LEVEL II SCOUR ANALYSIS FOR BRIDGE 24 (WODSTH00190024) on TOWN HIGHWAY 19, crossing NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

U.S. Geological Survey
Open-File Report 96-238

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

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By SCOTT A. OLSON and DONALD L. SONG

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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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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Slope	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

OTHER ABBREVIATIONS

BF	bank full	LWW	left wingwall
cfs	cubic feet per second	MC	main channel
D_{50}	median diameter of bed material	RAB	right abutment
DS	downstream	RABUT	face of right abutment
elev.	elevation	RB	right bank
f/p	flood plain	ROB	right overbank
ft^2	square feet	RWW	right wingwall
ft/ft	feet per foot	TH	town highway
JCT	junction	UB	under bridge
LAB	left abutment	US	upstream
LABUT	face of left abutment	USGS	United States Geological Survey
LB	left bank	VTAOT	Vermont Agency of Transportation
LOB	left overbank	WSPRO	water-surface profile model

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 27 (WODSTH00190024) ON TOWN HIGHWAY 19, CROSSING NORTH BRIDGEWATER BROOK, WOODSTOCK, VERMONT

***By* Scott A. Olson and Donald L. Song**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure WODSTH00190024 on Town Highway 19 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 east-central Vermont in the town of Woodstock. The 3.6-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left and right banks are covered by moderate tree cover along the immediate banks with some pasture/ grassland beyond.

In the study area, the North Bridgewater Brook has a sinuous channel with a slope of approximately 0.03 ft/ft, an average channel top width of 44 ft and an average channel depth of 4 ft. The channel bed materials ranges from sand to boulders with a D_{50} (median diameter) of 70.1 mm or 0.229 ft. The geomorphic assessment at the time of the Level I and Level II site visits on August 17, 1994 and December 13, 1994, indicated that the reach was stable. Localized bank cutting existed at the immediate downstream left bank.

The Town Highway 19 crossing of the North Bridgewater Brook is a 26-ft-long, one-lane bridge consisting of one 23-ft steel-beam span (Vermont Agency of Transportation, written commun., August 3, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. Type-2 (less than 3 ft diameter) stone fill protects the upstream left wingwall which is impacted by flow. The channel bed under the bridge is constructed of wood. This construction is preventing channel degradation along the impacted left abutment.The channel is skewed approximately 40 degrees to the opening; the opening-skew-to-roadway is 10 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 0.0 to 0.8 ft. Abutment scour ranged from 6.6 to 14.9 ft. with the worst-case scenario occurring 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.

