LEVEL II SCOUR ANALYSIS FOR BRIDGE 30 (ALBATH00250030) on TOWN HIGHWAY 25, crossing the BLACK RIVER, ALBANY, VERMONT

U.S. Geological Survey
Open-File Report 96-194

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

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By Erick M. Boehmler and R. Hammond

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Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

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

OTHER ABBREVIATIONS

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

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

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

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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 30 (ALBATH00250030) ON TOWN HIGHWAY 25, CROSSING THE BLACK RIVER, ALBANY, VERMONT

***By* Erick M. Boehmler and R. Hammond**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure ALBATH00250030 on town highway 25 crossing the Black River, Albany, 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 were compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the New England Upland physiographic province of north-central Vermont in the town of Albany. The 58.8-mi^2 drainage area is in a rural, forested basin. In the vicinity of the study site, the banks have predominantly grass vegetation coverage with a few shrubs.

In the study area, the Black River has a non-incised, highly meandering channel with a slope of approximately 0.0005 ft/ft, an average channel top width of 56 ft and an average channel depth of 4 ft. The predominant channel bed material is fine sand (D_{50} is 1.68 mm or 0.00551 ft). The geomorphic assessment at the time of the Level I and Level II site visit on June 5, 1995, indicated that the reach was laterally unstable.

The town highway 25 crossing of the Black River is a 42-ft-long, one-lane bridge consisting of one 40-foot span steel-beam superstructure with a timber deck (Vermont Agency of Transportation, written commun., August 3, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is not skewed to the opening and the opening-skew-to-roadway is zero degrees.

A scour hole 0.5 ft deeper than the mean thalweg depth was observed along mid-channel from 40 feet upstream to about 10 feet under the bridge during the Level I assessment. The left abutment is slightly undermined at the downstream end. The only scour protection measures at the site were sparse type-1 stone fill (less than 12 inches diameter) on the upstream right road embankment, along the left and right abutments, and along the upstream left wingwall. 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.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

NORTH

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

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

LEVEL II SUMMARY

Structure Number ALBATH00250030 ***Stream*** Black River

County Orleans ***Road*** TH025 ***District*** 09

Description of Bridge

Bridge length 42 ***ft*** ***Bridge width*** 13.8 ***ft*** ***Max span length*** 40 ***ft***

Alignment of bridge to road (on curve or straight) Left, Straight; Right, Curve

Abutment type Vertical ***Embankment type*** Sloping

Stone fill on abutment? Yes ***Date of inspection*** 6/5/94

Description of stone fill Type-1 is sparse along the upstream end of the left and entire length of the right abutment walls, and around the corner of the left abutment and its upstream left wingwall. The fill on the left abutment has slumped.

Brief description of piers/abutments Abutments and wingwalls are concrete.

Is bridge skewed to flood flow according to N ***survey?*** N ***Angle*** 0

The more severe channel bends are further upstream and downstream in the reach than two bridge lengths.

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	6/5/94	0	0
Level II	6/5/94	--	--

Potential for debris Moderate. There is mainly shrubs and grass on the immediate banks of this highly meandering and laterally unstable channel.

Describe any features near or at the bridge that may affect flow (include observation date) Some wetland areas were observed on the overbank areas on 6/5/94.

Description of the Geomorphic Setting

General topography The channel is located within a 510 foot-wide, highly irregular flood plain with moderately sloped valley walls on both sides.

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

Date of inspection 6/5/95

DS left: Steep channel bank and minor levee to a narrow flood plain.

DS right: Steep channel bank and minor levee to wide, irregular flood plain.

US left: Steep channel bank and minor levee to a narrow flood plain.

US right: Steep channel bank and minor levee to a wide, irregular flood plain.

Description of the Channel

Average top width 56 ***ft*** ***Average depth*** 4 ***ft***

Predominant bed material Fine Sand ***Bank material*** Fine Sand

Highly meandering, with alluvial boundaries, natural levees, and a wide, irregular, flood plain.

6/5/95

Vegetative co

Grass

DS left: Grass and shrubs

DS right: Grass and shrubs

US left: Grass

US right: N

Do banks appear stable? Cut-banks with block failure of bank material were evident on the upstream and downstream left bank and the downstream right bank. Heavy fluvial erosion was noted on both banks through the reach near this site on 6/5/95.

date of observation.

