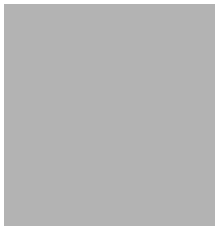
LEVEL II SCOUR ANALYSIS FOR BRIDGE 22 (WODSTH00180022) on TOWN HIGHWAY 18, crossing NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

U.S. Geological Survey
Open-File Report 96-159



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

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By SCOTT A. OLSON

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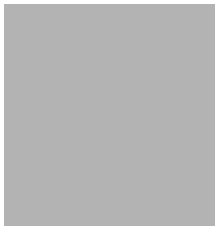

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VERMONT AGENCY OF TRANSPORTATION
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Pembroke, New Hampshire

1996

U.S. DEPARTMENT OF THE INTERIOR
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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 22 (WODSTH00180022) ON TOWN HIGHWAY 18, CROSSING NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

By **Scott A. Olson**

INTRODUCTION

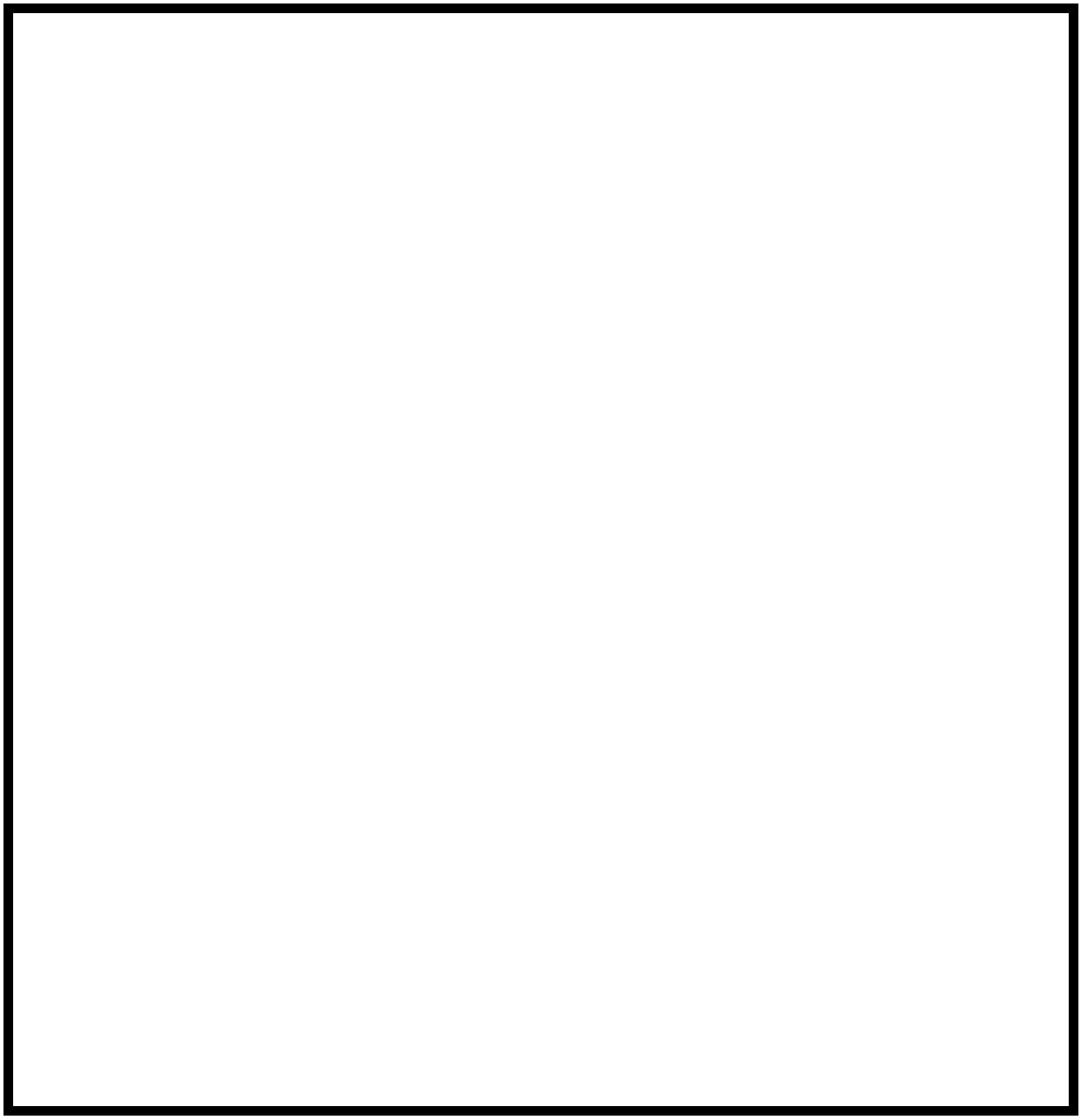
This report provides the results of a detailed Level II analysis of scour potential at structure WODSTH00180022 on town highway 18 crossing North Bridgewater Brook, Woodstock, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge, available from VTAOT files, was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont. The 4.34-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left bank is forested and the right bank is covered by shrub and brush and is adjacent to woods. The right bank of North Bridgewater Brook is parallel to town highway 18 upstream of the bridge.