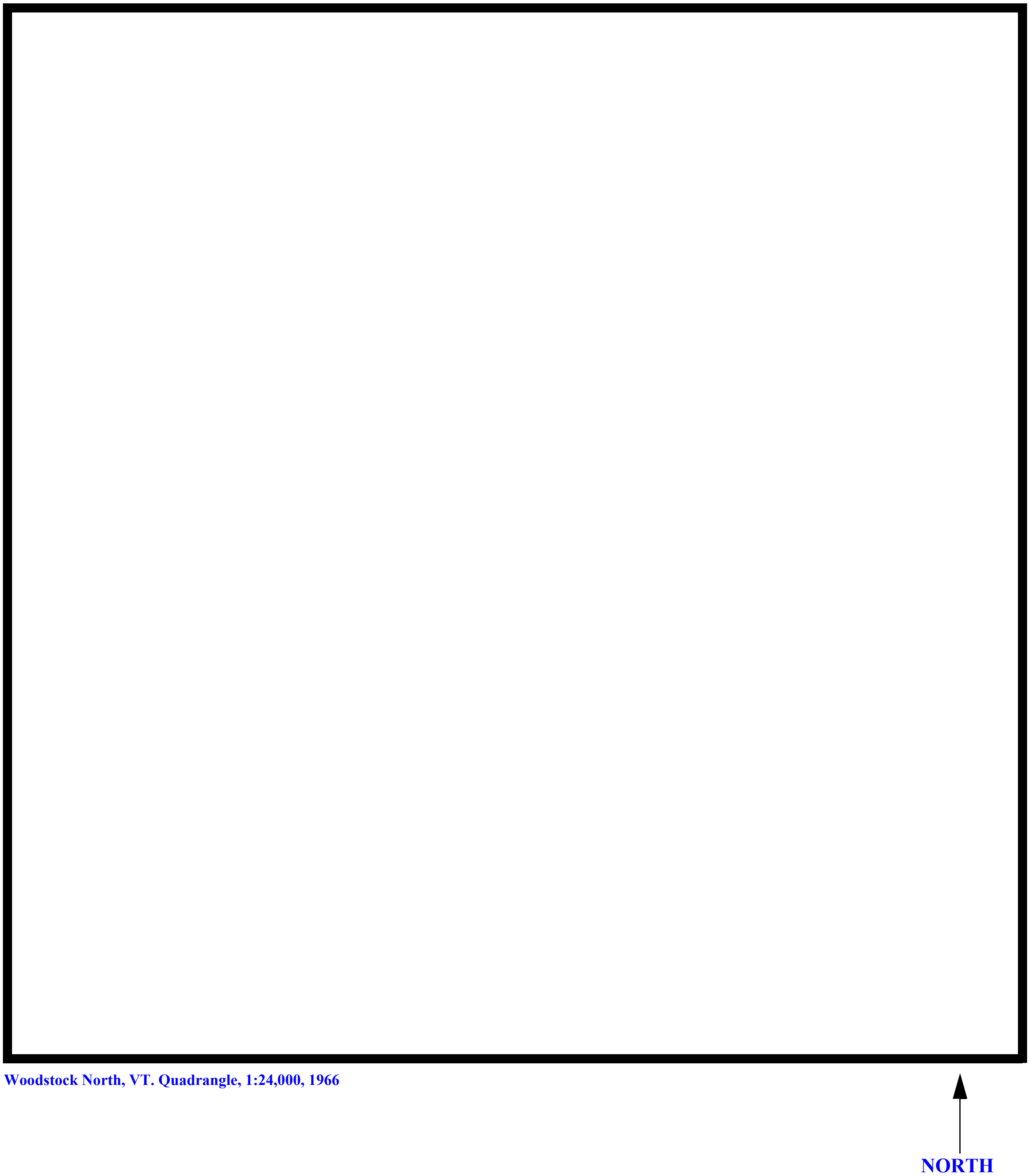

Figure 1. Location of study area on USGS 1:24,000 scale map.

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

LEVEL II SUMMARY

Structure Number WODSTH00190024 **Stream** North Bridgewater Brook

County Windsor **Road** TH049 **District** 04

Description of Bridge

Bridge length 26 ***ft*** ***Bridge width*** 14.2 ***ft*** ***Max span length*** 23 ***ft***

Alignment of bridge to road (on curve or straight) straight

Abutment type vertical ***Embankment type*** sloping

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

Description of stone fill Type-2 stone fill along the upstream left wingwall.

Abutments and wingwalls are concrete.

The channel bed under the bridge is constructed of wood.

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 40

There is a moderate bend is the channel resulting in an impact on the left abutment.

Opening skew-to-roadway is 10 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	12/13/94	0	0
Level II	12/13/94	-	-

Potential for debris Moderate

Describe any features near or at the bridge that may affect flow (include observation date)

A gravel and cobble point bar along the right bank under the bridge noted on 08/17/94 and 12/13/94.

Description of the Geomorphic Setting

General topography The bridge is in a steep, narrow valley with moderate relief.

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

Date of inspection 8/17& 12/13/95

DS left: narrow flood plain to valley wall

DS right: narrow flood plain to valley wall

US left: narrow flood plain to valley wall

US right: narrow flood plain to valley wall

Description of the Channel

Average top width 44 ***ft*** ***Average depth*** 4 ***ft***

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

high gradient, slightly sinuous, upland stream with narrow flood plains.

12/13/95

Vegetative co field grasses with woody vegetation along the immediate bank.

DS left: field grasses with woody vegetation along the immediate bank.

DS right: forested.

US left: field grasses with woody vegetation along the immediate bank.

US right: N

Do banks appear stable? 12/13/94-- The overall reach is stable, however, the banks near the bridge are unstable due to eddy currents set up at the downstream side of the left abutment. This eddy current is causing localized bank cutting.

date of observation.

8/17/94 and 12/13/94--None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 3.60 ***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. Basin is primarily forested with some open areas for agricultural uses.

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 965 ***ft³/s*** ***Q500*** 1,640 ***ft³/s***

Q100 was estimated from a drainage area relationship with Woodstock bridge 22 [(3.6/4.3) to the 0.7 power] which is just downstream of the study site. Bridge 22 had the Q100 determined by the Vermont Agency of Transportation (written commun., March, 1995). 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 No datum tie.

Description of reference marks used to determine USGS datum. RM1 is a chiseled triangle on the top of the downstream end of the right abutment footing (elev. 4997.35 ft, arbitrary datum). RM2 is a chiseled square on the top of the downstream end of the left abutment footing (elev. 4996.18 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT	0	1	Exit section
FV	35	2	DS full valley section (templated from EXIT)
BRO	35	1	DS Bridge opening.
RDWAY	13	1	Roadway section.
SURVA	95	1	Surveyed approach section used as a template section for the modelled approach
APPR	70	2	Modelled approach section (templated from SURVA).

[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 0.045 to 0.065, and overbank "n" values ranged from 0.042 to 0.083.

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 0.027 ft/ft which was determined from an analysis of the topographic map (U.S. Geological Survey, 1966) and surveyed thalweg and water surface points downstream of the structure.

The surveyed approach section (SURVA) was moved along the approach channel slope (0.031 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

The modeled 100- and 500-year discharges overtop the bridge and roadway. The incipient overtopping discharge was 1,160 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 5004.0 *ft*
Average low steel elevation 5004.0 *ft*

100-year discharge 965 *ft³/s*
Water-surface elevation in bridge opening 5002.0 *ft*
Road overtopping? N *Discharge over road* -- *ft³/s*
Area of flow in bridge opening 136 *ft²*
Average velocity in bridge opening 7.1 *ft/s*
Maximum WSPRO tube velocity at bridge 8.6 *ft/s*

Water-surface elevation at Approach section with bridge 5003.1
Water-surface elevation at Approach section without bridge 5000.1
Amount of backwater caused by bridge 3.0 *ft*

500-year discharge 1,640 *ft³/s*
Water-surface elevation in bridge opening 5002.0 *ft*
Road overtopping? Y *Discharge over road* 278 *ft³/s*
Area of flow in bridge opening 136 *ft²*
Average velocity in bridge opening 10.0 *ft/s*
Maximum WSPRO tube velocity at bridge 11.1 */s*

Water-surface elevation at Approach section with bridge 5005.1
Water-surface elevation at Approach section without bridge 5001.1
Amount of backwater caused by bridge 4.0 *ft*

Incipient overtopping discharge 1,160 *ft³/s*
Water-surface elevation in bridge opening 5002.0 *ft*
Area of flow in bridge opening 136 *ft²*
Average velocity in bridge opening 8.5 *ft/s*
Maximum WSPRO tube velocity at bridge 10.4 *ft/s*

Water-surface elevation at Approach section with bridge 5003.9
Water-surface elevation at Approach section without bridge 5000.5
Amount of backwater caused by bridge 3.4 *ft*

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

The 100-year, 500-year and the incipient road-overflow discharges resulted in unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October4, 1996). Therefore, contraction scour for all three discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). The results of Laursen's clear-water contraction scour for all three events were also computed and can be found in appendix F.

