LEVEL II SCOUR ANALYSIS FOR BRIDGE 42 (RANDVT00120042) on STATE HIGHWAY 12, crossing the THIRD BRANCH WHITE RIVER, RANDOLPH, VERMONT

U.S. Geological Survey
Open-File Report 96-187

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
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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 42 (RANDVT00120042) ON STATE HIGHWAY 12, CROSSING THE THIRD BRANCH WHITE RIVER, RANDOLPH, VERMONT

By Scott A. Olson and Matthew A. Weber

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure RANDVT00120042 on State Highway 12 crossing the Third 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 61.9-mi^2 drainage area is in a predominantly rural drainage basin. In the vicinity of the study site, the left and right banks have moderate tree cover with residential and commercial buildings on the overbank areas.

In the study area, the Third Branch White River has a sinuous channel with a slope of approximately 0.013 ft/ft, an average channel top width of 133 ft and an average channel depth of 5 ft. The predominant channel bed material is gravel with a median grain size (D_{50}) of 49.6 mm (0.163 ft). Bank material is sand and gravel (D_{50} is 3.08 mm or 0.010 ft). The geomorphic assessment at the time of the Level I site visits on July 8, 1994 and December 13, 1994, indicated that the reach has experienced vertical degradation. A drop structure has been constructed downstream of the bridge to prevent further degradation. In addition to the degradation of the stream bed, there is local pier scour at the bridge site as well. At the nose of the pier in the main channel, the bed is approximately three feet below the mean thalweg and two feet below the bottom of the pier footing.

The State Highway 12 crossing of the Third Branch White River is a 220-ft-long, two-lane bridge consisting of four concrete spans. The maximum span length is 57 ft. (Vermont Agency of Transportation, written commun., July 29, 1994). The bridge is supported by vertical, concrete abutments and three concrete piers. The toe of the left abutment is at the channel edge. The toe of the right abutment is set back on the right over-bank. The roadway centerline on the structure has a slight horizontal curve; however, the main channel is skewed approximately 5 degrees to the bridge. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

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

Randolph, 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 RANDVT00120042 ***Stream*** Third Branch White River

County Orange ***Road*** VT0012 ***District*** 04

Description of Bridge

Bridge length 220 ***ft*** ***Bridge width*** 36.5 ***ft*** ***Max span length*** 57 ***ft***

Alignment of bridge to road (on curve or straight) straight, bridge has slight curve

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

Stone fill on abutment? no ***Date of inspection*** 7/8/94 and 12/13/94

Description of stone fill None

Brief description of piers/abutments Abutments and piers are concrete. The Left abutment is at the channel edge. The right abutment is set back on the right over-bank. Only one of the three piers is in the main channel. Nose of this pier is undermined.

Is bridge skewed to flood flow according to Level II survey? Y ***Angle*** 5

Is bridge located on a bend in channel? N ***If so, describe (mild, moderate, severe)***

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	07/20/94	-	-
Level II	7/8/94 and 12/13/94	<5%	<5%

Potential for debris Moderate. There is also moderate potential for debris capture due to the piers. At the time of inspection, a log was lodged against the left pier.

Describe any features near or at the bridge that may affect flow (include observation date) July 8, 1994 and December 13, 1994. There is a drop structure 30 feet downstream of the bridge.

Description of the Geomorphic Setting

General topography This is an upland river with moderate gradient. Floodplains are generally narrow with high stream banks.

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

Date of inspection 7/8/95 and 12/13/94

DS left: Steep high bank.

DS right: Narrow flood plain to steep high bank.

US left: Narrow flood plain to steep high bank.

US right: Narrow flood plain to steep high bank.

Description of the Channel

Average top width 133 ft ***Average depth*** 5 ft

Predominant bed material gravel ***Bank material*** sand/gravel

sinuous with narrow flood plains.

7/8/94 & 12/13/94

Vegetative co Forested.

DS left: Forested on immediate bank; a large building on over-bank.

DS right: Moderate tree cover and grass.

US left: Forested.

US right: Yes

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

July 8, 1994 and December 13, 1994. A log is lodged against the pier in the main channel.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 61.9 ***mi***^{2}

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? N

USGS gage description

USGS gage number

Gage drainage area ***mi***^{2}

Is there a lake/p No

Calculated Discharges

Q100 10,500 ***ft***^{3}***/s*** ***Q500*** 15,000 ***ft***^{3}***/s***

Q100 and Q500 discharges were taken from the Federal Emergency Management Agency Flood Insurance study (Federal Emergency Management Agency, 1991) for the Town of Randolph.

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 Subtract 442.53 ft from USGS datum to get VTAOT plans datum.