In the study area, North Bridgewater Brook has a sinuous channel with a slope of approximately 0.038 ft/ft, an average channel top width of 48 ft and an average channel depth of 7 ft. The predominant channel bed materials are gravel and cobbles (D_{50} is 63.2 mm or 0.207 ft). Due to cut banks and other channel features the geomorphic assessment at the time of the Level I and Level II site visit on August 16, 1994, indicated that the reach was laterally unstable. In addition, the stream approach to the bridge has a high gradient. However, near the upstream face of the bridge the gradient shallows. Approximately 100 feet downstream of the bridge the gradient steepens again.

The town highway 18 crossing of North Bridgewater Brook is a 40-ft-long, two-lane bridge consisting of one 35-foot concrete span (Vermont Agency of Transportation, written commun., August 2, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The left and right abutments are not protected by stone fill. 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.

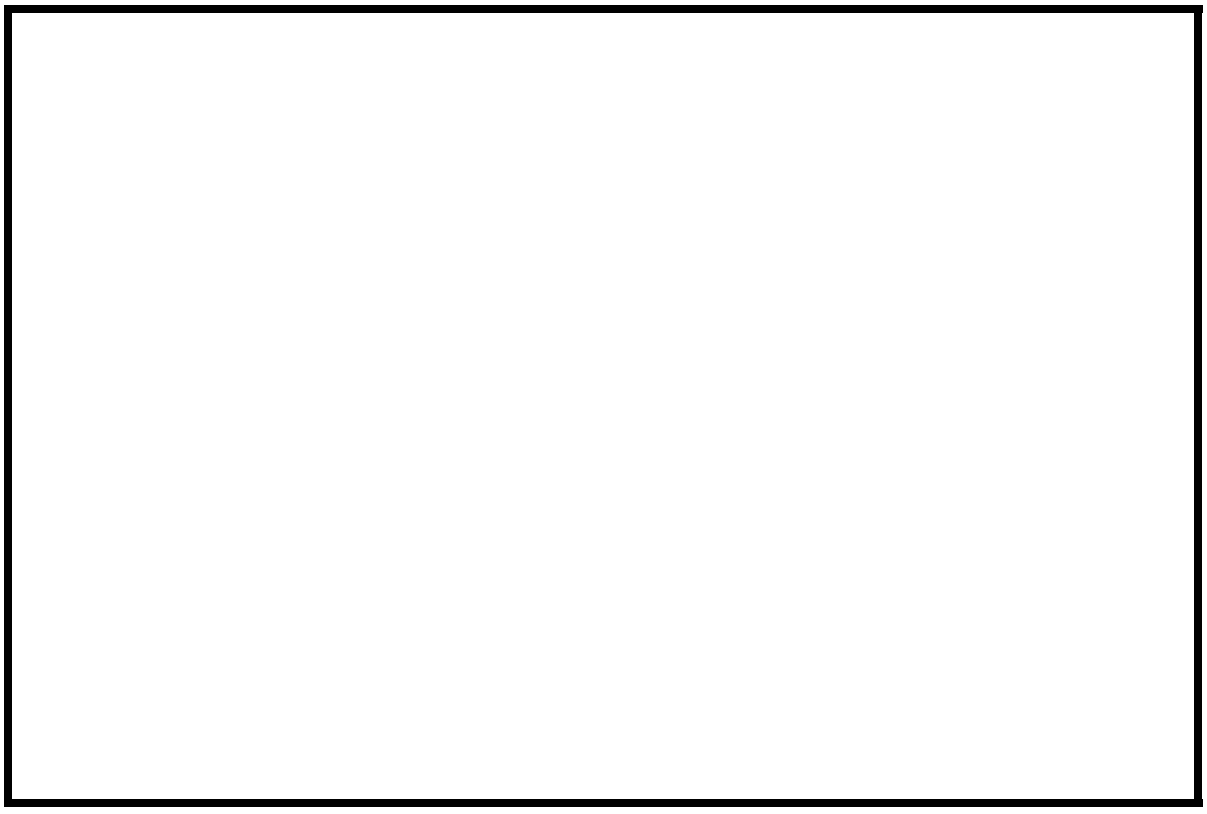


Woodstock North, VT. Quadrangle, 1:24,000, 1966

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 WODSTH00180022 ***Stream*** North Bridgewater Brook

County Windsor ***Road*** TH018 ***District*** 04

Description of Bridge

Bridge length 40 ***ft*** ***Bridge width*** 25.5 ***ft*** ***Max span length*** 35 ***ft***

Alignment of bridge to road (on curve or straight) moderate S-curve

Abutment type Concrete, vertical ***Embankment type*** sloping

Stone fill on abutment? no ***Date of inspection*** 08/16/94

Description of stone fill Type II around wingwalls. Stone fill is in good condition on wingwalls. Some stone fill is also on abutments but is very sparse and not protecting the abutment.

