LEVEL II SCOUR ANALYSIS FOR BRIDGE 54 (RANDTH00BR0054) on BROOK STREET, crossing THAYER BROOK, RANDOLPH, VERMONT

U.S. Geological Survey
Open-File Report 96-308

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

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By SCOTT A. OLSON

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Pembroke, New Hampshire

1996

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

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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 54 (RANDTH00BR0054) ON BROOK STREET, CROSSING THAYER BROOK, RANDOLPH, VERMONT

By **Scott A. Olson**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure RANDTH00BR0054 on Brook Street crossing Thayer Brook, 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 5.39-mi^2 drainage area is in a predominantly rural basin. In the vicinity of the study site, the immediate banks are forested.

In the study area, Thayer Brook has an incised, sinuous channel with a slope of approximately 0.03 ft/ft, an average channel top width of 60 ft and an average channel depth of 3 ft. The predominant channel bed materials are gravel and cobble (D_{50} is 42.4 mm or 0.139 ft). The geomorphic assessment at the time of the Level I and Level II site visits on August 3, 1994 and December 5, 1994, indicated that the reach was vertically and laterally unstable. This assessment was due to the extreme channel misalignment with the bridge opening and the presence of a drop structure downstream of the bridge protecting against channel degradation.

The Brook Street crossing of Thayer Brook is a 34-ft-long, two-lane bridge consisting of one 31-foot concrete span (Vermont Agency of Transportation, written communication, August 2, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. Streamflow attacks the upstream right wingwall and has undermined the upstream end of the right abutment. Type-2 stone fill (less than 36 inches diameter) exists only on the upstream and downstream sides of the left road embankment. No other protection was noted. The bank full channel skew at the bridge face is approximately 20 degrees; the opening-skew-to-roadway is also 20 degrees. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 1.3 to 2.7 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 5.3 to 15.1 ft. and 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.