Description of reference marks used to determine USGS datum. RM1 is the top of the first "A" in "CASHMAN" on a bronze plaque in the sidewalk at the downstream, right end of the bridge (elev. 534.71 ft, arbitrary datum). RM2 is a the bridge rail seat immediately above the downstream streamward end of the left abutment (elev. 527.54 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
XSDS1	0	1	
XSDS2	270	1	
DSDRP	450	1	Section just downstream of drop structure
USDRP	480	1	Exit section (at drop structure--submerged sharp-crested weir analysis done to determine water surface).
FV	510	2	Downstream full valley section (templated from XSUS1)
BRDGE	510	1	Bridge section
XSUS1	590	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 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). Channel "n" values for the reach ranged from 0.025 to 0.038, and overbank "n" values ranged from 0.040 to 0.103.

A step-backwater solution could not be found at the drop structure downstream of bridge 42. Thus, alternative methods for computing starting water surface elevations for the bridge model were necessary. The elevations were determined by a weir rating developed for the drop structure combined with an estimated rating developed for the flow on the right over-bank. To develop these rating curves, the tailwater elevations for the drop structure were needed.

To determine the tailwater elevations at the drop structure, the three cross sections surveyed downstream of the drop structure were modelled. Normal depth was assumed as the starting water surface for this initial model and was computed by use of the slope-conveyance method outlined in the User's manual for WSPRO (Shearman, 1990). The slope used was 0.013 ft/ft which was determined from surveyed thalweg points 210 ft and 480 ft downstream of the drop structure. The resulting tailwater elevations for the 100-year and 500-year events were 506.5 and 508.7 ft, respectively. The crest of the drop structure is 499.9 ft.

Submerged sharp-crested weir computations (Brater and King, 1982, pp **5**-4 to **5**-17) were then done to determine the rating curve for headwater elevations at the drop structure. A rating of the over-bank flow right of the drop structure was also necessary. The overbank was modelled with WSPRO using the overbank geometry of the cross sections on and downstream of the drop structure. The starting water surface of this over-bank model was the drop structure tailwater. The rating developed from this crude model was graphically combined with the weir rating to determine the water surface at the upstream side of the drop structure. The 100-year and 500-year water surface elevations are 508.8 and 510.6 feet, respectively. These elevations were used as the starting water surface elevation for the bridge model.

Bridge Hydraulics Summary

Average bridge embankment elevation 530.9 ***ft***
Average low steel elevation 526.5 ***ft***

100-year discharge 10,500 ***ft³/s***
Water-surface elevation in bridge opening 509.0 ***ft***
Road overtopping? N ***Discharge over road*** -- ***ft³/s***
Area of flow in bridge opening 1060 ***ft²***
Average velocity in bridge opening 9.9 ***ft/s***
Maximum WSPRO tube velocity at bridge 14.7 ***ft/s***

Water-surface elevation at Approach section with bridge 510.0
Water-surface elevation at Approach section without bridge 509.7
Amount of backwater caused by bridge 0.3 ***ft***

500-year discharge 15,000 ***ft³/s***
Water-surface elevation in bridge opening 510.8 ***ft***
Road overtopping? N ***Discharge over road*** -- ***ft³/s***
Area of flow in bridge opening 1330 ***ft²***
Average velocity in bridge opening 11.3 ***ft/s***
Maximum WSPRO tube velocity at bridge 17.1 ***ft/s***

Water-surface elevation at Approach section with bridge 512.0
Water-surface elevation at Approach section without bridge 511.7
Amount of backwater caused by bridge 0.3

Incipient overtopping discharge ______ ***ft³/s***
Water-surface elevation in bridge opening ______ ***ft***
Area of flow in bridge opening ______ ***ft²***
Average velocity in bridge opening ______ ***ft/s***
Maximum WSPRO tube velocity at bridge ______ ***ft/s***

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

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

Contraction scour in the main channel was computed by use of the live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16) for the 500-year discharge. Contraction scour for the 100-year discharge and in the over-bank was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p.35, equation 18). For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour at the left abutment was computed using the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48).

Pier scour was computed using the Colorado State University pier scour equation (Richardson and others, 1993, p. 39, equation 21). Two methods were used for determining variables for the scour computations of the pier in the main channel and the most conservative answer used. The first method used the velocity of the maximum velocity flow tube in the main channel and the pier width in the equation. The second method used the width of the pier footing since it was exposed and the velocity at the exposed footing. The velocity at the exposed footing was a depth weighted estimate of the maximum velocity flow tube (Richardson and others, 1993, p. 41, equation 23). Variables used in the equation for the over-bank pier included the pier width and the maximum velocity in the over-bank flow tubes. Only the over-bank flow tubes were used since the thalweg was not expected to shift.

Potential scour at the drop structure was not computed. However, failure of the drop structure would result is significant lowering of the bed at the bridge.