Brief description of piers (shape)

Is bridge skewed to flood flow according to Y ***survey?*** ***Angle*** Y 45

The skew angle of the stream to the bridge is 45 degrees. Opening skew to roadway is 30 degrees and the left abutment is attacked at approximately 20 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	08/16/94	0	0
Level II	same	--	--

Potential for debris Moderate due to high banks with noticeable slip-failure and lateral instability of stream

Describe any features near or at the bridge that may affect flow (include observation date) On 08/16/94 it was noted that a small boulder point bar exists under the bridge which may further constrict flow. Flood flows will impact the left abutment heavily and may cause pile-up of water and increase scour.

Description of the Geomorphic Setting

General topography Narrow, incised valley with steep valley walls; road and stream run along valley bottom

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

Date of inspection 08/16/94

DS left: two-lane road, then steep valley wall

DS right: steep valley wall

US left: steep valley wall

US right: two-lane road, then steep valley wall

Description of the Channel

Average top width 48 ***ft*** ***Average depth*** 7 ***ft***

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

Channel type (straight, sinuous, with no flood plains. It is semi-alluvial and laterally unstable

Vegetative cover at bridge site and date of observation. 08/16/94

DS left: Forest

DS right: Shrub and brush

US left: Forest

US right: Shrub and brush; road at top of bank.

Do banks appear stable? N

Describe any bank protection and its effectiveness. 08/16/94--Banks are reported to be steep and eroded by means of slip failures from above the channel. The USLB has stone fill and it is in good condition; the USRB is protected by stone fill but the fill is eroded in places; the DSLB and DSRB are protected by stone fill and the stone fill is in good condition.

Describe any obstructions in channel and date of observation. 08/16/94--A point bar exists under the structure.

Hydrology

Drainage area 4.34 ***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? No

USGS gage description --

USGS gage number --

Gage drainage area ***mi^2***

Is there a lake/p -- No

Calculated Discharges

Q100 1,100 ***ft^3/s*** ***Q500*** 1,870 ***ft^3/s***

Q100 is taken from VTAOT files (VTAOT, written communication, May, 1995). Q500 determined by multiplying 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 Subtract 411 feet from VTAOT datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled triangle on top of the DS right wingwall where it meets the right abutment with an arbitrary survey elevation of 501.27 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
FV	50	2	Downstream Full-valley section (Templated from EXITX)
BRO	50	1	Bridge section
RDWAY	65	1	Road Grade section
APPR	115	2	Modelled Approach section (Templated from SURVA)
SURVA	135	1	Approach section as surveyed (Used as a template)

[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). 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 0.064 to 0.065.

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 0.038 ft/ft which was determined from surveyed thalweg points downstream of the bridge.

The surveyed approach section (SURVA) was moved along the approach channel slope (0.03 ft/ft) to establish the modelled approach section (APPR), 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.

In the unconstricted hydraulic model through the reach, the energy equation was not balanced between the FV and APPR sections, and the APPR section defaulted to critical depth. The default to critical depth was allowed since additional analyses indicated that flow in the unconstricted model run would indeed be close to critical depth.

Bridge Hydraulics Summary

Average bridge embankment elevation 501.4 *ft*
Average low steel elevation 499.1 *ft*

100-year discharge 1,100 *ft³/s*
Water-surface elevation in bridge opening 492.8 *ft*
Road overtopping? no *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 114 *ft²*
Average velocity in bridge opening 9.6 *ft/s*
Maximum WSPRO tube velocity at bridge 11.3 *ft/s*

Water-surface elevation at Approach section with bridge 495.4
Water-surface elevation at Approach section without bridge 494.8
Amount of backwater caused by bridge 0.6 *ft*

500-year discharge 1,870 *ft³/s*
Water-surface elevation in bridge opening 493.9 *ft*
Road overtopping? no *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 145 *ft²*
Average velocity in bridge opening 12.9 *ft/s*
Maximum WSPRO tube velocity at bridge 15.4 *ft/s*

Water-surface elevation at Approach section with bridge 498.6
Water-surface elevation at Approach section without bridge 496.3
Amount of backwater caused by bridge 2.3