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.

The computed scour depths do not take into account the wooden constructed channel bed under the bridge. This construction may completely armor the under bridge channel from scour.

Scour was also computed for the incipient overtopping discharge of 1,160 ft^3/s. The results indicate that incipient overtopping is the worst case scenario for left abutment scour.

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	0.0	0.8	0.0
Depth to armoring	0.9	4.6	2.2
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	11.8	14.9	13.3
Right abutment	6.9	7.4	6.6
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	1.0	1.9	1.4
Right abutment	1.0	1.9	1.4
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

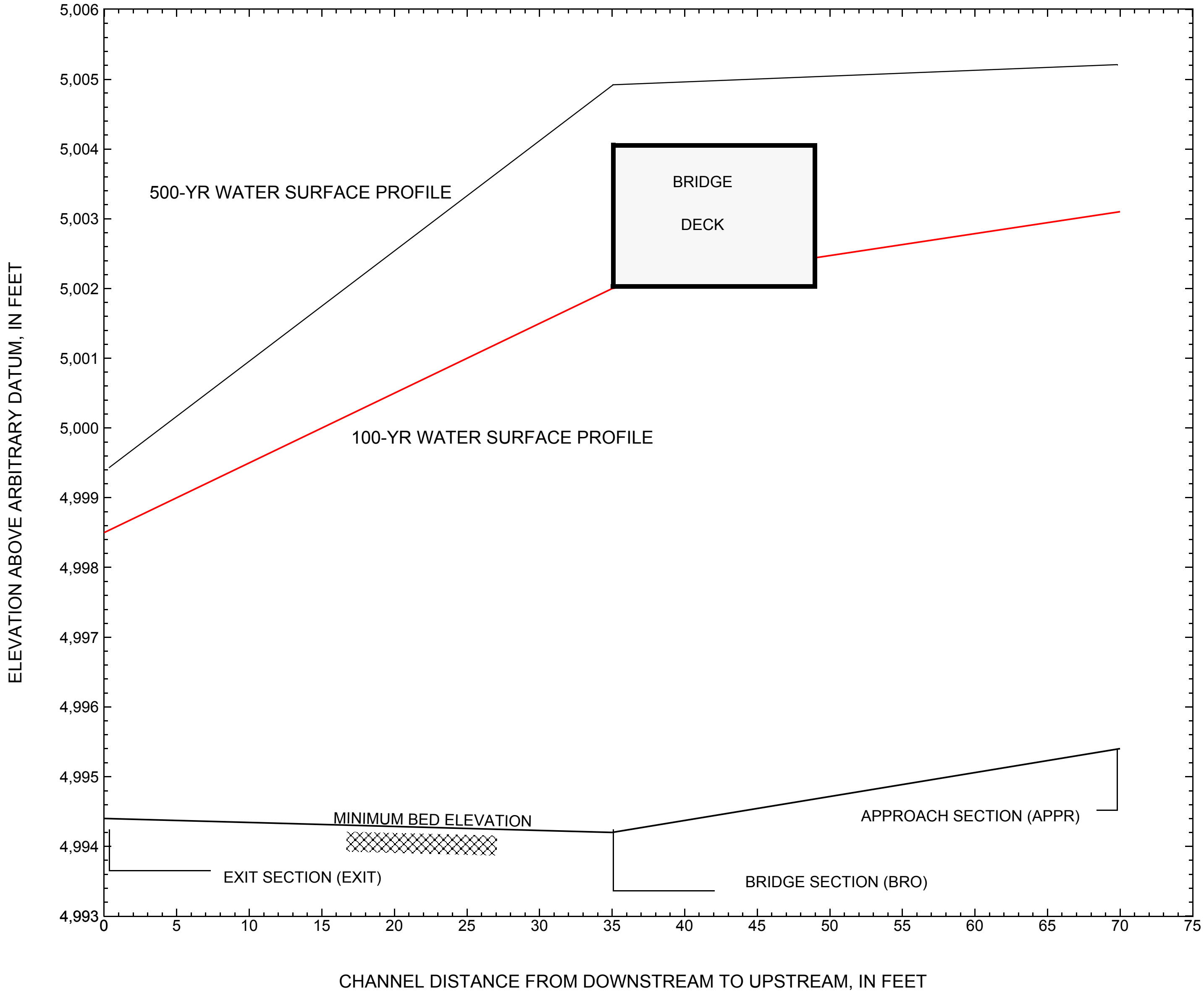

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure WODSTH00190024 on town highway 19, crossing North Bridgewater Brook, Woodstock, Vermont.