Scour Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	2.5	--
Clear-water scour	2.5	--	--
Depth to armoring	12.4	20.8	--
Left overbank	--	--	--
Right overbank	1.6	3.6	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	19.0	23.7	--
Right abutment	0.0–	0.0–	---
Pier scour			
Pier 1	11.6	12.3	--
Pier 2	7.2	7.2	--
Pier 3	0.0	0.0	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:			
Left abutment	3.0	3.7	--
Right abutment	--	--	--
Piers:			
Pier 1	4.1	5.5	--
Pier 2	0.9	2.1	--
	--	--	--

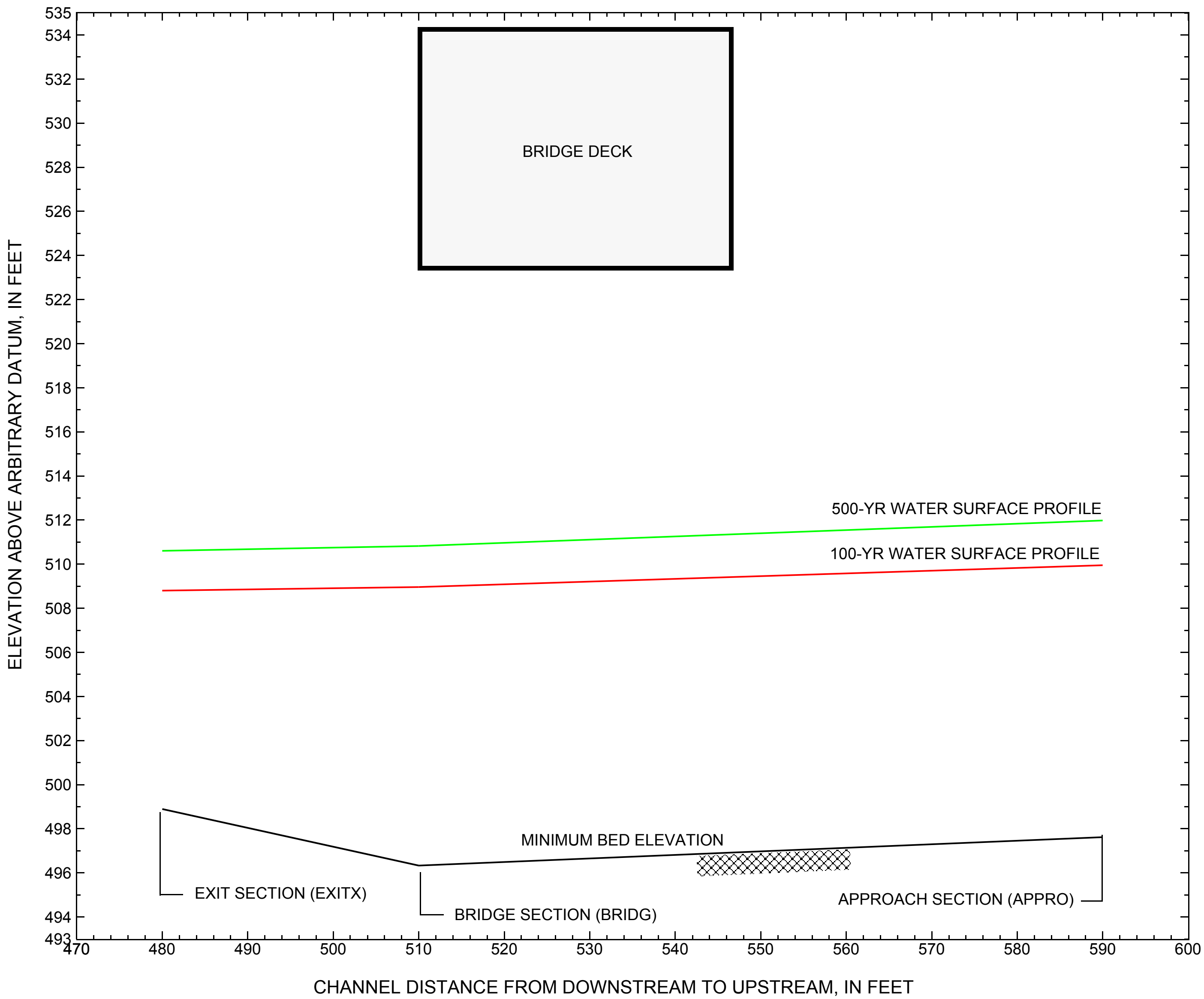

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure RANDVT00120042 on State Highway 12, crossing the Third Branch White River, Randolph, Vermont.