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 for the 100-year and 500-year discharge was computed by use of the clear-water equation (Richardson and others, 1993, p. 35, equation 18) because the mean velocity in the channel was slightly lower than the critical velocity. 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). The Froehlich equation gives "excessively conservative estimates of scour depths" (Richardson and others, 1993, p. 48). 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	0.3 1.7	--	8.0
Depth to armoring	26.9	--	--
Left overbank	--	--	--
Right overbank	--	--	5.1

Local scour:			
Abutment scour	8.5	--	5.3
Left abutment	6.9	--	--
Right abutment			
Pier scour	--	--	--
Pier 1	--	--	--
Pier 2	--	--	1.7
Pier 3			

Rock Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:	2.2	--	1.7
Left abutment	2.2	--	--
Right abutment	--	--	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2			

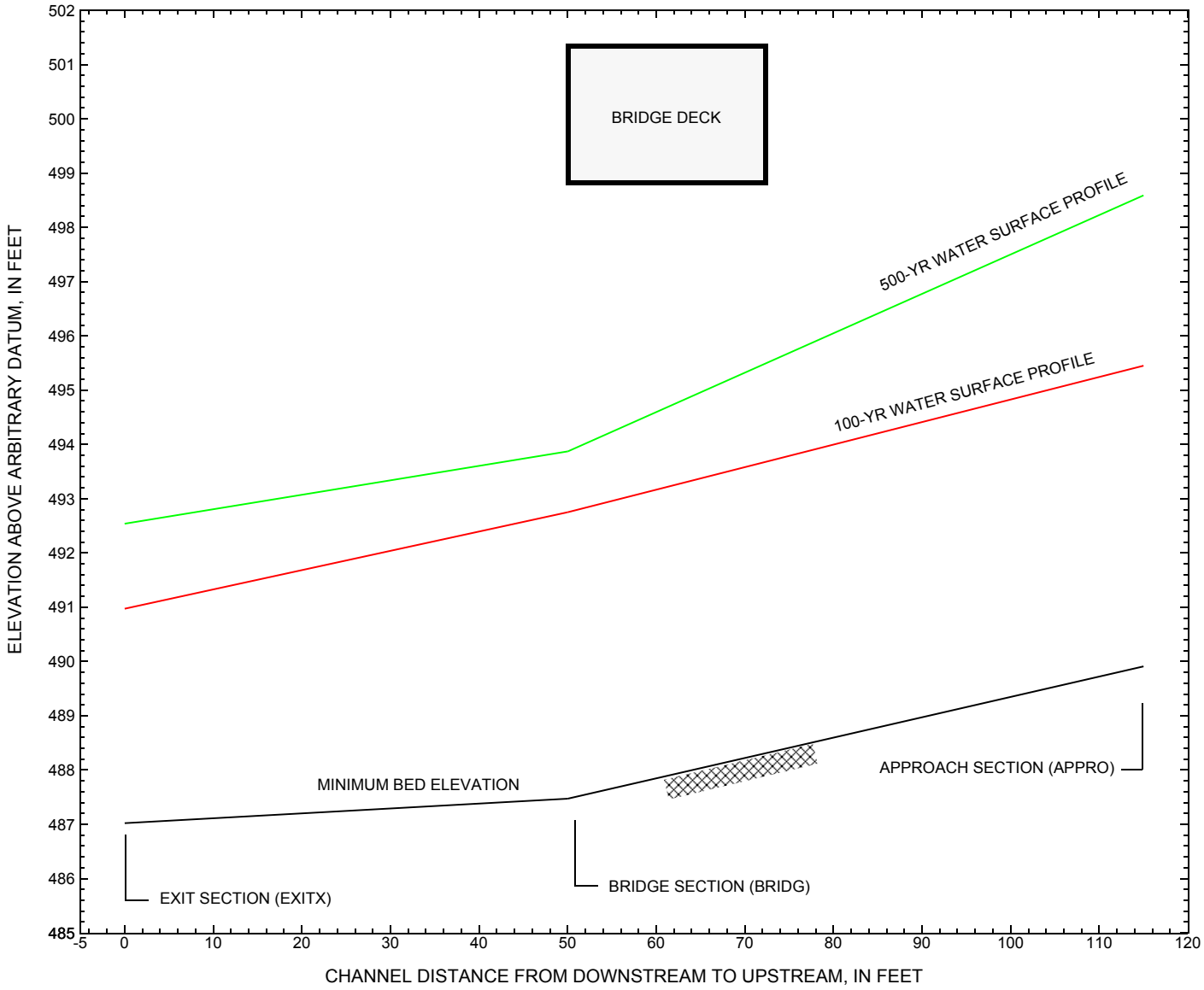


Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure WODSTH00180022 on town highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