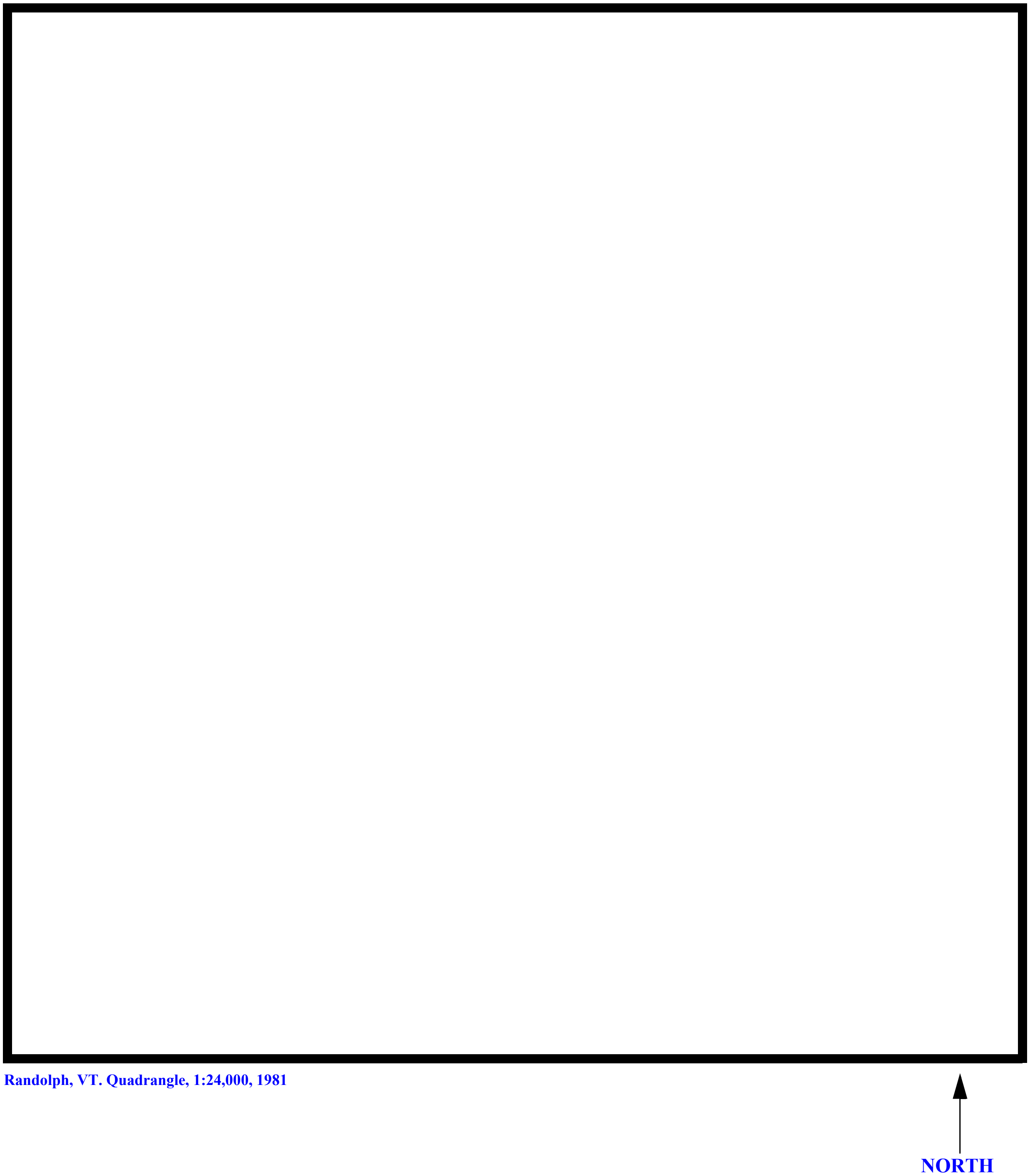

Figure 1. Location of study area on USGS 1:24,000 scale map.

Figure 2. Location of study area on Vermont Agency of Transportation town highway map.

LEVEL II SUMMARY

Structure Number RANDTH00BR0054 ***Stream*** Thayer Brook

County Orange ***Road*** TH00BR ***District*** 04

Description of Bridge

Bridge length 34 ***ft*** ***Bridge width*** 23.1 ***ft*** ***Max span length*** 31 ***ft***

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

Abutment type vertical and concrete ***Embankment type*** sloping

Stone fill on abutment? no ***Date of inspection*** 08/03/94 and 12/5/94

Type-2 stone fill has been placed on the upstream and downstream sides of the left road embankment. Not other protection exists.

Abutments and wingwalls are concrete. The right abutment is undermined due to scour. Scour at the right abutment is 3.5 feet below the mean thalweg. There are no piers

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

There is a moderate bend upstream. The channel approach to the bridge has shifted to the right and flows attack the right wingwall.

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	8/3/94 and 12/5/94 0 94	0	08/03/
Level II		-	-

Potential for debris Moderate due to cut banks and debris accumulation upstream.

Describe any features near or at the bridge that may affect flow (include observation date) August 3, 1994 and December 5, 1994. The stream impacts the upstream right wingwall due to poor alignment between the bridge and the channel. There is a drop structure 29 feet downstream of the bridge.

Description of the Geomorphic Setting

General topography The bridge crosses a high gradient upland stream with narrow flood plains in a moderate relief valley.

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

Date of inspection 08/03/94 and 12/05/94

DS left: Steep, 8 foot high channel bank with moderately sloping overbank

DS right: Steep channel bank to narrow flood plain.

US left: Steep valley wall.

US right: Steep channel bank to narrow flood plain.

Description of the Channel

Average top width 60 ***ft*** ***Average depth*** 3 ***ft***

Predominant bed material gravel and cobble ***Bank material*** gravel

incised, upland stream with narrow flood plains and only slight sinuosity.

8/3/94 and 12/05/94

Vegetative co Trees on immediate bank; primarily brush with trees on the overbank.

DS left: Forested.

DS right: Forested.

US left: Trees on immediate bank; primarily brush and grass on the overbank.

US right: N

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

August 3, 1994 and December 5, 1994. The channel approach to the bridge has laterally moved to the right and is now impacting the right abutment. There is also vertical instability. A drop structure has been constructed downstream of the bridge to prevent further degradation.

August 3, 1994 and December 5, 1994. None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 5.39 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

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

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

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

USGS gage description

USGS gage number

Gage drainage area ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 1,080 ***ft³/s*** ***Q500*** 1,840 ***ft³/s***

The Q100 was based upon a drainage area relationship [(5.4/3.5) to the 0.7 power] with a site on Thayer Brook with flood frequency estimates available from VTAOT (Landry, D., oral communication, March 1995). This site had a drainage area of 3.5 square miles. Q500 was estimated by multiplying the Q100 by 1.7 (Richardson and others, 1983).

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 Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a chiseled square on the top of the upstream end of the left abutment (elev. 518.25 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
Drop	35	1	EXIT section (on the drop structure)
FV	60	2	Downstream full valley section (templated from Drop)
BR	73	2	Bridge section (moved to SRD of bridge centerline).
UFACE	86	2	Upstream full valley section (templated from APPR)
APPR	140	1	Approach section (identical to APTEM)
APTEM	140	1	Surveyed approach section (used as a template for the unconstricted upstream bridge face section--UFACE).