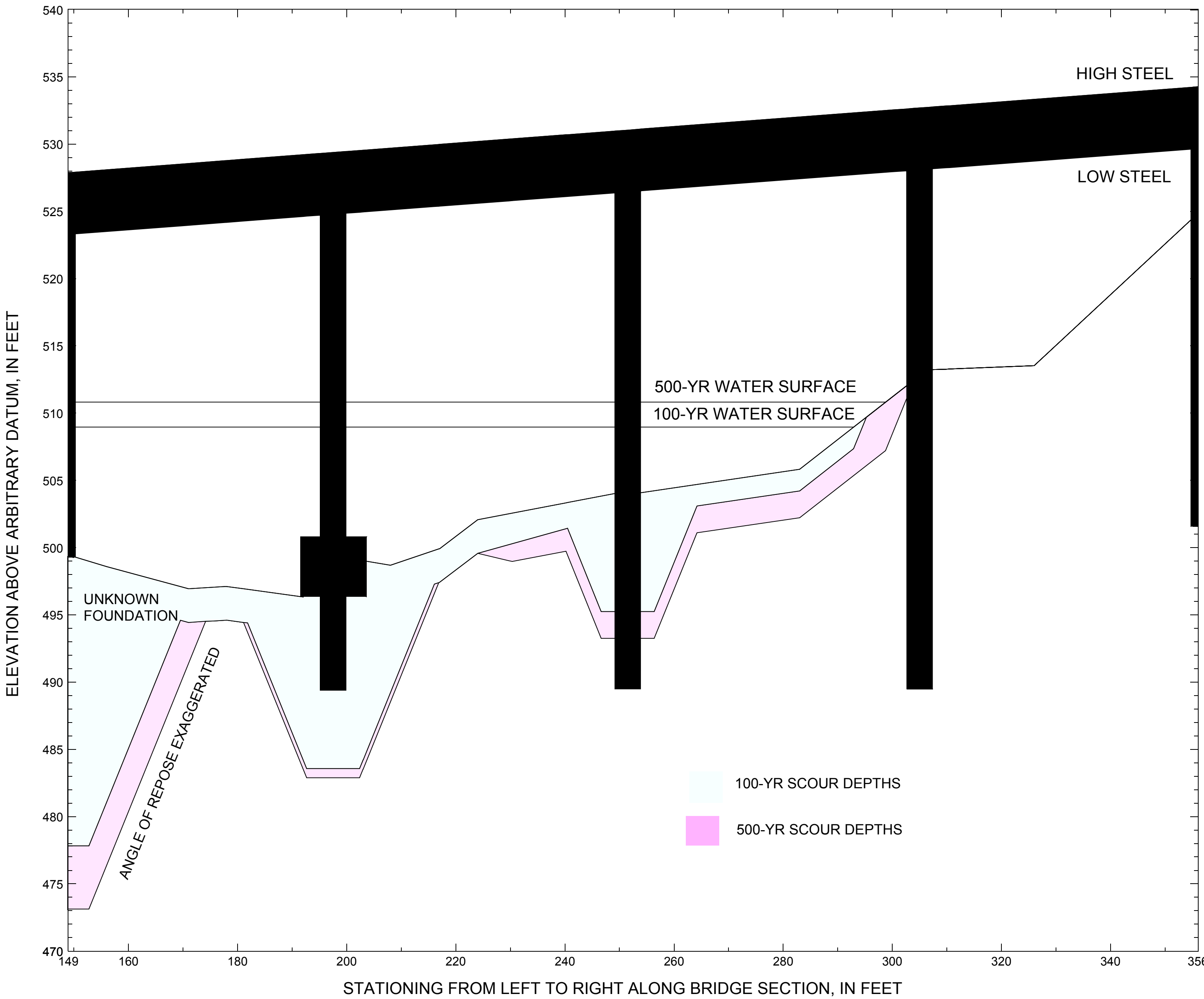

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure RANDVT00120042 on State Highway 12, crossing the Third Branch White River, Randolph, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure RANDVT00120042 on State Highway 12, crossing the Third 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 10,500 cubic-feet per second											
Left abutment	150	80.33	--	--	499.3	2.5	19.0	--	21.5	477.8	--
Pier1	198	81.76	--	489.5	497.7	2.5	--	11.6	14.1	483.6	-5.9
Pier 2	252	83.69	--	489.5	504.0	1.6	--	7.2	8.8	495.2	5.7
Pier 3	305	85.63	--	489.5	512.7	--	--	--	0.0	512.7	23.2
Right abutment	355	87.57	530.10	501.6	524.5	--	--	--	0.0	524.5	22.9

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 RANDVT00120042 on State Highway 12, crossing the Third 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 15,000 cubic-feet per second											
Left abutment	150	80.33	--	--	499.3	2.5	23.7	--	26.2	473.1	--
Pier 1	198	81.76	--	489.5	497.7	2.5	--	12.3	14.8	482.9	-6.6
Pier 2	252	83.69	--	489.5	504.0	3.6	--	7.2	10.8	493.2	3.7
Pier 3	305	85.63	--	489.5	512.7	--	--	--	0.0	512.7	23.2
Right abutment	355	87.57	530.10	501.6	524.5	--	--	--	0.0	524.5	22.9