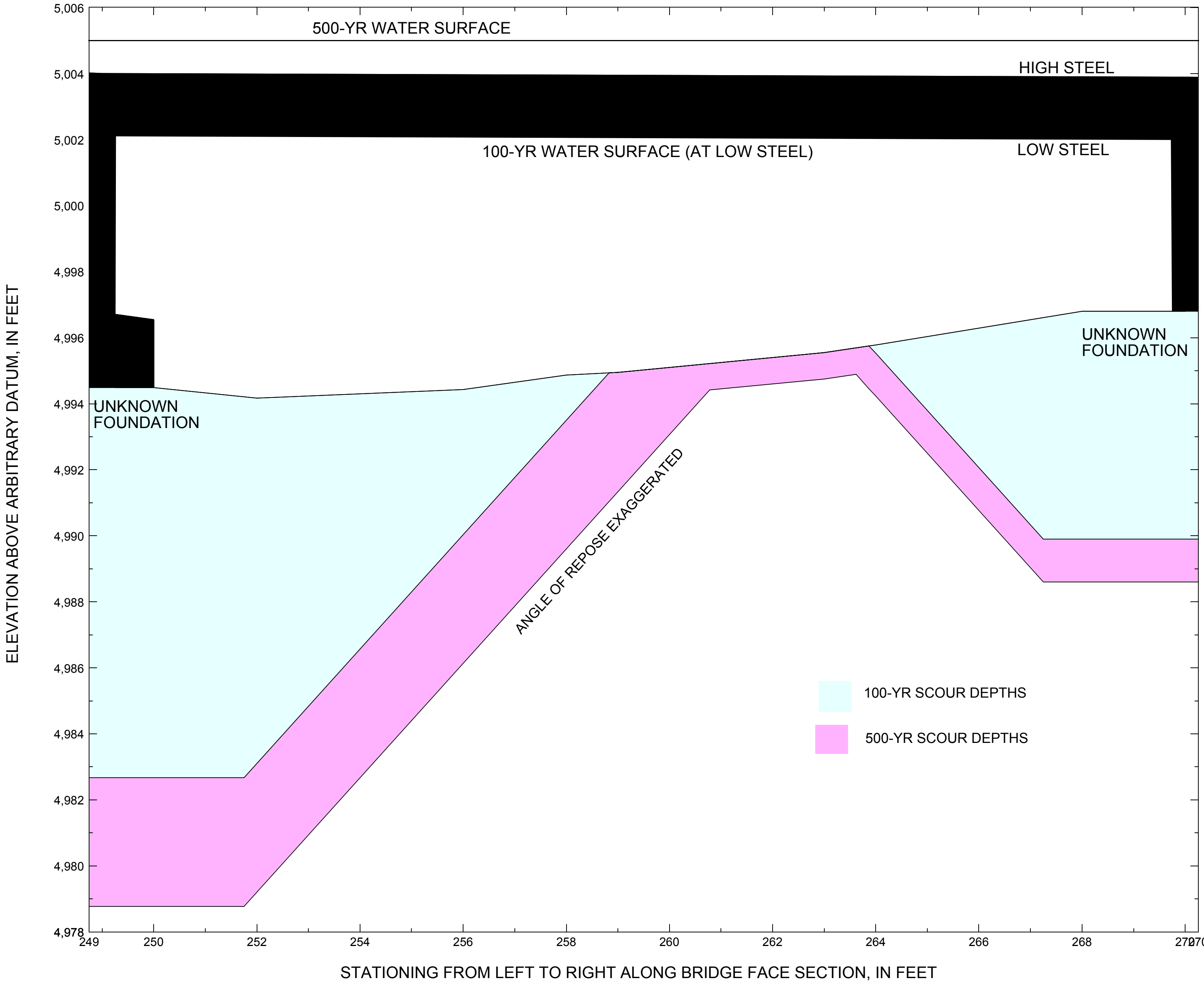

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure WODSTH00190024 on town highway 1 9, crossing North Bridgewater Brook, Woodstock, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure WODSTH00190024 on Town Highway 19, crossing North Bridgewater Brook, Woodstock, 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 965 cubic-feet per second											
Left abutment	249	--	5002.04	--	4994.5	0.0	11.8	--	11.8	4982.7	--
Right abutment	270	--	5001.99	--	4996.8	0.0	6.9	--	6.9	4989.9	--

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 WODSTH00190024 on Town Highway 19, crossing North Bridgewater Brook, Woodstock, 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 1,640 cubic-feet per second											
Left abutment	249	--	5002.04	--	4994.5	0.8	14.9	--	15.7	4978.8	--
Right abutment	270	--	5001.99	--	4996.8	0.8	7.4	--	8.2	4988.6	--

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

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Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

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Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