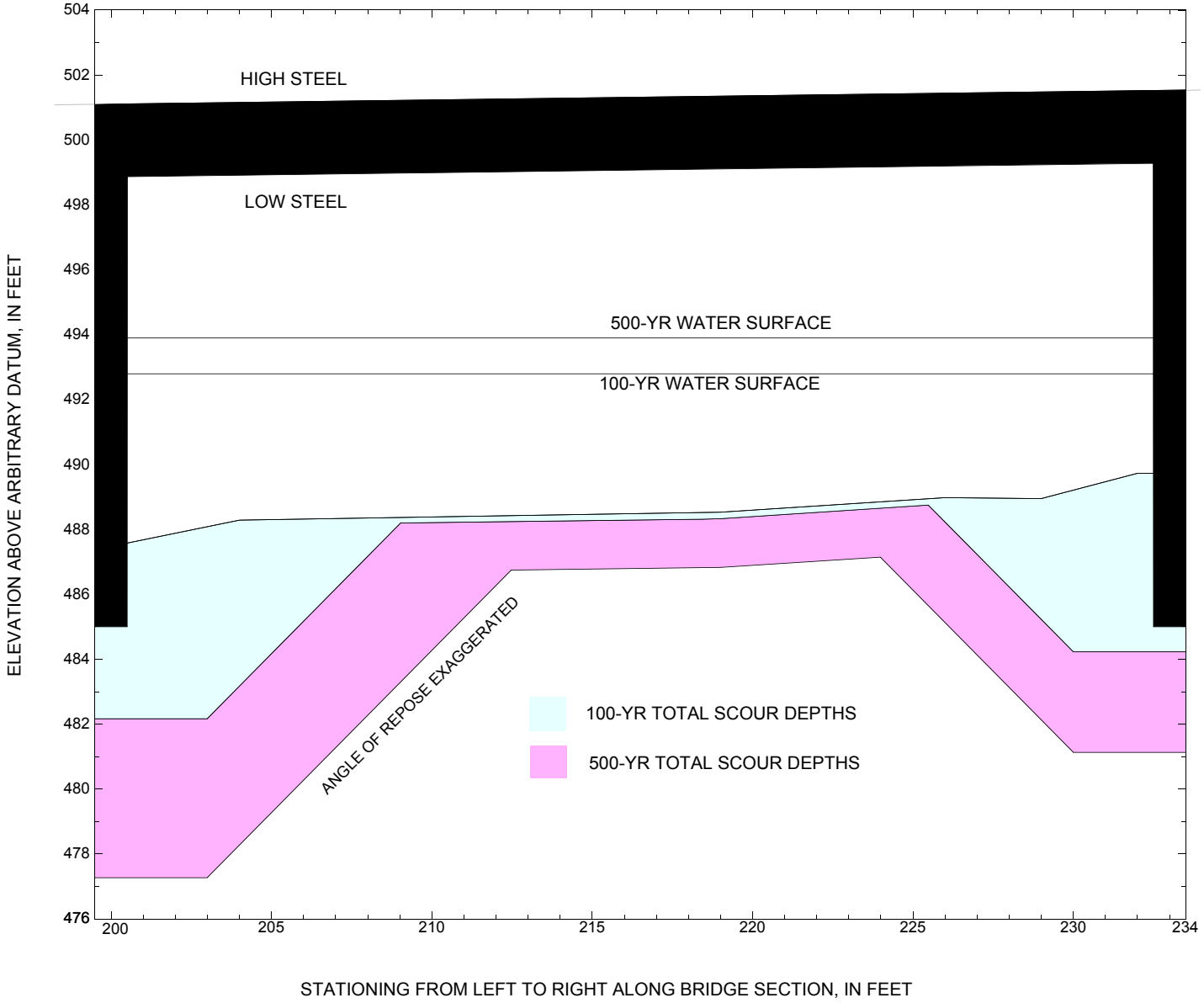


Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure WODSTH00180022 on town highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure WODSTH00180022 on Town Highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 8,030 cubic-feet per second											
Left abutment	200	910.1	498.8	485	487.5	0.3	5.1	--	5.4	482.1	-3
Right abutment	233	910.6	499.3	485	489.7	0.3	5.3	--	5.6	484.1	-1

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure WODSTH00180022 on Town Highway 18, crossing North Bridgewater Brook, Woodstock, Vermont.

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

Description	Station[1]	VTAOT plans' bridge seat elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 11,600 cubic-feet per second											
Left abutment	200	910.1	498.8	485	487.5	1.7	8.5	--	10.2	477.3	-9
Right abutment	233	910.6	499.3	485	489.7	1.7	6.9	--	8.6	481.1	-5

[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.