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

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

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1            HYDRAULIC ANALYSIS
T2            Randolph, VT BRIDGE #042, Third Branch White River
T3            USGS  BOW,NH   03/10/95
*
J3            6 29 30 28 17 13 23 3 * 5 15 14 7 4 11 12 3
*
Q             10500 15000
WS            508.8 510.6
*
*               USDRP is on crest of drop structure
*
XS   USDRP      480
GR             99., 526.65     100., 525.93     105., 521.35     118., 507.91
GR            122., 504.00     124., 501.56     129., 500.75     134., 499.89
GR            135., 499.35     140., 498.89     140., 499.95     150., 499.94
GR            151., 499.72     172., 499.78     199., 499.84     202., 500.06
GR            204., 499.89     205., 501.30     210., 501.61     215., 502.49
GR            219., 502.89     220., 500.75     228., 502.88     233., 504.29
GR            241., 505.74     249., 504.55     265., 503.90     275., 506.43
GR            285., 512.25     312., 512.99     327., 520.70     349., 534.62
N                 0.090        0.025        0.072
SA                       105.         233.
*
*             Using approach geometry for the full valley since the
*             Bed elevation at the downstream face of the bridge is lower
*             than the min elevation of USDRP, which the full valley section
*             would default to.
*
XS   FV       510
GR             97., 522.67     125., 505.21     136., 504.06     149., 504.67
GR            150., 503.90     160., 499.81     165., 498.52     191., 498.00
GR            218., 497.62     234., 499.80     252., 504.63     255., 505.67
GR            258., 505.90     276., 505.33     292., 503.74     301., 505.58
GR            316., 521.74
N             0.040     0.035        0.103
SA                150           252
*
BR   BRDGE    510 530.10 5
GR            150., 530.10     151., 499.32     156., 498.59
GR            171., 496.94     178., 497.11     192., 496.33     192., 500.44
GR            195., 500.43     200., 500.46     203., 500.41     203., 499.03
GR            208., 498.69     217., 499.92     224., 502.08     249., 504.01
GR            254., 504.09     283., 505.82     303., 512.16     303., 511.25
GR            307., 513.22     307., 513.22     326., 513.53     355., 524.47
GR            355., 530.10     150., 530.10
N               0.038    0.067
SA                  224
CD            1 36.5 * 534.70 * * *
PW            500.43,4.7 504.05,4.7 504.05,9.4 512,9.4 512,14.1 530.10,14.1
*
AS   XSUS1         590.
GR             97., 522.67     125., 505.21     136., 504.06     149., 504.67
GR            150., 503.90     160., 499.81     165., 498.52     191., 498.00
GR            218., 497.62     234., 499.80     252., 504.63     255., 505.67
GR            258., 505.90     276., 505.33     292., 503.74     301., 505.58
GR            316., 521.74
N             0.040     0.035        0.103
SA                150           252
BP            150
*
HP 1 BRDGE 508.96 1 508.96
HP 2 BRDGE 508.96 * * 10500
HP 2 BRDGE 509.16 * * 10500
HP 1 XSUS1 509.95 1 509.95
HP 2 XSUS1 509.95 * * 10500
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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          HYDRAULIC ANALYSIS
          Randolph, VT BRIDGE #042, Third Branch White River
          USGS  BOW,NH   03/10/95
         *** RUN DATE & TIME: 03-15-95  08:55
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
    WSEL  SA#    AREA       K  TOPW  WETP  ALPH   LEW   REW    QCR
            1    758.  124553.   73.   88.                   13865.
            2    303.   18021.   69.   69.                    3612.
  508.96        1061.  142574.  142.  158.  1.33  151.  293.  14288.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
        WSEL    LEW    REW   AREA       K       Q   VEL
      508.96  150.7  292.9 1061.3 142574.  10500.  9.89

X STA.      150.7      157.9      162.1      165.9      169.3      172.5
 A(I)            71.5       45.2       42.7       39.6       37.7
 V(I)            7.35      11.61      12.30      13.26      13.91

X STA.      172.5      175.6      178.7      181.8      184.8      187.8
 A(I)            36.9       37.1       36.2       36.2       36.7
 V(I)           14.23      14.15      14.52      14.48      14.29

X STA.      187.8      190.6      197.4      203.4      207.3      211.3
 A(I)            35.7       63.3       51.5       39.2       39.7
 V(I)           14.71       8.30      10.19      13.40      13.24

X STA.      211.3      215.6      220.8      231.8      251.8      292.9
 A(I)            41.3       44.4       74.7      110.0      141.7
 V(I)           12.71      11.83       7.03       4.77       3.70

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
        WSEL    LEW    REW   AREA       K       Q   VEL
      509.16  150.7  293.5 1089.7 147671.  10500.  9.64

X STA.      150.7      158.0      162.2      166.0      169.5      172.6
 A(I)            73.3       46.4       43.7       40.6       38.6
 V(I)            7.16      11.33      12.00      12.94      13.59