None as of 6/5/95.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 58.8 ***mi***^{2}

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	***Percent of drainage area***
New England Upland	100

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

Is there a USGS gage on the stream of interest? Yes

USGS gage description Black River at Coventry, VT

USGS gage number 04295500

Gage drainage area 122. ***mi***^{2}

Is there a lake/ No

Calculated Discharges

Q100 2,900 ***ft***^{3}***/s*** ***Q500*** 3,930 ***ft***^{3}***/s***

The 100- and 500-year discharges are based on a drainage area relationship [(58.8/122.)exp 0.5] with the gaged area above Coventry, VT. The exponent in the drainage relationship was computed based on gaged records and VTAOT database values at bridge 23 in Craftsbury of the Q100. The drainage area used above bridge number 23 is 30.9 square miles.

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 None

Description of reference marks used to determine USGS datum. RM1 is a chiseled "X" on top of the DS end of the left abutment (elev. 501.87 ft, arbitrary datum). RM2 is a chiseled "X" on top of the US end of the right abutment (elev. 501.79 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-37	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	8	1	Road Grade section
APPRO	55	2	Modelled Approach section (Templated from APTEM)
APTEM	60	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 0.030 to 0.040, and overbank "n" values ranged from 0.035 to 0.045.

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 0.0005 ft/ft which was estimated from the topographic map (U.S. Geological Survey, 1986a&b) and surveyed channel points downstream of the site.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.024 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.

A culvert that passes through the right road embankment will take some flood plain flow. However, efforts to model the culvert flow as another bridge opening showed the culvert would convey less than five percent of the total flow. Hence, the culvert conveyance was assumed to be insignificant and was not considered in the model from which scour was computed.

The modeled 100-year discharge only overtops the left roadway embankment, while the 500-year discharge overtops both roadway embankments and bridge deck.

Bridge Hydraulics Summary

Average bridge embankment elevation 502.4 *ft*
Average low steel elevation 500.4 *ft*

100-year discharge 2,900 *ft³/s*
Water-surface elevation in bridge opening 500.4 *ft*
Road overtopping? Y *Discharge over road* 34 *ft³/s*
Area of flow in bridge opening 386 *ft²*
Average velocity in bridge opening 7.4 *ft/s*
Maximum WSPRO tube velocity at bridge 8.7 *ft/s*

Water-surface elevation at Approach section with bridge 501.9
Water-surface elevation at Approach section without bridge 500.6
Amount of backwater caused by bridge 1.3 *ft*

500-year discharge 3,930 *ft³/s*
Water-surface elevation in bridge opening 501.4 *ft*
Road overtopping? Y *Discharge over road* 736 *ft³/s*
Area of flow in bridge opening 386 *ft²*
Average velocity in bridge opening 8.2 *ft/s*
Maximum WSPRO tube velocity at bridge 9.7 *ft/s*

Water-surface elevation at Approach section with bridge 503.0
Water-surface elevation at Approach section without bridge 501.3
Amount of backwater caused by bridge 1.7

Incipient overtopping discharge 2,621 *ft³/s*
Water-surface elevation in bridge opening 500.1 *ft*
Area of flow in bridge opening 375 *ft²*
Average velocity in bridge opening 7.0 *ft/s*
Maximum WSPRO tube velocity at bridge 8.7 *ft/s*

Water-surface elevation at Approach section with bridge 501.1
Water-surface elevation at Approach section without bridge 500.4
Amount of backwater caused by bridge 0.7 *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 and 500-year discharges resulted in submerged orifice flow and contraction scour was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Contraction scour was computed by use of the live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16) for the incipient road-overflow discharge. 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. In this case, the 500-year discharge model resulted in the worst case contraction scour with a scour depth of 18.6 ft.

Abutment scour for the left abutment 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.

Abutment scour at the right abutment was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. Variables for the HIRE abutment scour equation are defined the same as those defined for the Froehlich abutment scour equation.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	6.3
Clear-water scour	16.3	18.6	--
Depth to armoring	N/A	N/A	N/A
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	10.4	10.6	10.3
Right abutment	8.3	10.5	6.2
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	1.1	1.3	1.2
Right abutment	1.1	1.3	1.2
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