U.S. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

U.S. Geological Survey, 1966, Woodstock North, 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            Woodstock, VT BRIDGE #022
T3            USGS  BOW,NH   04/24/95
*
Q             1100 1870
SK            0.038 0.038
*
*             The starting slope was determined from a field survey
*
XS   EXIT      0
GR           143., 499.37     152., 498.87     164., 495.76     182., 492.83
GR           198., 491.31     200., 489.70     202., 487.92     206., 487.47
GR           211., 487.02     213., 487.02     216., 487.48     219., 487.61
GR           223., 487.23     229., 487.17     233., 488.67     237., 492.27
GR           244., 495.32     253., 497.54     266., 499.33
N             0.065
*
XS   FV       50 * * * 0.009
*
BR   BRO      50 498.82 33.2
GR           201., 498.82     200., 487.47     204., 488.29     210., 488.42
GR           219., 488.53     226., 488.98     229., 488.95     233., 489.73
GR           234., 499.33     201., 498.82
N             0.064
CD            1 45.7 * * 52.5 8.5
*
XR   RDWAY    65 25.5 2
GR           116., 510        116., 500.03     200., 501.11     243., 501.57
GR           311., 502.99     355., 503.35     355., 510
BP           200
*
XT   SURVA     135
GR           191., 505.58     200., 497.95     204., 495.44     208., 493.21
GR           211., 491.54     213., 490.51     217., 490.99     228., 491.33
GR           233., 492.86     237., 496.45     244., 499.49     249., 502.20
GR           334., 503.55     335., 510
*
AS   APPR      115
GT            -0.6
N             0.065     0.030
SA                  249.
BP            200
*
HP 1 BRO     492.75 1 492.75
HP 2 BRO     492.75 * * 1100
HP 1 APPR    495.45 1 495.45
HP 2 APPR    495.45 * * 1100
*
HP 1 BRO     493.87 1 493.87
HP 2 BRO     493.87 * * 1870
HP 1 APPR    498.59 1 498.59
HP 2 APPR    498.59 * * 1870
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
           HYDRAULIC ANALYSIS
           Woodstock, VT BRIDGE #022
           USGS  BOW,NH   04/24/95
          *** RUN DATE & TIME: 04-24-95  10:29
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRO  ;  SRD =      50.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     114.    5728.    27.    36.                       1322.
   492.75          114.    5728.    27.    36.  1.00   200.   233.   1322.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRO  ;  SRD =      50.

         WSEL     LEW     REW    AREA        K        Q    VEL
       492.75   200.0   233.3   114.2    5728.    1100.   9.63

X STA.       200.0      202.8      204.4      205.9      207.4      208.8
  A(I)            10.5        6.3        5.7        5.3        5.2
  V(I)            5.25       8.68       9.65      10.37      10.59

X STA.       208.8      210.2      211.6      212.9      214.3      215.6
  A(I)             5.0        4.9        4.9        4.9        4.8
  V(I)           10.90      11.17      11.12      11.30      11.34

X STA.       215.6      217.0      218.4      219.8      221.3      222.8
  A(I)             4.9        4.9        4.9        5.1        5.1
  V(I)           11.20      11.25      11.19      10.83      10.85

X STA.       222.8      224.4      226.1      227.9      229.9      233.3
  A(I)             5.3        5.5        5.6        6.3        9.1
  V(I)           10.44      10.04       9.85       8.74       6.03

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     115.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     129.    6841.    34.    36.                       1431.
   495.45          129.    6841.    34.    36.  1.00   203.   237.   1431.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     115.

         WSEL     LEW     REW    AREA        K        Q    VEL
       495.45   203.0   236.6   128.7    6841.    1100.   8.55

X STA.       203.0      209.3      211.2      212.6      213.6      214.7
  A(I)            11.5        7.7        6.7        5.9        5.7
  V(I)            4.78       7.12       8.24       9.31       9.71

X STA.       214.7      215.7      216.8      217.9      219.0      220.0
  A(I)             5.5        5.5        5.3        5.4        5.4
  V(I)            9.99       9.94      10.29      10.12      10.19

X STA.       220.0      221.1      222.2      223.4      224.5      225.7
  A(I)             5.4        5.4        5.4        5.6        5.6
  V(I)           10.10      10.17      10.12       9.86       9.81

X STA.       225.7      226.9      228.2      229.6      231.5      236.6
  A(I)             5.9        6.0        6.5        7.4       10.7
  V(I)            9.34       9.14       8.46       7.43       5.13
```

WSPRO OUTPUT FILE (continued)

```
           HYDRAULIC ANALYSIS
           Woodstock, VT BRIDGE #022
           USGS  BOW,NH   04/24/95
          *** RUN DATE & TIME: 04-24-95  10:29
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRO  ;  SRD =      50.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     145.    8190.    28.    38.                       1890.
   493.87          145.    8190.    28.    38.  1.00   200.   233.   1890.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRO  ;  SRD =      50.