X STA.      172.6      175.8      178.9      182.0      185.0      188.0
 A(I)            37.7       38.0       37.9       36.7       37.2
 V(I)           13.92      13.83      13.85      14.31      14.12

X STA.      188.0      191.0      198.0      203.8      207.7      211.7
 A(I)            37.5       65.2       51.4       40.3       40.6
 V(I)           14.01       8.05      10.21      13.02      12.94

X STA.      211.7      216.1      221.3      233.3      253.1      293.5
 A(I)            42.2       45.1       82.7      111.2      143.4
 V(I)           12.43      11.64       6.35       4.72       3.66

   CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = XSUS1;  SRD =     590.
    WSEL  SA#    AREA       K  TOPW  WETP  ALPH   LEW   REW    QCR
            1    155.   15741.   33.   34.                    1913.
            2   1086.  221101.  102.  104.                   20099.
            3    248.    9745.   53.   55.                    3043.
  509.95        1488.  246587.  188.  193.  1.38  117.  305.  20240.

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = XSUS1;  SRD =     590.
        WSEL    LEW    REW   AREA       K       Q   VEL
      509.95  117.4  305.1 1488.5 246587.  10500.  7.05

X STA.      117.4      144.4      157.6      163.9      169.2      174.1
 A(I)           124.4       87.9       64.5       60.7       57.0
 V(I)            4.22       5.98       8.13       8.65       9.21

X STA.      174.1      179.0      183.8      188.5      193.2      197.8
 A(I)            57.3       56.2       55.9       55.7       56.0
 V(I)            9.16       9.34       9.39       9.42       9.37

X STA.      197.8      202.5      207.1      211.6      216.1      220.8
 A(I)            55.9       56.2       55.2       55.2       56.9
 V(I)            9.39       9.34       9.51       9.51       9.23

X STA.      220.8      225.8      231.6      238.2      248.5      305.1
 A(I)            58.3       63.1       65.2       78.6      268.2
 V(I)            9.00       8.32       8.05       6.68       1.96
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          HYDRAULIC ANALYSIS
          Randolph, VT BRIDGE #042, Third Branch White River
          USGS  BOW,NH   03/10/95
         *** RUN DATE & TIME: 03-15-95  08:55
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
    WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
            1     894.  161676.    73.    90.                     17748.
            2     436.   31249.    74.    75.                      5987.
  510.82         1330.  192925.   148.   166.  1.34   151.   299.  19563.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
        WSEL     LEW     REW    AREA        K        Q    VEL
      510.82   150.6   298.8  1330.3  192925.   15000.  11.28

X STA.       150.6      158.3      162.9      166.8      170.4      173.8
  A(I)            89.7       58.1       51.5       49.1       46.4
  V(I)            8.36      12.92      14.56      15.27      16.18

X STA.       173.8      177.1      180.4      183.7      186.9      190.0
  A(I)            46.0       45.4       45.5       44.0       44.5
  V(I)           16.31      16.52      16.49      17.06      16.85

X STA.       190.0      196.3      201.2      206.3      210.3      214.7
  A(I)            73.6       50.9       58.0       47.5       49.8
  V(I)           10.19      14.75      12.93      15.77      15.07

X STA.       214.7      219.4      227.2      241.8      260.5      298.8
  A(I)            50.6       71.3      115.1      127.1      166.2
  V(I)           14.82      10.52       6.52       5.90       4.51

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRDGE;  SRD =     510.
        WSEL     LEW     REW    AREA        K        Q    VEL
      511.04   150.6   299.5  1362.8  199309.   15000.  11.01

X STA.       150.6      158.4      163.0      166.9      170.5      173.9
  A(I)            91.9       59.5       52.7       50.3       47.4
  V(I)            8.16      12.61      14.22      14.91      15.82

X STA.       173.9      177.4      180.7      183.9      187.1      190.2
  A(I)            47.9       46.2       45.3       46.0       45.1
  V(I)           15.66      16.23      16.57      16.30      16.61

X STA.       190.2      196.7      201.7      206.7      210.7      215.0
  A(I)            75.1       52.8       58.6       48.6       50.8
  V(I)            9.98      14.21      12.80      15.44      14.78

X STA.       215.0      219.9      228.0      242.8      261.1      299.5
  A(I)            52.9       74.4      119.0      127.1      171.2
  V(I)           14.18      10.08       6.30       5.90       4.38

   CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = XSUS1;  SRD =     590.
    WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
            1     224.   27213.    36.    38.                      3182.
            2    1293.  295762.   102.   104.                     26115.
            3     358.   17360.    55.    58.                      5178.
  511.98         1875.  340335.   193.   200.  1.42   114.   307.  27841.