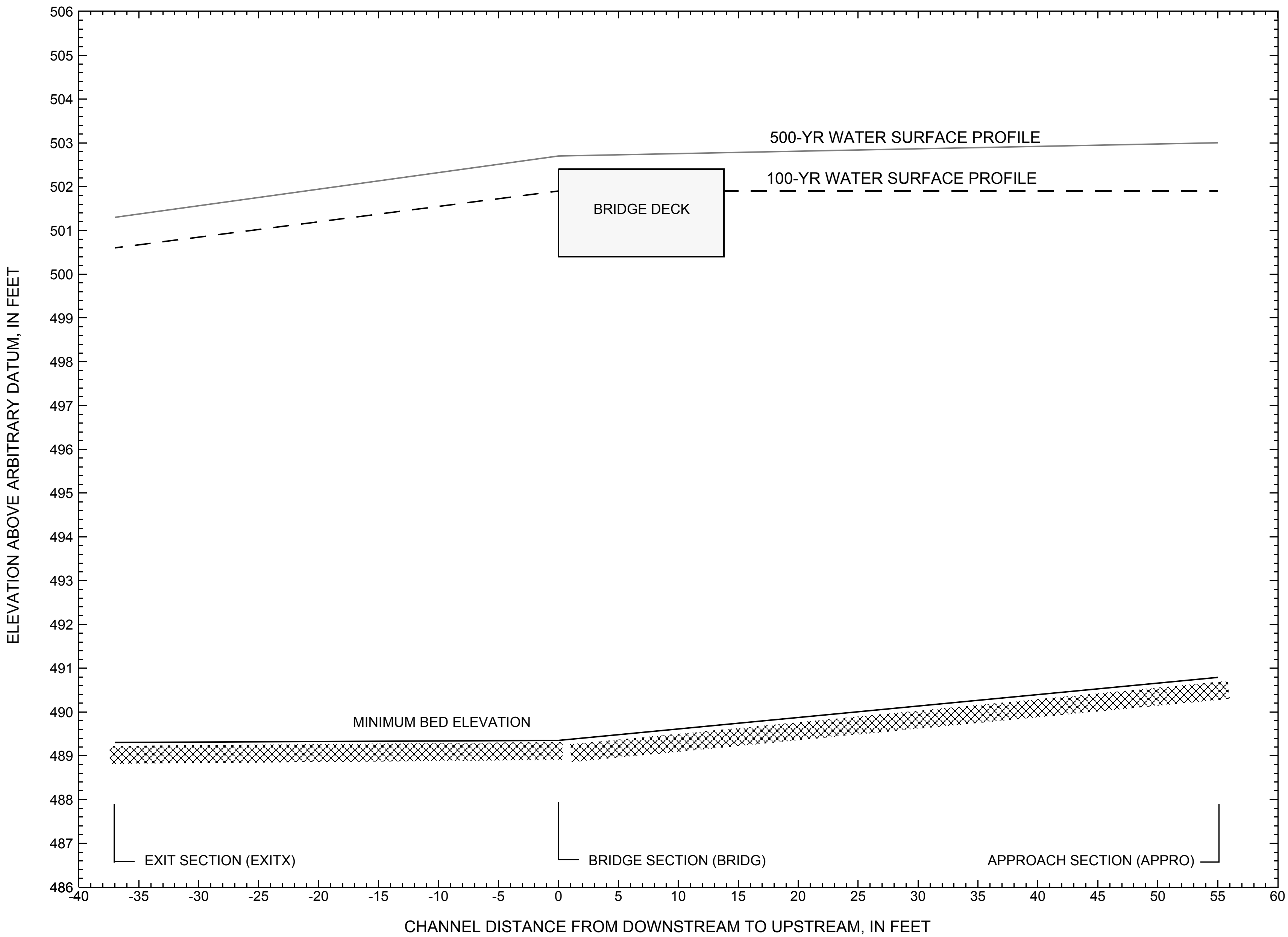

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure ALBATH00250030 on town highway 25, crossing the Black River, Albany, Vermont.