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, Photoinspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
T2        CREATED ON 21-AUG-95 FOR BRIDGE WODSTH00190024 USING FILE brid027.dca
T3        HYDRAULIC ANALYSIS OF BRID027    SAO
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           3780 4910 2590
WS          497.7  499.0 496.3
SK          0.0066 0.0066 0.0066
*
XS   EXITX    -34
GR         -301.4, 520.38   -225.3, 509.84   -119.4, 501.86    -81.6, 498.79
GR          -22.0, 498.52    -14.9, 493.78     -7.6, 491.91      0.0, 490.27
GR            2.1, 489.88      7.8, 488.61     15.0, 488.93     19.0, 488.76
GR           26.8, 489.84     31.9, 490.71     36.5, 491.60     39.8, 493.72
GR           52.9, 499.36     78.5, 501.06    112.8, 500.77    136.5, 505.29
GR          225.0, 517.63
N            0.035    0.045     0.040
SA                 -22       52.9
*
XS   FULLV   0 * * * 0.011
*
BR   BRIDG   0 499.0 10
GR            0.0, 498.45      0.3, 490.40      0.9, 490.42      0.9, 489.90
GR            1.0, 489.35      4.2, 489.20      8.2, 488.98     12.9, 489.37
GR           18.1, 489.38     23.0, 489.48     25.4, 489.86     26.9, 490.74
GR           27.3, 491.48     29.4, 491.48     29.5, 499.46      0.0, 498.45
N            0.040
CD           1 21.2 * * 57.5 3.8
*
XR   RDWAY   7 12.0 2
GR         -325.2, 513.84   -303.4, 509.56   -248.8, 510.37   -140.0, 509.00
GR          -39.6, 500.23      0.0, 499.67     29.9, 500.83     77.2, 502.85
GR          141.1, 506.70    238.2, 515.76
BP          0
*
AS   APPRO     39
GR         -333.2, 513.84   -312.2, 509.56   -259.9, 510.37   -146.3, 509.00
GR         -112.4, 506.26    -62.8, 501.48    -41.0, 499.56    -25.4, 499.93
GR          -12.9, 499.63     -8.3, 494.90     -4.7, 491.42     -2.8, 490.54
GR            0.0, 490.14      3.4, 489.64      8.1, 489.39     14.7, 489.80
GR           19.8, 490.17     24.8, 490.79     41.1, 492.58     45.6, 494.67
GR           57.7, 500.40    116.1, 504.50    212.2, 515.76
N           0.035        0.045        0.035
SA                  -13.         57.7
BP           0
*
HP 1 BRIDG    499.46 1 499.46
HP 2 BRIDG    499.46 * * 2917
HP 2 RDWAY    501.93 * * 880
HP 1 APPRO    502.01 1 502.01
HP 2 APPRO    502.01 * * 3780
*
HP 1 BRIDG    499.08 1 499.08
HP 2 BRIDG    499.08 * * 3435
HP 2 RDWAY    502.54 * * 1482
HP 1 APPRO    502.60 1 502.60
HP 2 APPRO    502.60 * * 4910
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
        CREATED ON 21-AUG-95 FOR BRIDGE WODSTH00190024 USING FILE brid027.dca
        HYDRAULIC ANALYSIS OF BRID027    SAO
           *** RUN DATE & TIME: 08-29-95  09:52
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW     REW     QCR
             1     271.  23608.    0.    75.                            0.
  499.46           271.  23608.    0.    75.  1.00     0.    30.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.46     0.0    29.5   270.6   23608.    2917.  10.78

X STA.         0.0        2.9        4.5        5.9        7.2        8.5
  A(I)             23.8       14.9       13.4       12.3       12.3
  V(I)             6.13       9.80      10.88      11.84      11.87

X STA.         8.5        9.8       11.0       12.2       13.5       14.7
  A(I)             12.0       11.7       11.7       11.5       11.6
  V(I)            12.15      12.46      12.44      12.65      12.62

X STA.        14.7       15.9       17.2       18.4       19.6       20.8
  A(I)             11.7       11.7       11.5       11.7       11.9
  V(I)            12.50      12.45      12.70      12.47      12.21

X STA.        20.8       22.1       23.4       24.8       26.5       29.5
  A(I)             12.2       12.4       13.5       15.2       23.6
  V(I)            11.93      11.75      10.80       9.62       6.18

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       7.
         WSEL     LEW     REW    AREA        K        Q    VEL
       501.93   -59.1    55.7   159.3    7223.     880.   5.52

X STA.       -59.1      -43.0      -38.4      -34.5      -31.0      -27.7
  A(I)             11.3        7.3        6.7        6.4        6.0
  V(I)             3.89       6.00       6.59       6.88       7.34

X STA.       -27.7      -24.6      -21.5      -18.0      -14.5      -11.2
  A(I)              6.0        5.9        7.1        7.0        7.0
  V(I)             7.34       7.50       6.24       6.28       6.33

X STA.       -11.2       -7.9       -4.7       -1.5        1.7        5.2
  A(I)              6.9        7.0        7.0        7.2        7.5
  V(I)             6.39       6.25       6.27       6.11       5.88

X STA.         5.2        9.4       14.1       20.1       28.5       55.7
  A(I)              8.3        8.6        9.6       11.0       15.7
  V(I)             5.33       5.14       4.60       3.99       2.80

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      39.
     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW     REW     QCR
             1      97.   5988.   55.    55.                          728.
             2     669.  94106.   71.    76.                        11667.
             3      18.    679.   23.    23.                           94.
  502.01           784. 100774.  149.   155.  1.13    -68.    81.   9585.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      39.
         WSEL     LEW     REW    AREA        K        Q    VEL
       502.01   -68.3    80.6   784.0  100774.    3780.   4.82

X STA.       -68.3      -18.3       -5.3       -1.8        1.1        3.7
  A(I)             84.6       60.5       38.3       34.2       31.7
  V(I)             2.24       3.12       4.94       5.53       5.97

X STA.         3.7        6.2        8.6       11.0       13.4       15.8
  A(I)             30.7       30.4       29.8       29.7       30.3
  V(I)             6.15       6.21       6.34       6.36       6.25

X STA.        15.8       18.4       21.0       23.7       26.6       29.7
  A(I)             30.4       30.8       32.0       32.0       33.5
  V(I)             6.23       6.14       5.90       5.91       5.65

X STA.        29.7       33.0       36.5       40.5       45.7       80.6
  A(I)             34.4       36.0       38.3       44.6       71.8
  V(I)             5.49       5.25       4.93       4.24       2.63
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       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
        CREATED ON 21-AUG-95 FOR BRIDGE WODSTH00190024 USING FILE brid027.dca
        HYDRAULIC ANALYSIS OF BRID027    SAO
           *** RUN DATE & TIME: 08-29-95  09:52
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     269.   25972.    11.    64.                       7553.
   499.08          269.   25972.    11.    64.  1.00     0.    29.   7553.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.08     0.0    29.5   268.5   25972.    3435.  12.79