[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 0.040, and overbank "n" values ranged from 0.050 to 0.085.

The starting water surface elevation for the bridge model was determined by a submerged sharp-crested weir computation since a drop structure existed downstream of the bridge. First, a tailwater elevation was necessary for the weir computation. A section surveyed 30 feet downstream of the drop structure was propagated to the downstream face of the drop structure and normal depth was assumed for this section. 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 0.03 ft/ft which is the slope of the thalweg downstream of the drop structure. The calculated tailwater elevations at the drop structure for the 100-year and 500-year events were 499.0 and 499.8 ft. The crest of the weir is 498.7 ft.

Submerged sharp-crested weir computations (Brater and King, 1982, pp **5**-4 to **5**-17) were then done to determine the headwater elevations at the drop structure. The headwater elevations for the 100-year and 500-year events were 502.0 and 503.5 ft, respectively. These elevations were then used as the starting water-surface elevation for the bridge model.

WSPRO's bridge routines were not used in this model. A simple step-backwater model was utilized with the bridge section modelled at the centerline of the bridge and unconstricted sections at each face of the bridge templated from the respective upstream or downstream section. For example, the surveyed approach section was adjusted for the approach channel slope and put at the upstream face of the bridge.

For the modelled discharges, WSPRO assumes critical depth at the bridge section. Supercritical models were developed. Analyzing both the supercritical and subcritical profiles for each discharge, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satifactory solutions.

Bridge Hydraulics Summary

Average bridge embankment elevation 518.0 *ft*
Average low steel elevation 515.7 *ft*

100-year discharge 1,080 *ft³/s*
Water-surface elevation in bridge opening 502.4 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 99.0 *ft²*
Average velocity in bridge opening 10.9 *ft/s*
Maximum WSPRO tube velocity at bridge 12.8 *ft/s*

Water-surface elevation at Approach section with bridge 504.3
Water-surface elevation at Approach section without bridge N/A
Amount of backwater caused by bridge N/A *ft*

500-year discharge 1,840 *ft³/s*
Water-surface elevation in bridge opening 503.9 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 141.2 *ft²*
Average velocity in bridge opening 13.0 *ft/s*
Maximum WSPRO tube velocity at bridge 15.8 *ft/s*

Water-surface elevation at Approach section with bridge 506.5
Water-surface elevation at Approach section without bridge N/A
Amount of backwater caused by bridge N/A

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 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 was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

Scour Results

Contraction scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	1.3	2.7	--
Depth to armoring	26.2	N/A	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-yr discharge	500-yr discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	5.3	8.5	--
Right abutment	13.9	15.1	--
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Rock Riprap Sizing

	100-yr discharge	500-yr discharge	Incipient overtopping discharge
	(D_{50} in feet)		
Abutments:			
Left abutment	1.5	2.2	--
Right abutment	1.5	2.2	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