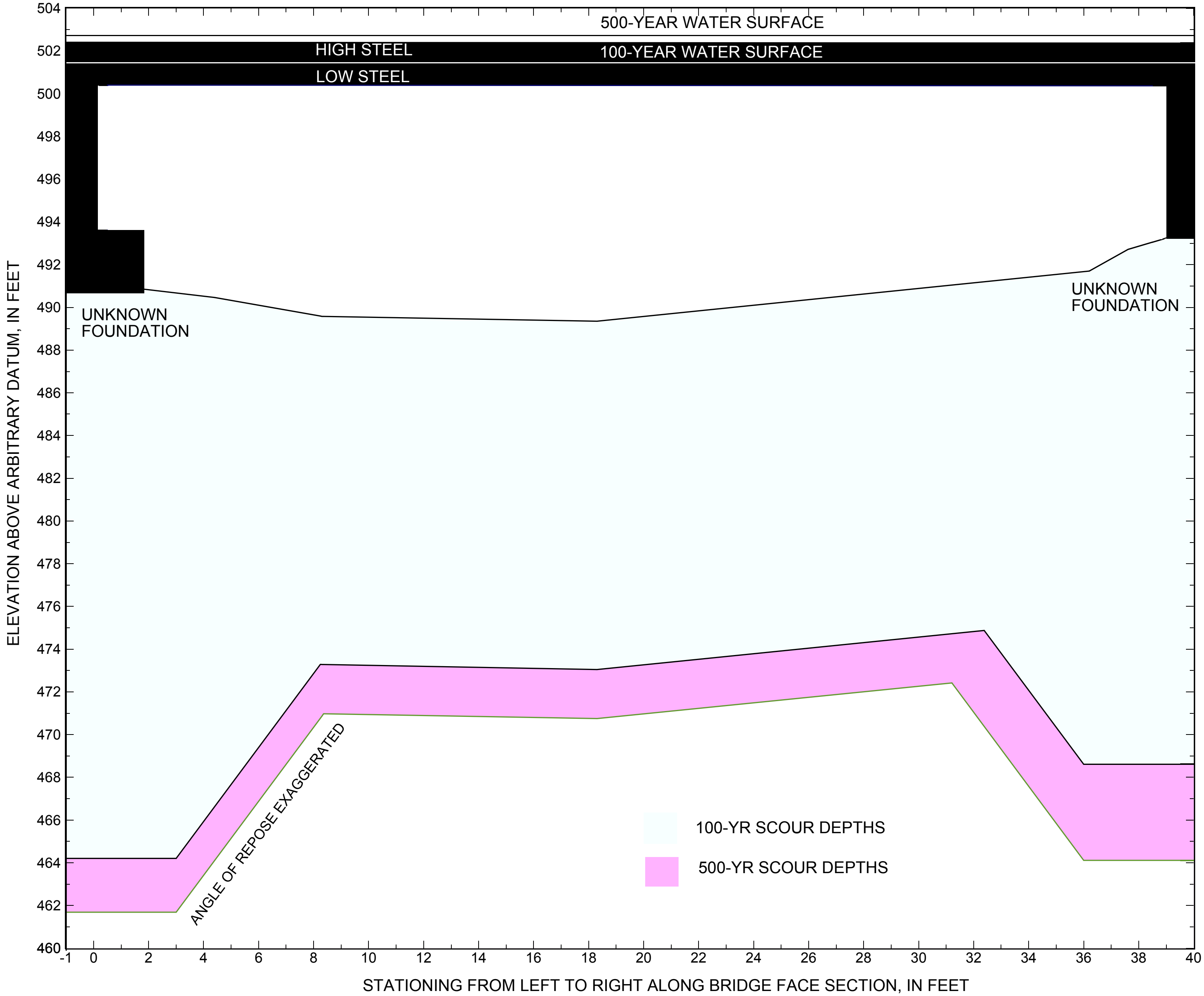

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure ALBATH00250030 on town highway 25, crossing the Black River, Albany, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure ALBATH00250030 on Town Highway 25, crossing the Black River, Albany, 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 2,900 cubic-feet per second											
Left abutment	0.0	--	500.4	--	490.9	16.3	10.4	--	26.7	464.2	--
Right abutment	39.0	--	500.4	--	493.2	16.3	8.3	--	24.6	468.6	--

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 ALBATH00250030 on Town Highway 25, crossing the Black River, Albany, 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 3,930 cubic-feet per second											
Left abutment	0.0	--	500.4	--	490.9	18.6	10.6	--	29.2	461.7	--
Right abutment	39.0	--	500.4	--	493.2	18.6	10.5	--	29.1	464.1	--

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, 1986, Craftsbury, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photos taken, 1980, Field Checked, 1982, Scale 1:24,000, Contour Interval, 6 meters.

