56  0.19  499.40 *******   2749.  498.84
       57.    57.    60.   51258.  1.23  0.00    0.01    0.62    5.40
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      67.   -67.     511.  0.59  0.14  499.56 *******   2749.  498.96
      124.    67.   116.   70598.  1.32  0.02    0.00    0.65    5.37
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =   498.84     498.40

           <<<<<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      57.     5.     295.  1.35 *****  500.00  496.20   2747.  498.65
       57. ******    51.   32380.  1.00 ***** *******    0.65    9.33

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   3.  0.800  0.000  498.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      65.        <<<<<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      46.    -91.     938.  0.21  0.09  501.04  495.65   2749.  500.83
      124.    49.   162.  126310.  1.58  0.00    0.00    0.34    2.93

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ******   500.81

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS       0.  -113.    59.   2749.   44586.     448.    6.13  498.49
   FULLV:FV      57.  -114.    60.   2749.   51258.     509.    5.40  498.84
   BRIDG:BR      57.     5.    51.   2747.   32380.     295.    9.33  498.65
   RDWAY:RG      65.**************      0.       0.       0.    2.00********
   APPRO:AS     124.   -91.   162.   2749.  126310.     938.    2.93  500.83

 SECOND USER DEFINED TABLE.
    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    496.53    0.74  491.24  506.91************  0.72  499.21  498.49
   FULLV:FV  ********    0.62  491.24  506.91  0.19  0.00  0.56  499.40  498.84
   BRIDG:BR    496.20    0.65  488.39  498.65************  1.35  500.00  498.65
   RDWAY:RG  ****************  500.78  512.29************  0.21  501.02********
   APPRO:AS    495.65    0.34  489.13  507.86  0.09  0.00  0.21  501.04  500.83
```

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 RANDTH00660034, in Randolph, Vermont.

APPENDIX D:

HISTORICAL DATA FORM