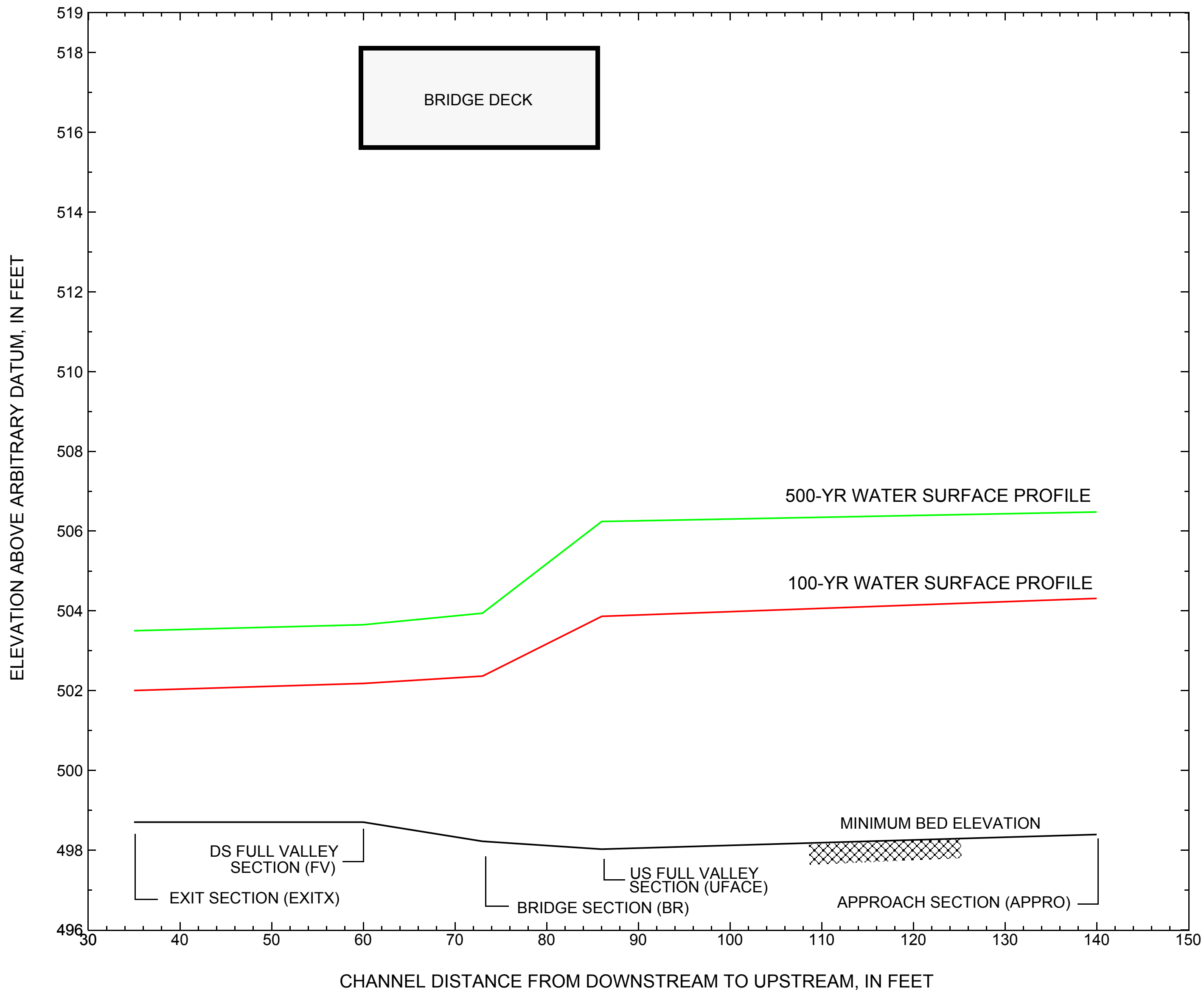

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure RANDTH00BR0054 on Brook Street, crossing Thayer Brook, Randolph, Vermont.