X STA.         0.0        3.1        4.8        6.4        7.9        9.3
  A(I)            25.8       16.0       14.9       14.1       13.2
  V(I)            6.67      10.75      11.53      12.21      12.97

X STA.         9.3       10.7       12.0       13.4       14.8       16.1
  A(I)            13.2       13.1       12.8       12.7       12.8
  V(I)           12.97      13.11      13.37      13.49      13.43

X STA.        16.1       17.4       18.7       19.7       20.7       21.7
  A(I)            12.5       11.8        9.5        9.5        9.7
  V(I)           13.73      14.56      18.04      18.16      17.70

X STA.        21.7       22.7       23.8       25.1       26.5       29.5
  A(I)             9.8       10.5       11.3       12.9       22.4
  V(I)           17.58      16.37      15.23      13.28       7.66

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       7.
         WSEL     LEW     REW    AREA        K        Q    VEL
       502.54   -66.0    69.9   235.8   12943.    1482.   6.28

X STA.       -66.0      -46.1      -40.4      -35.9      -31.9      -28.2
  A(I)            17.4       11.4       10.4        9.4        9.1
  V(I)            4.27       6.47       7.10       7.87       8.18

X STA.       -28.2      -24.6      -21.0      -17.0      -13.2       -9.3
  A(I)             9.0        9.1       10.5       10.2       10.4
  V(I)            8.21       8.12       7.09       7.27       7.12

X STA.        -9.3       -5.6       -2.0        1.7        5.6       10.0
  A(I)            10.2       10.4       10.3       10.8       11.3
  V(I)            7.26       7.13       7.21       6.83       6.58

X STA.        10.0       14.9       20.8       27.8       37.7       69.9
  A(I)            11.8       12.8       13.4       15.8       22.2
  V(I)            6.30       5.78       5.52       4.70       3.35

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      39.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     131.    9266.    61.    62.                       1090.
             2     710.  104094.    71.    76.                      12776.
             3      34.    1561.    31.    31.                        205.
   502.60          876.  114921.   163.   169.  1.16   -74.    89.  10707.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      39.

         WSEL     LEW     REW    AREA        K        Q    VEL
       502.60   -74.4    89.0   876.1  114921.    4910.   5.60
X STA.       -74.4      -28.7       -7.6       -3.1        0.0        2.8
  A(I)            87.4       74.5       47.2       37.5       35.5
  V(I)            2.81       3.30       5.20       6.55       6.91

X STA.         2.8        5.5        8.0       10.5       13.1       15.6
  A(I)            34.4       33.3       32.8       33.2       32.8
  V(I)            7.13       7.37       7.48       7.40       7.49

X STA.        15.6       18.3       21.0       23.9       26.9       30.1
  A(I)            33.7       34.2       34.4       35.8       36.1
  V(I)            7.28       7.17       7.14       6.85       6.79

X STA.        30.1       33.5       37.2       41.4       47.2       89.0
  A(I)            37.9       39.6       42.1       49.5       84.0
  V(I)            6.48       6.20       5.83       4.96       2.92
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       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
       CREATED ON 21-AUG-95 FOR BRIDGE WODSTH00190024 USING FILE brid027.dca
       HYDRAULIC ANALYSIS OF BRID027    SAO
          *** RUN DATE & TIME: 08-29-95  09:52
   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     182.   18569.    29.    40.                       2598.
  495.91          182.   18569.    29.    40.  1.00     0.    29.   2598.

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      495.91     0.1    29.5   182.3   18569.    2590.  14.21

X STA.         0.1        3.0        4.6        5.9        7.1        8.3
  A(I)            17.4       10.3        8.9        8.2        8.2
  V(I)            7.45      12.60      14.49      15.81      15.88

X STA.         8.3        9.4       10.6       11.7       12.9       14.1
  A(I)             7.6        7.8        7.5        7.6        7.5
  V(I)           16.95      16.69      17.19      17.04      17.17

X STA.        14.1       15.3       16.4       17.6       18.9       20.1
  A(I)             7.6        7.6        7.7        7.9        7.8
  V(I)           17.11      17.11      16.92      16.38      16.63

X STA.        20.1       21.4       22.7       24.2       25.9       29.5
  A(I)             8.1        8.5        9.1       10.2       16.8
  V(I)           15.90      15.15      14.22      12.70       7.70

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      39.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            2     465.   53272.    67.    72.                       6943.
  499.11          465.   53272.    67.    72.  1.00   -12.    55.   6943.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      39.
        WSEL     LEW     REW    AREA        K        Q    VEL
      499.11   -12.4    55.0   465.5   53272.    2590.   5.56

X STA.       -12.4       -3.6       -0.8        1.6        3.8        5.9
  A(I)            38.6       24.5       21.9       20.5       20.0
  V(I)            3.36       5.29       5.90       6.31       6.47

X STA.         5.9        7.9        9.9       11.9       13.9       16.0
  A(I)            19.0       19.3       19.2       19.1       19.4
  V(I)            6.80       6.70       6.75       6.79       6.67

X STA.        16.0       18.2       20.4       22.7       25.2       27.9
  A(I)            19.5       19.8       20.5       20.8       21.8
  V(I)            6.64       6.55       6.31       6.22       5.94

X STA.        27.9       30.7       34.0       37.5       41.6       55.0
  A(I)            22.5       24.2       25.1       27.4       42.4
  V(I)            5.76       5.36       5.16       4.73       3.06

       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
       CREATED ON 21-AUG-95 FOR BRIDGE BRIDTH00490027 USING FILE brid027.dca
       HYDRAULIC ANALYSIS OF BRID027    SAO
          *** RUN DATE & TIME: 08-29-95  09:52