         WSEL     LEW     REW    AREA        K        Q    VEL
       493.87   200.0   233.4   145.0    8190.    1870.  12.89

X STA.       200.0      203.0      204.8      206.4      207.8      209.3
  A(I)            13.8        8.4        7.4        6.6        6.6
  V(I)            6.76      11.12      12.72      14.10      14.07

X STA.       209.3      210.6      212.0      213.4      214.7      216.1
  A(I)             6.3        6.2        6.2        6.1        6.1
  V(I)           14.85      15.19      15.12      15.34      15.39

X STA.       216.1      217.4      218.8      220.1      221.6      223.0
  A(I)             6.1        6.1        6.1        6.2        6.3
  V(I)           15.35      15.39      15.33      15.08      14.81

X STA.       223.0      224.6      226.2      228.0      229.9      233.4
  A(I)             6.6        6.7        7.0        7.9       12.3
  V(I)           14.16      13.91      13.26      11.77       7.63

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =     115.

     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     251.   17054.    45.    49.                       3382.
   498.59          251.   17054.    45.    49.  1.00   199.   243.   3382.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =     115.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.59   198.5   243.3   251.5   17054.    1870.   7.44

X STA.       198.5      206.5      209.1      210.9      212.4      213.7
  A(I)            22.1       15.3       12.8       11.9       10.9
  V(I)            4.24       6.13       7.33       7.83       8.56

X STA.       213.7      214.9      216.1      217.3      218.6      219.8
  A(I)            10.2       10.3       10.0       10.2       10.1
  V(I)            9.15       9.04       9.35       9.20       9.25

X STA.       219.8      221.0      222.3      223.6      224.9      226.3
  A(I)            10.0       10.3       10.2       10.5       10.8
  V(I)            9.31       9.07       9.15       8.89       8.62

X STA.       226.3      227.7      229.3      231.1      233.4      243.3
  A(I)            11.2       11.9       13.0       15.3       24.4
  V(I)            8.35       7.83       7.21       6.12       3.84
```

WSPRO OUTPUT FILE (continued)

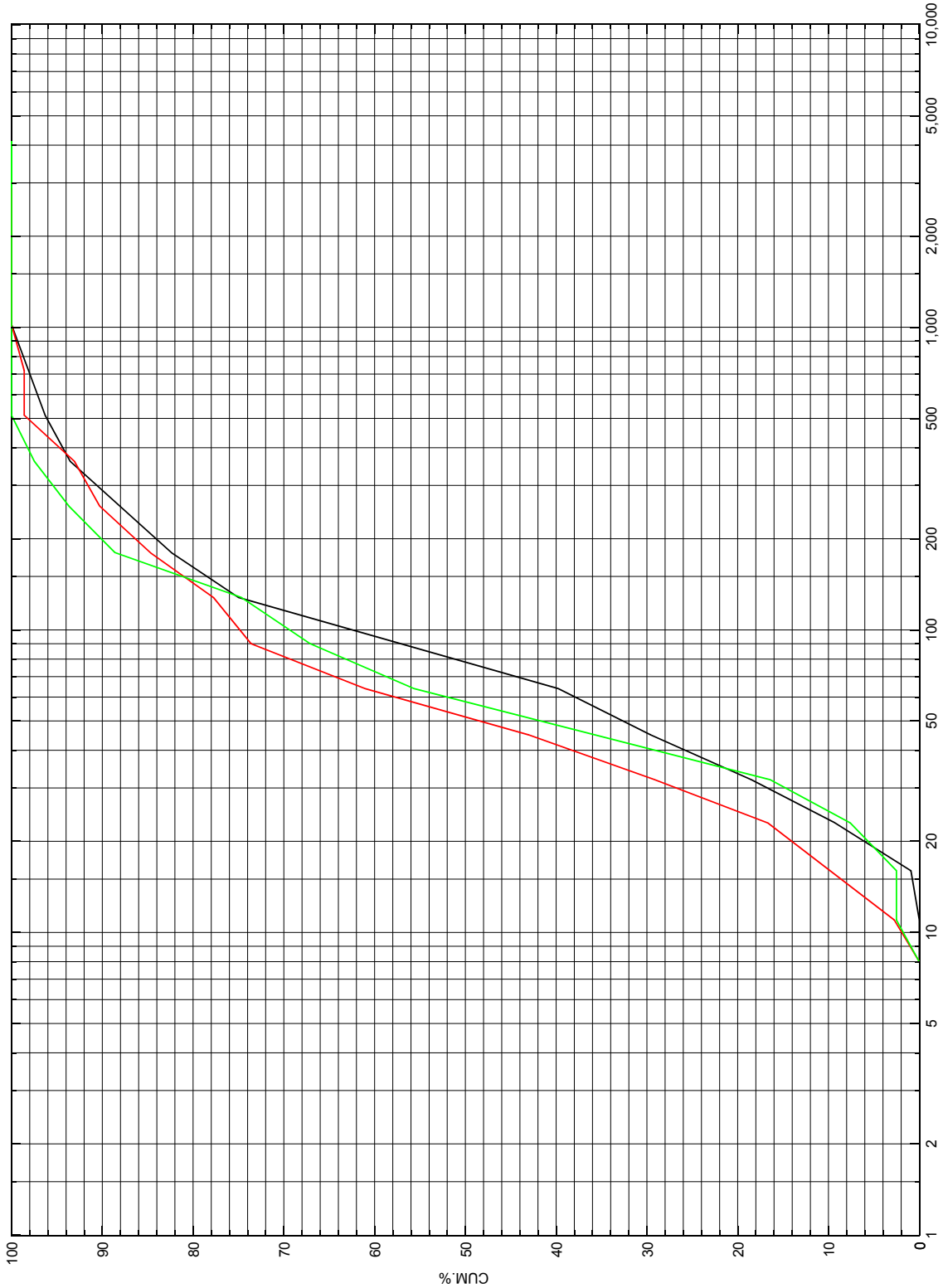
```
           HYDRAULIC ANALYSIS
           Woodstock, VT BRIDGE #022
           USGS  BOW,NH   04/24/95
          *** RUN DATE & TIME: 04-24-95  10:29