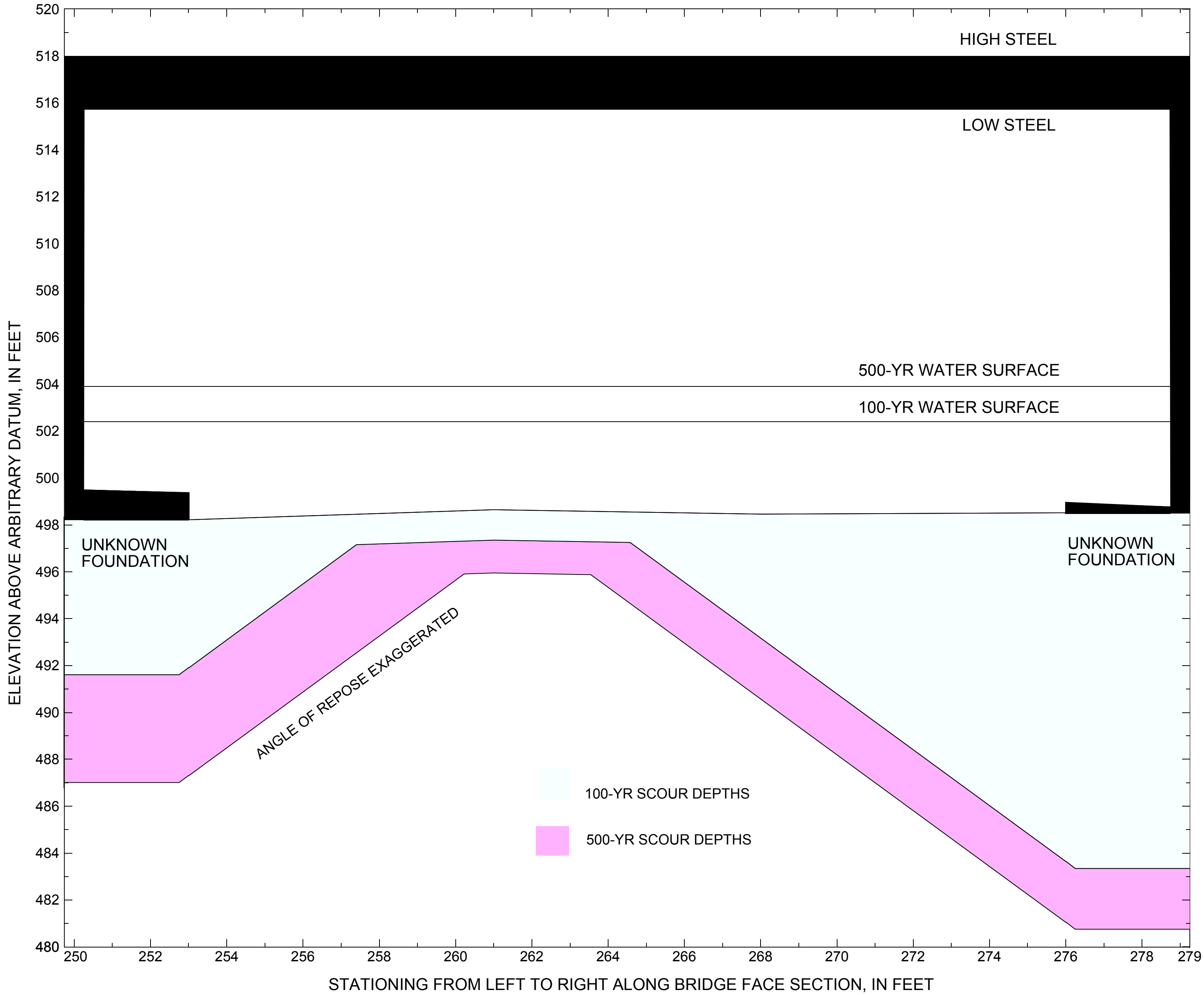

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure RANDTH00BR0054 on Brook Street, crossing Thayer Brook, Randolph, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure RANDTH00BR0054 on Brook Street, crossing Thayer Brook, 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 1,080 cubic-feet per second											
Left abutment	250	--	515.7	--	498.2	1.3	5.3	--	6.6	491.6	--
Right abutment	279	--	515.7	--	498.5	1.3	13.9	--	15.2	483.3	--

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 RANDTH00BR0054 on Brook Street, crossing Thayer Brook, 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 1,840 cubic-feet per second											
Left abutment	250	--	515.7	--	498.2	2.7	8.5	--	11.2	487.0	--
Right abutment	279	--	515.7	--	498.5	2.7	15.1	--	17.8	480.7	--

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, Randolph, 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            HYDRAULIC ANALYSIS
T2            Randolph, VT BRIDGE #054
T3            USGS  BOW,NH   03/16/95
*
Q             1080 1080 1840 1840
WS            502.0 500 503.5 501
SK            -1 0.027 -1 0.027
*
XS   Drop      35
GR           241., 506.14     250., 503.60     254., 498.73     271., 498.70
GR           287., 498.74     299., 498.72     303., 500.06     307., 501.53
GR           319., 504.46     341., 504.19
N             0.060        0.030        0.085
SA                 250.         319.
*
*              The following bridge is not being modeled with bridge
*            hydraulics     low chord=515.74
*
XS   FV        60
*
XS   BR        73 20
GR           250., 510.08     250., 499.51     253., 499.37     253., 498.22
GR           261., 498.65     268., 498.46     276., 498.52     276., 498.95
GR           278., 498.75     279., 509.37     279., 515.73
N                0.040
*
XT   APTEM     140
GR           224., 519.49     232., 515.67     250., 507.08     274., 501.75
GR           284., 500.60     296., 499.97     300., 499.20     305., 498.86
GR           308., 498.39     311., 498.97     312., 500.14     313., 501.41
GR           321., 505.81     361., 506.77     381., 522.01
*
XS   UFACE     86
GT            -0.37
N             0.050        0.035
SA                  321.
*
XS   APPR      140
GT              0
N             0.050        0.035
SA                  321.
*
*
HP 1 BR       502.36 1 502.36
HP 2 BR       502.36 * * 1080
HP 1 APPR     504.31 1 504.31
HP 2 APPR     504.31 * * 1080
*
HP 1 BR       503.94 1 503.94
HP 2 BR       503.94 * * 1840
HP 1 APPR     506.48 1 506.48
HP 2 APPR     506.48 * * 1840
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
          HYDRAULIC ANALYSIS
          Randolph, VT BRIDGE #054
          USGS  BOW,NH   03/16/95
         *** RUN DATE & TIME: 10-26-95  08:09
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BR   ;  SRD =      73.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      99.    7466.    27.    34.                        1084.
  502.36           99.    7466.    27.    34.  1.00   250.   278.   1084.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BR   ;  SRD =      73.
        WSEL     LEW     REW    AREA        K        Q    VEL
      502.36   250.0   278.3    99.0    7466.    1080.  10.91