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

EXITX:XS   ******   -21.     431.  1.20 *****  498.92  495.78   3780.  497.72
      -34. ******    49.   46486.  1.00 ***** *******    0.62    8.77

FULLV:FV      34.   -21.     420.  1.26  0.23  499.19 *******   3780.  497.93
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        0.    34.    49.   44734.  1.00  0.03    0.01    0.65    9.01
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      39.   -11.     403.  1.37  0.29  499.53 *******   3780.  498.16
       39.    39.    53.   43284.  1.00  0.05   -0.01    0.66    9.38
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   501.85       0.00     497.71     499.67

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   497.20     500.81     500.94     499.00

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>


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

BRIDG:BR      34.     0.     271.  1.81 *****  501.27  496.42   2917.  499.46
        0. ******    30.   23608.  1.00 ***** *******    0.63   10.78

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.478  0.000  499.00 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       7.    27.  0.04  0.41  502.38    0.00    880.  501.93

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    691.    73.   -59.    14.   2.3   1.7   6.6   5.6   2.1   3.0
   RT:    189.    41.    14.    56.   1.7   0.9   5.2   5.2   1.3   3.0

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

APPRO:AS      18.   -68.     784.  0.41  0.09  502.42  496.45   3780.  502.01
       39.    19.    81.  100810.  1.13  0.42    0.00    0.39    4.82

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

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
        CREATED ON 21-AUG-95 FOR BRIDGE BRIDTH00490027 USING FILE brid027.dca
        HYDRAULIC ANALYSIS OF BRID027    SAO
           *** RUN DATE & TIME: 08-29-95  09:52
   FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -34.   -21.    49.   3780.   46486.     431.    8.77  497.72
   FULLV:FV       0.   -21.    49.   3780.   44734.     420.    9.01  497.93
   BRIDG:BR       0.     0.    30.   2917.   23608.     271.   10.78  499.46
   RDWAY:RG       7.*******   691.    880.*****************    2.00  501.93
   APPRO:AS      39.   -68.    81.   3780.  100810.     784.    4.82  502.01

  SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    495.78    0.62  488.61  520.38************  1.20  498.92  497.72
   FULLV:FV  ********    0.65  488.98  520.75  0.23  0.03  1.26  499.19  497.93
   BRIDG:BR    496.42    0.63  488.98  499.46************  1.81  501.27  499.46
   RDWAY:RG  ****************  499.67  515.76  0.04******  0.41  502.38  501.93
   APPRO:AS    496.45    0.39  489.39  515.76  0.09  0.42  0.41  502.42  502.01

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL
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 EXITX:XS   ******   -83.     529.  1.40 *****  500.28  496.79   4910.  498.89
      -34. ******    52.   60381.  1.04 ***** *******    0.84    9.28

  ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.82     499.08     497.16

  ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   498.39     520.75    0.50

  ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   498.39     520.75     497.16

 FULLV:FV      34.   -62.     505.  1.49  0.23  500.56  497.16   4910.  499.08
        0.    34.    51.   57803.  1.01  0.05    0.00    0.82    9.72
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS      39.   -13.     477.  1.65  0.29  500.93 *******   4910.  499.28
       39.    39.    55.   55212.  1.00  0.08   -0.01    0.68   10.29
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>







 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   499.08     499.00

            <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

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

 BRIDG:BR      34.     0.     268.  2.55 *****  501.62  497.20   3435.  499.08
        0. ******    29.   25993.  1.00 ***** *******    0.75   12.79

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   6.  0.800  0.000  499.00 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
    RDWAY:RG       7.    27.  0.05  0.57  503.11    0.00   1482.  502.54

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
    LT:   1117.    82.   -66.    16.   2.9   2.1   7.6   6.4   2.7   3.1
    RT:    364.    54.    16.    70.   2.2   1.1   5.9   5.9   1.7   3.0

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

 APPRO:AS      18.   -74.     875.  0.57  0.11  503.16  497.48   4910.  502.60
       39.    19.    89.  114813.  1.16  0.42    0.00    0.46    5.61

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

                      <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
 WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
 V090192           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

         U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
         CREATED ON 21-AUG-95 FOR BRIDGE BRIDTH00490027 USING FILE brid027.dca
         HYDRAULIC ANALYSIS OF BRID027    SAO
            *** RUN DATE & TIME: 08-29-95  09:52
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -34.   -83.    52.   4910.   60381.     529.    9.28  498.89
    FULLV:FV       0.   -62.    51.   4910.   57803.     505.    9.72  499.08
    BRIDG:BR       0.     0.    29.   3435.   25993.     268.   12.79  499.08
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   RDWAY:RG       7.*******  1117.   1482.******************    2.00  502.54
   APPRO:AS      39.   -74.    89.   4910.  114813.     875.    5.61  502.60

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    496.79    0.84  488.61  520.38************  1.40  500.28  498.89
   FULLV:FV    497.16    0.82  488.98  520.75  0.23  0.05  1.49  500.56  499.08
   BRIDG:BR    497.20    0.75  488.98  499.46************  2.55  501.62  499.08
   RDWAY:RG  ****************  499.67  515.76  0.05******  0.57  503.11  502.54
   APPRO:AS    497.48    0.46  489.39  515.76  0.11  0.42  0.57  503.16  502.60

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

EXITX:XS   ******   -19.     331.  0.95 *****  497.18  494.57   2590.  496.23
      -34. ******    46.   31878.  1.00 ***** *******    0.61    7.82