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

EXIT :XS   ******   198.     118.  1.34 *****  492.31  490.78   1100.  490.97
        0. ******   236.    5641.  1.00 ***** *******    0.92    9.29

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "FV   "     KRATIO =  1.64

FV   :FV      50.   186.     181.  0.57  1.16  493.46 *******   1100.  492.88
       50.    50.   237.    9268.  1.00  0.00   -0.01    0.57    6.07
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPR ":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.32     494.11     494.76

 ===110 WSEL NOT FOUND AT SECID "APPR ":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   492.38     509.40    0.50

 ===115 WSEL NOT FOUND AT SECID "APPR ":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   492.38     509.40     494.76

 ===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 "APPR "
                   WSBEG,WSEND,CRWS =   494.76     509.40     494.76

APPR :AS      65.   204.     106.  1.67 *****  496.43  494.76   1100.  494.76
      115.    65.   236.    5192.  1.00 ***** *******    1.00   10.36
         <<<<<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

BRO  :BR      50.   200.     114.  1.44  1.87  494.19  492.28   1100.  492.75
       50.    50.   233.    5721.  1.00  0.00    0.00    0.83    9.64

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  498.82 ****** ****** ******

    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
APPR :AS      19.   203.     129.  1.14  0.71  496.59  494.76   1100.  495.45
      115.    23.   237.    6835.  1.00  1.69    0.01    0.77    8.55

       M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
      0.000  0.000    6962.   204.   238.   494.42
```

WSPRO OUTPUT FILE (continued)

```
           HYDRAULIC ANALYSIS
           Woodstock, VT BRIDGE #022
           USGS  BOW,NH   04/24/95
          *** RUN DATE & TIME: 04-24-95  10:29

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

EXIT :XS   ******   185.     187.  1.56 *****  494.10  492.33   1870.  492.54
        0. ******   238.    9591.  1.00 ***** *******    0.94   10.01

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "FV   "     KRATIO =  1.68

FV   :FV      50.   174.     280.  0.70  1.13  495.23 *******   1870.  494.54
       50.    50.   241.   16078.  1.00  0.00   -0.01    0.58    6.69
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPR ":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.39     495.28     496.30

 ===110 WSEL NOT FOUND AT SECID "APPR ":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   494.04     509.40    0.50

 ===115 WSEL NOT FOUND AT SECID "APPR ":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   494.04     509.40     496.30

 ===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 "APPR "
                   WSBEG,WSEND,CRWS =   496.30     509.40     496.30

APPR :AS      65.   202.     158.  2.17 *****  498.47  496.30   1870.  496.30
      115.    65.   238.    9121.  1.00 ***** *******    1.00   11.81
         <<<<<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

BRO  :BR      50.   200.     145.  2.58  2.22  496.46  493.83   1870.  493.87
       50.    50.   233.    8196.  1.00  0.13    0.00    0.99   12.89

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  498.82 ****** ****** ******

    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

APPR :AS      19.   199.     251.  0.86  0.61  499.45  496.30   1870.  498.59
      115.    24.   243.   17036.  1.00  2.38    0.00    0.55    7.44

       M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
      0.079  0.000   18428.   204.   237.   498.11
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution at the approach cross-section for structure WODSTH00180022, in Woodstock, Vermont.

APPENDIX D:

HISTORICAL DATA FORM