U.S. Geological Survey, 1986, Irasburg, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photos taken, 1981, Field Checked, 1982, Scale 1:24,000, Contour Interval, 6 meters.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File alba030.wsp
T2        Hydraulic analysis for structure ALBATH00250030   Date: 25-JAN-96
T3        Town Highway 25 Bridge Crossing the Black River, Albany, VT     EMB
Q           2900.0,   3930.0,  2621.0
SK          0.0005,   0.0005,  0.0005
*
J3          6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
XS   EXITX    -37     0.
GR         -135.0, 504.45   -100.1, 499.99    -75.8, 499.49     -8.8, 499.77
GR           -3.1, 499.15      0.0, 493.54      8.5, 489.70     12.9, 489.30
GR           21.3, 490.30     30.2, 490.39     30.2, 490.38     34.6, 489.96
GR           40.3, 493.38     44.3, 497.60     51.7, 499.88     75.0, 499.61
GR          136.3, 498.45    226.3, 498.14    268.7, 497.44    323.0, 497.88
GR          406.7, 497.05    455.3, 497.61    471.4, 504.35
*
N           0.035        0.040        0.045
SA                  -3.1          51.7
*
XS   FULLV      0  * * *   0.0012
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0     500.4       0.0
GR            0.0, 500.41      0.0, 493.36      0.5, 493.50      1.3, 493.30
GR            1.7, 490.87      4.4, 490.46      8.3, 489.58     18.3, 489.35
GR           27.3, 490.49     36.2, 491.70     37.6, 492.71     38.8, 493.24
GR           38.9, 493.46     39.0, 500.35      0.0, 500.41
*
*         BRTYPE  BRWDTH       WWANGL    WWWID
CD          1      21.5 * *     38.8      6.8
N           0.030
*
*             SRD    EMBWID   IPAVE
XR   RDWAY      8       13.8     2
GR         -128.7, 503.77    -73.3, 501.97    -42.2, 501.28      0.0, 502.45
GR           41.3, 502.32    113.7, 502.05    248.7, 502.62    308.6, 503.39
GR          391.7, 504.32    451.3, 506.07
*
XT   APTEM     60           0.
GR          -76.4, 502.35    -51.1, 499.29    -25.3, 499.54    -17.2, 498.48
GR           -9.9, 497.40     -8.2, 495.40      0.0, 491.69     12.5, 490.79
GR           31.8, 493.48     38.6, 493.33     45.2, 497.24     47.6, 497.87
GR           58.1, 499.25    130.1, 499.80    226.7, 499.62    276.8, 498.96
GR          304.1, 498.64    342.3, 498.65    455.3, 500.00    471.0, 504.00
*
AS   APPRO     55 * * * 0.0242
GT
N           0.035        0.040        0.045
SA                 -17.2          45.2
*
HP 1 BRIDG   500.41 1 500.41
HP 2 BRIDG   500.41 * * 2868
HP 2 RDWAY   501.87 * *   34
HP 1 APPRO   501.94 1 501.94
HP 2 APPRO   501.94 * * 2900
*
HP 1 BRIDG   500.41 1 500.41
HP 2 BRIDG   500.41 * * 3183
HP 2 RDWAY   502.72 * *  736
HP 1 APPRO   502.95 1 502.95
HP 2 APPRO   502.95 * * 3930
*
HP 1 BRIDG   500.10 1 500.10
HP 2 BRIDG   500.10 * * 2621
HP 1 APPRO   501.07 1 501.07
HP 2 APPRO   501.07 * * 2621
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
   HP 1 BRIDG   500.41 1 500.41
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      386     48948      0     95                           0
    500.41           386     48948      0     95  1.00      0     39        0
1
   HP 2 BRIDG   500.41 * * 2868
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        500.41     0.0    39.0   386.3   48948.    2868.   7.42

 X STA.         0.0        3.8        5.9        7.7        9.4       11.0
   A(I)            32.5       21.5       18.7       18.4       17.1
   V(I)            4.41       6.67       7.68       7.80       8.36

 X STA.        11.0       12.5       14.1       15.6       17.1       18.6
   A(I)            16.8       17.1       16.6       16.4       16.5
   V(I)            8.52       8.40       8.66       8.73       8.71

 X STA.        18.6       20.1       21.7       23.3       25.0       26.7
   A(I)            16.6       16.8       17.0       17.5       17.3
   V(I)            8.65       8.54       8.44       8.19       8.31

 X STA.        26.7       28.6       30.6       32.7       35.0       39.0
   A(I)            18.4       18.8       20.0       20.7       31.7
   V(I)            7.78       7.64       7.18       6.92       4.53
1
   HP 2 RDWAY   501.87 * *   34
     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.