FULLV:FV      34.   -18.     321.  1.01  0.24  497.46 *******   2590.  496.44
        0.    34.    45.   30437.  1.00  0.03    0.01    0.63    8.07
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS      39.   -10.     313.  1.07  0.29  497.78 *******   2590.  496.71
       39.    39.    50.   29981.  1.00  0.03    0.01    0.64    8.28
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"     Q,CRWS =     2590.     495.91

           <<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

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

BRIDG:BR      34.     0.     182.  3.14 *****  499.05  495.91   2590.  495.91
        0.    34.    29.   18550.  1.00 ***** *******    1.00   14.22

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  499.00 ****** ****** ******



    XSID:CODE    SRD   FLEN    HF   VHD      EGL     ERR       Q    WSEL
   RDWAY:RG       7.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      18.   -12.     465.  0.48  0.13  499.59  495.21   2590.  499.11
       39.    19.    55.   53271.  1.00  0.41    0.00    0.37    5.56

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.510  0.289   37862.     1.    30.   499.05

                   <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V090192            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid027.wsp
        CREATED ON 21-AUG-95 FOR BRIDGE BRIDTH00490027 USING FILE brid027.dca
        HYDRAULIC ANALYSIS OF BRID027    SAO
           *** RUN DATE & TIME: 08-29-95  09:52
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -34.   -19.    46.   2590.   31878.     331.    7.82  496.23
   FULLV:FV       0.   -18.    45.   2590.   30437.     321.    8.07  496.44
   BRIDG:BR       0.     0.    29.   2590.   18550.     182.   14.22  495.91
   RDWAY:RG       7.**************      0.******************    2.00********
   APPRO:AS      39.   -12.    55.   2590.   53271.     465.    5.56  499.11

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       1.    30.   37862.

 SECOND USER DEFINED TABLE.
```
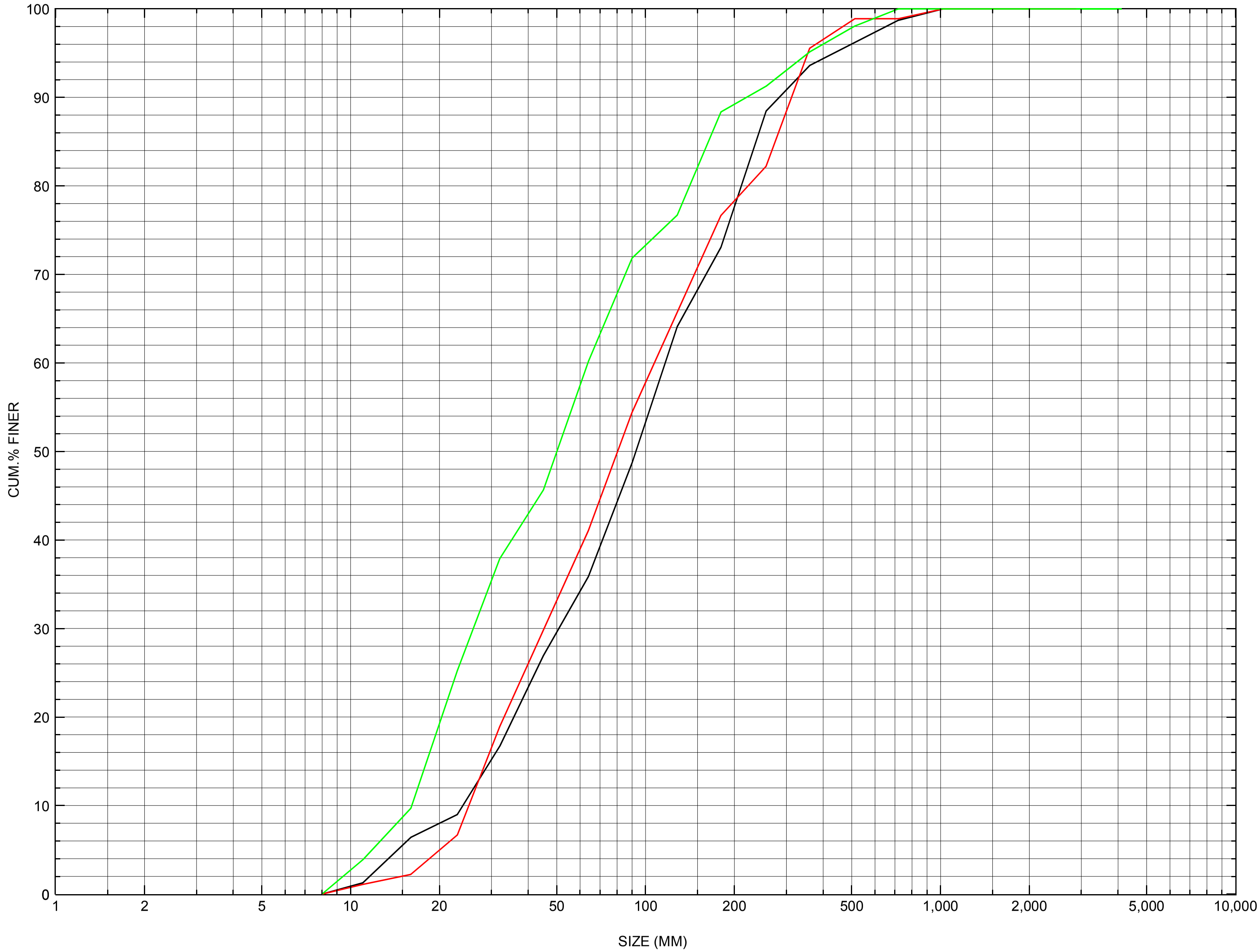

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure WODSTH00190024, in Woodstock, Vermont.

APPENDIX D:

HISTORICAL DATA FORM