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = XSUS1;  SRD =     590.
        WSEL     LEW     REW    AREA        K        Q    VEL
      511.98   114.1   306.9  1874.6  340335.   15000.   8.00

X STA.       114.1      140.3      154.5      161.7      167.4      172.6
  A(I)           151.1      113.2       82.8       74.6       71.0
  V(I)            4.96       6.63       9.06      10.05      10.57

X STA.       172.6      177.8      183.0      188.0      192.9      197.8
  A(I)            71.3       71.0       69.2       68.8       69.2
  V(I)           10.51      10.57      10.85      10.90      10.84

X STA.       197.8      202.7      207.7      212.4      217.3      222.3
  A(I)            69.3       69.6       68.3       69.7       70.1
  V(I)           10.82      10.77      10.98      10.75      10.70

X STA.       222.3      227.6      233.8      241.3      252.4      306.9
  A(I)            71.8       78.1       83.8       96.8      354.8
  V(I)           10.44       9.60       8.94       7.75       2.11
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           HYDRAULIC ANALYSIS
           Randolph, VT BRIDGE #042, Third Branch White River
           USGS  BOW,NH   03/10/95
          *** RUN DATE & TIME: 03-15-95  08:55

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

USDRP:XS   ******   117.    1102.  1.77 *****  510.57  507.15  10500.  508.80
      480. ******   279.  221490.  1.25 ***** *******    0.72    9.52

FV   :FV      30.   118.    1388.  1.22  0.07  510.63 *******  10500.  509.41
      510.    30.   305.  224117.  1.37  0.00    0.00    0.57    7.56
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

XSUS1:AS      80.   118.    1436.  1.14  0.17  510.81 *******  10500.  509.67
      590.    80.   305.  234601.  1.37  0.00    0.01    0.55    7.31
        <<<<<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

BRDGE:BR      30.   151.    1061.  1.72  0.10  510.68  507.56  10500.  508.96
      510.    30.   293.  142611.  1.13  0.00   -0.01    0.68    9.89

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1.   0.   1.  0.941  0.060  530.10 ****** ****** ******

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

XSUS1:AS      44.   117.    1488.  1.07  0.15  511.02  506.49  10500.  509.95
      590.    48.   305.  246570.  1.38  0.20    0.01    0.52    7.05

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.231  0.113  218223.   160.   302.   509.87

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

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD     LEW     REW    XSTW     AREA      VEL    YMIN    WSEL
   USDRP:XS     480.    117.    279.    162.     1102.     9.52  498.89  508.80
   FV   :FV     510.    118.    305.    186.     1388.     7.56  497.62  509.41
   BRDGE:BR     510.    151.    293.    142.     1061.     9.89  496.33  508.96
   XSUS1:AS     590.    117.    305.    188.     1488.     7.05  497.62  509.95