X STA.       250.0       253.2       254.6       255.9       257.1       258.3
  A(I)            8.9         5.4         5.0         4.5         4.5
  V(I)           6.08        9.93       10.88       12.05       11.94

X STA.       258.3       259.6       260.8       262.0       263.3       264.5
  A(I)            4.5         4.3         4.3         4.4         4.3
  V(I)          12.07       12.53       12.53       12.38       12.66

X STA.       264.5       265.7       266.8       268.0       269.2       270.4
  A(I)            4.2         4.3         4.2         4.3         4.4
  V(I)          12.72       12.61       12.81       12.57       12.36

X STA.       270.4       271.6       272.8       274.1       275.6       278.3
  A(I)            4.5         4.5         4.8         5.4         8.5
  V(I)          12.12       11.98       11.26       10.08        6.35

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     140.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     190.   12409.    56.    58.                        1983.
  504.31          190.   12409.    56.    58.  1.00   262.   318.   1983.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     140.
        WSEL     LEW     REW    AREA        K        Q    VEL
      504.31   262.5   318.3   189.6   12409.    1080.   5.70

X STA.       262.5       275.1       279.4       282.6       285.4       287.9
  A(I)           17.8        12.4        10.8        10.3         9.6
  V(I)           3.04        4.36        4.98        5.25        5.64

X STA.       287.9       290.1       292.3       294.4       296.3       298.1
  A(I)            9.1         8.9         8.5         8.5         8.2
  V(I)           5.96        6.06        6.32        6.38        6.60

X STA.       298.1       299.7       301.2       302.6       304.0       305.4
  A(I)            7.7         7.6         7.5         7.5         7.4
  V(I)           7.00        7.11        7.16        7.20        7.30

X STA.       305.4       306.7       308.0       309.4       311.2       318.3
  A(I)            7.5         7.7         8.2         9.5        15.0
  V(I)           7.16        7.04        6.60        5.69        3.61

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BR   ;  SRD =      73.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     141.   12719.    27.    38.                        1841.
  503.94          141.   12719.    27.    38.  1.00   250.   278.   1841.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BR   ;  SRD =      73.
        WSEL     LEW     REW    AREA        K        Q    VEL
      503.94   250.0   278.5   141.2   12719.    1840.  13.03

X STA.       250.0       253.2       254.6       255.9       257.2       258.4
  A(I)           13.5         7.7         7.1         6.5         6.4
  V(I)           6.81       11.89       13.04       14.09       14.47

X STA.       258.4       259.7       260.8       262.0       263.2       264.4
  A(I)            6.1         6.0         6.0         5.9         6.0
  V(I)          14.96       15.44       15.40       15.49       15.40

X STA.       264.4       265.6       266.7       267.9       269.0       270.2
  A(I)            5.8         5.9         6.0         5.9         6.0
  V(I)          15.80       15.71       15.43       15.51       15.23

X STA.       270.2       271.4       272.7       274.0       275.6       278.5
  A(I)            6.3         6.5         6.9         7.8        12.9
  V(I)          14.53       14.24       13.28       11.82        7.12

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     140.

    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     325.   26630.    68.    71.                        4026.
            2       9.     192.    28.    28.                          31.
  506.48          334.   26822.    96.    99.  1.04   253.   349.   3477.
```

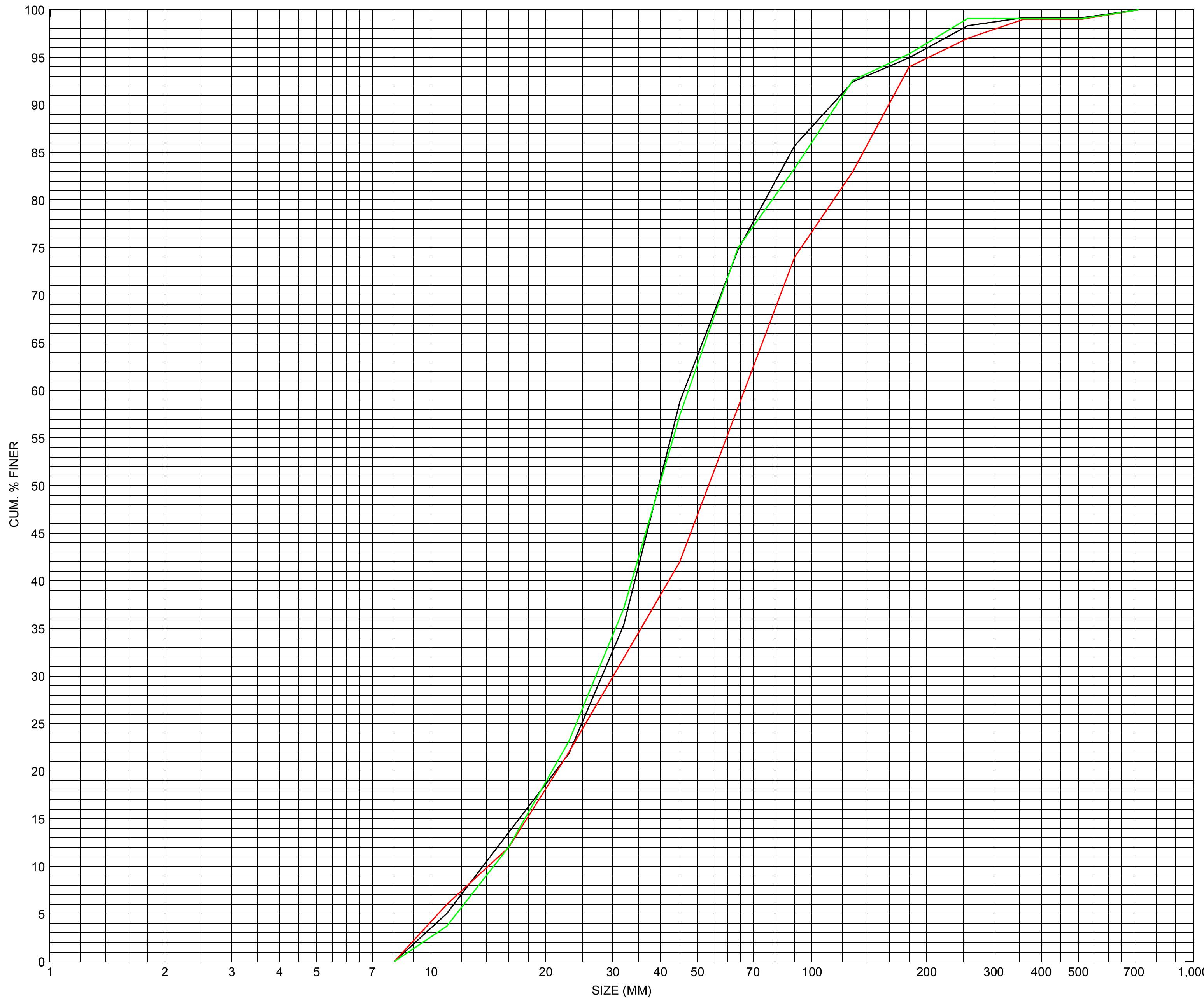
WSPRO OUTPUT FILE (continued)

```
    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     140.
         WSEL     LEW     REW    AREA        K        Q    VEL
       506.48   252.7   348.9   334.5   26822.    1840.   5.50

X STA.       252.7      269.7      274.6      278.3      281.5      284.4
  A(I)            32.0       21.4       18.6       17.3       16.4
  V(I)            2.88       4.29       4.96       5.31       5.60

X STA.       284.4      287.0      289.4      291.8      294.0      296.2
  A(I)            15.4       14.9       14.8       14.1       13.9
  V(I)            5.99       6.18       6.23       6.52       6.61

X STA.       296.2      298.2      300.0      301.8      303.5      305.2
  A(I)            13.5       13.4       13.0       12.9       12.9
  V(I)            6.83       6.89       7.10       7.14       7.14

X STA.       305.2      306.9      308.6      310.5      313.3      348.9
  A(I)            13.1       13.6       14.4       18.1       31.0
  V(I)            7.03       6.74       6.40       5.10       2.97

            HYDRAULIC ANALYSIS
            Randolph, VT BRIDGE #054
            USGS  BOW,NH   03/16/95
           *** RUN DATE & TIME: 10-26-95  08:09

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

Drop :XS   ******   251.     168.  0.65 *****  502.65  501.24   1080.  502.00
       35. ******   309.   16578.  1.00 ***** *******    0.67    6.44

FV   :XS      25.   251.     178.  0.57  0.10  502.75 *******   1080.  502.18
       60.    25.   310.   18097.  1.00  0.00    0.01    0.61    6.07

 ===110 WSEL NOT FOUND AT SECID "BR   ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   501.68     515.73    0.50