 SECOND USER DEFINED TABLE.
    XSID:CODE       Q    CRWS     FR#     EGL  VHD     HF     HO    WSEL
   USDRP:XS    10500.  507.15    0.72  510.57  1.77************  508.80
   FV   :FV    10500.********    0.57  510.63  1.22  0.07  0.00  509.41
   BRDGE:BR    10500.  507.56    0.68  510.68  1.72  0.10  0.00  508.96
   XSUS1:AS    10500.  506.49    0.52  511.02  1.07  0.15  0.20  509.95
```

WSPRO OUTPUT FILE (continued)

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            HYDRAULIC ANALYSIS
            Randolph, VT BRIDGE #042, Third Branch White River
            USGS  BOW,NH   03/10/95
           *** RUN DATE & TIME: 03-15-95  08:55

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

USDRP:XS   ******   115.    1398.  2.31 *****  512.91  508.78  15000.  510.60
      480. ******   282.  311067.  1.29 ***** *******    0.74   10.73

FV   :FV      30.   115.    1759.  1.59  0.07  512.97 *******  15000.  511.38
      510.    30.   306.  311188.  1.41  0.00   -0.01    0.59    8.53
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

XSUS1:AS      80.   115.    1812.  1.51  0.18  513.16 *******  15000.  511.66
      590.    80.   307.  324504.  1.41  0.00    0.01    0.56    8.28
         <<<<<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

BRDGE:BR      30.   151.    1330.  2.22  0.11  513.03  509.50  15000.  510.82
      510.    30.   299.  192795.  1.12  0.00   -0.01    0.70   11.28

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1.   0.   1.  0.945  0.061  530.10 ****** ****** ******

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

XSUS1:AS      44.   114.    1874.  1.41  0.15  513.39  508.13  15000.  511.98
      590.    44.   307.  340266.  1.42  0.22    0.01    0.54    8.00

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.205  0.118  299694.   158.   306.   511.89

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

  FIRST USER DEFINED TABLE.
    XSID:CODE     SRD    LEW     REW   XSTW     AREA      VEL    YMIN    WSEL
   USDRP:XS     480.   115.    282.   167.     1398.    10.73  498.89  510.60
   FV   :FV     510.   115.    306.   191.     1759.     8.53  497.62  511.38
   BRDGE:BR     510.   151.    299.   148.     1330.    11.28  496.33  510.82
   XSUS1:AS     590.   114.    307.   193.     1874.     8.00  497.62  511.98

 SECOND USER DEFINED TABLE.
    XSID:CODE        Q    CRWS     FR#     EGL  VHD     HF     HO    WSEL
   USDRP:XS     15000.  508.78    0.74  512.91  2.31************  510.60
   FV   :FV     15000.********    0.59  512.97  1.59  0.07  0.00  511.38
   BRDGE:BR     15000.  509.50    0.70  513.03  2.22  0.11  0.00  510.82
   XSUS1:AS     15000.  508.13    0.54  513.39  1.41  0.15  0.22  511.98
```
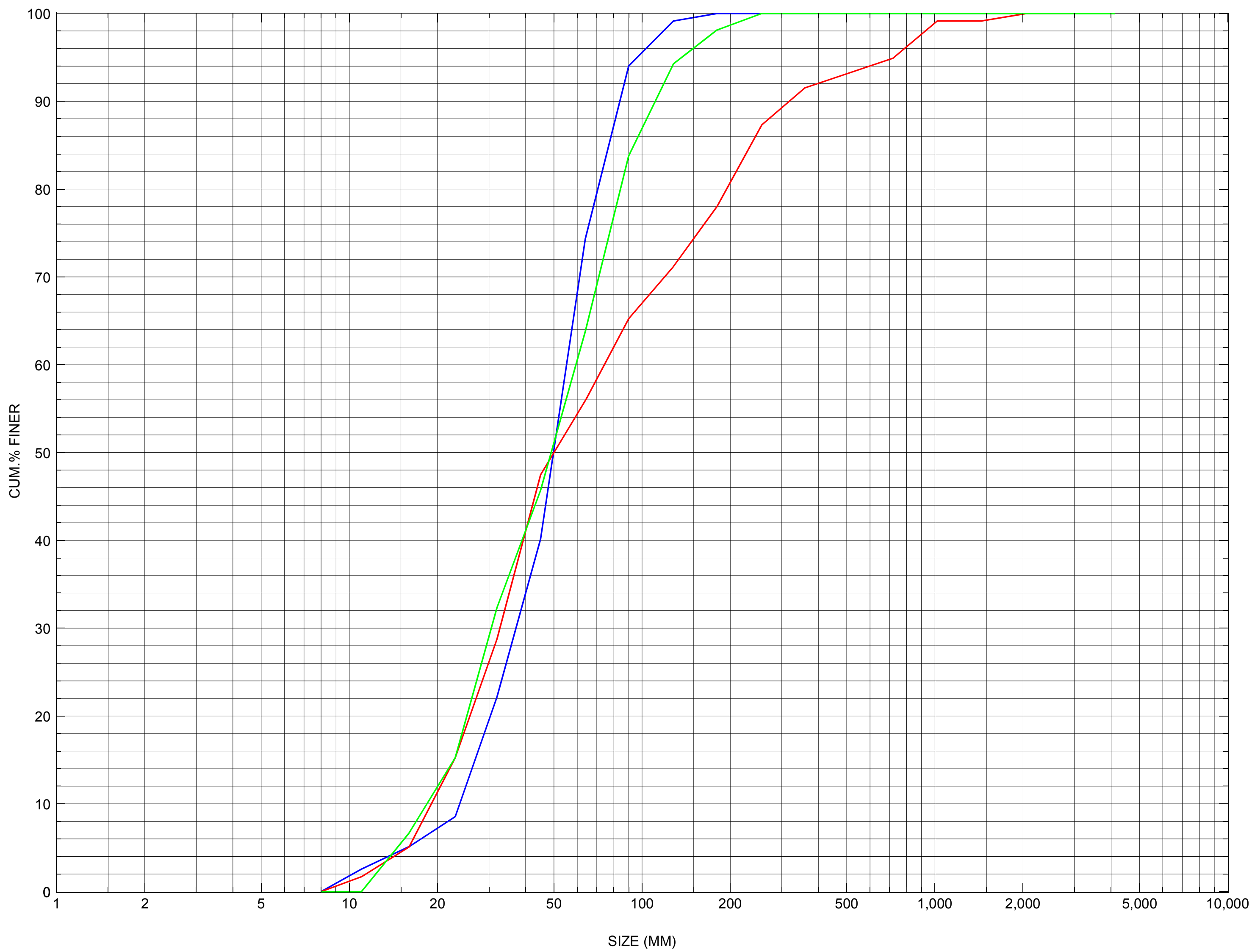

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects upstream of structure RANDVT00120042, in Randolph, Vermont.

APPENDIX D:

HISTORICAL DATA FORM