 ===115 WSEL NOT FOUND AT SECID "BR   ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   501.68     515.73     502.36

 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
             ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "BR   "
                  WSBEG,WSEND,CRWS =   502.36     515.73     502.36

BR   :XS      13.   250.      99.  1.85 *****  504.21  502.36   1080.  502.36
       73.    13.   278.    7453.  1.00 ***** *******    1.00   10.92

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "UFACE"     KRATIO =  1.61

UFACE:XS      13.   263.     185.  0.53  0.17  504.39 *******   1080.  503.86
       86.    13.   318.   11981.  1.00  0.00    0.01    0.56    5.84

APPR :XS      54.   262.     190.  0.50  0.42  504.82 *******   1080.  504.31
      140.    54.   318.   12413.  1.00  0.00    0.01    0.54    5.70

  FIRST USER DEFINED TABLE.
    XSID:CODE     SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   Drop :XS      35.   251.   309.   1080.   16578.     168.    6.44  502.00
   FV   :XS      60.   251.   310.   1080.   18097.     178.    6.07  502.18
   BR   :XS      73.   250.   278.   1080.    7453.      99.   10.92  502.36
   UFACE:XS      86.   263.   318.   1080.   11981.     185.    5.84  503.86
   APPR :XS     140.   262.   318.   1080.   12413.     190.    5.70  504.31

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   Drop :XS    501.24    0.67  498.70  506.14************  0.65  502.65  502.00
   FV   :XS  ********    0.61  498.70  506.14  0.10  0.00  0.57  502.75  502.18
   BR   :XS    502.36    1.00  498.22  515.73************  1.85  504.21  502.36
   UFACE:XS  ********    0.56  498.02  521.64  0.17  0.00  0.53  504.39  503.86
   APPR :XS  ********    0.54  498.39  522.01  0.42  0.00  0.50  504.82  504.31
```

```
            HYDRAULIC ANALYSIS
           Randolph, VT BRIDGE #054
           USGS  BOW,NH   03/16/95
          *** RUN DATE & TIME: 10-26-95  08:09

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

Drop :XS   ******   250.     260.  0.78 *****  504.28  502.28   1840.  503.50
       35. ******   315.   31511.  1.00 ***** *******    0.63    7.09

FV   :XS      25.   250.     269.  0.73  0.08  504.38 *******   1840.  503.65
       60.    25.   316.   33266.  1.00  0.00    0.01    0.60    6.83

 ===110 WSEL NOT FOUND AT SECID "BR   ":  REDUCED DELTAY.
                 WSLIM1,WSLIM2,DELTAY =   503.15     515.73    0.50

 ===115 WSEL NOT FOUND AT SECID "BR   ":  USED WSMIN = CRWS.
                 WSLIM1,WSLIM2,CRWS =   503.15     515.73     503.94

 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
            ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "BR   "
                 WSBEG,WSEND,CRWS =   503.94     515.73     503.94

BR   :XS      13.   250.     141.  2.64 *****  506.58  503.94   1840.  503.94
       73.    13.   278.   12716.  1.00 ***** *******    1.00   13.03

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "UFACE"     KRATIO =  2.20

UFACE:XS      13.   252.     348.  0.46  0.12  506.70 *******   1840.  506.24
       86.    13.   354.   28033.  1.05  0.00   -0.01    0.52    5.29

APPR :XS      54.   253.     334.  0.49  0.24  506.97 *******   1840.  506.48
      140.    54.   349.   26814.  1.04  0.02    0.01    0.53    5.50

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K      AREA     VEL    WSEL
   Drop :XS      35.   250.   315.   1840.   31511.     260.    7.09  503.50
   FV   :XS      60.   250.   316.   1840.   33266.     269.    6.83  503.65
   BR   :XS      73.   250.   278.   1840.   12716.     141.   13.03  503.94
   UFACE:XS      86.   252.   354.   1840.   28033.     348.    5.29  506.24
   APPR :XS     140.   253.   349.   1840.   26814.     334.    5.50  506.48

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   Drop :XS    502.28    0.63  498.70  506.14************  0.78  504.28  503.50
   FV   :XS  ********    0.60  498.70  506.14  0.08  0.00  0.73  504.38  503.65
   BR   :XS    503.94    1.00  498.22  515.73************  2.64  506.58  503.94
   UFACE:XS  ********    0.52  498.02  521.64  0.12  0.00  0.46  506.70  506.24
   APPR :XS  ********    0.53  498.39  522.01  0.24  0.02  0.49  506.97  506.48
```

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 RANDTH00BR0054, in Randolph, Vermont.

APPENDIX D:

HISTORICAL DATA FORM