          WSEL     LEW     REW    AREA        K        Q    VEL
        501.87   -68.8   -20.9    14.1     266.      34.   2.41

 X STA.       -68.8      -57.8      -54.5      -52.3      -50.4      -48.9
   A(I)             1.3        0.9        0.8        0.7        0.6
   V(I)            1.27       1.83       2.21       2.39       2.64

 X STA.       -48.9      -47.5      -46.3      -45.2      -44.2      -43.2
   A(I)             0.6        0.6        0.6        0.5        0.5
   V(I)            2.75       2.88       2.98       3.10       3.17

 X STA.       -43.2      -42.3      -41.4      -40.4      -39.3      -38.1
   A(I)             0.5        0.5        0.5        0.6        0.6
   V(I)            3.21       3.20       3.09       3.05       2.89

 X STA.       -38.1      -36.8      -35.2      -33.2      -30.5      -20.9
   A(I)             0.6        0.7        0.7        0.8        1.3
   V(I)            2.73       2.60       2.32       2.05       1.34
1
   HP 1 APPRO   501.94 1 501.94
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      55.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      125      8944     57     57                        1049
              2      540     82081     62     65                        9013
              3     1133     72870    418    419                       10584
    501.94          1798    163895    537    541  1.65    -73    463    14537
1
   HP 2 APPRO   501.94 * * 2900
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      55.
          WSEL     LEW     REW    AREA        K        Q    VEL
        501.94   -74.0   463.4  1797.8  163895.    2900.   1.61

 X STA.       -74.0      -19.2       -4.0        1.6        6.3       10.6
   A(I)           117.9       78.8       54.3       49.6       47.9
   V(I)            1.23       1.84       2.67       2.92       3.03

 X STA.        10.6       14.8       19.2       24.1       29.5       35.7
   A(I)            46.9       46.7       48.8       50.2       53.2
   V(I)            3.09       3.10       2.97       2.89       2.72

 X STA.        35.7       43.5       79.2      135.3      197.0      250.8
   A(I)            61.1      114.3      136.6      143.8      134.3
   V(I)            2.37       1.27       1.06       1.01       1.08
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 X STA.       250.8      290.7      323.3      357.2      398.2      463.4
   A(I)            120.2      110.3      114.4      122.7      145.4
   V(I)             1.21       1.31       1.27       1.18       1.00
1
   HP 1 BRIDG   500.41 1 500.41
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      386     48948      0     95                            0
    500.41           386     48948      0     95  1.00      0     39        0
1
   HP 2 BRIDG   500.41 * * 3183
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        500.41     0.0    39.0   386.3   48948.    3183.   8.24

 X STA.         0.0        3.8        5.9        7.7        9.4       11.0
   A(I)             32.5       21.5       18.7       18.4       17.1
   V(I)             4.89       7.40       8.52       8.66       9.28

 X STA.        11.0       12.5       14.1       15.6       17.1       18.6
   A(I)             16.8       17.1       16.6       16.4       16.5
   V(I)             9.46       9.32       9.61       9.69       9.67

 X STA.        18.6       20.1       21.7       23.3       25.0       26.7
   A(I)             16.6       16.8       17.0       17.5       17.3
   V(I)             9.60       9.48       9.37       9.09       9.22

 X STA.        26.7       28.6       30.6       32.7       35.0       39.0
   A(I)             18.4       18.8       20.0       20.7       31.7
   V(I)             8.63       8.47       7.97       7.68       5.02
1
   HP 2 RDWAY   502.72 * *  736
     VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =       8.

          WSEL     LEW     REW    AREA        K        Q    VEL
        502.72   -96.4   256.5   183.7    4909.     736.   4.01

 X STA.       -96.4      -70.7      -62.6      -56.5      -51.5      -47.1
   A(I)             10.7        7.3        6.4        6.0        5.6
   V(I)             3.44       5.07       5.76       6.17       6.62

 X STA.       -47.1      -43.3      -39.7      -35.7      -31.1      -25.7
   A(I)              5.3        5.1        5.3        5.4        5.8
   V(I)             6.94       7.28       6.99       6.76       6.34


 X STA.       -25.7      -18.4       -1.1       39.9       67.6       89.2
   A(I)              6.4        9.3       13.6       12.4       11.6
   V(I)             5.73       3.95       2.71       2.98       3.18

 X STA.        89.2      106.7      123.7      145.0      173.8      256.5
   A(I)             10.7       11.0       12.4       13.8       19.7
   V(I)             3.42       3.34       2.96       2.68       1.87
1
   HP 1 APPRO   502.95 1 502.95
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      55.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      184     16527     59     60                         1843
              2      603     98662     62     65                        10636
              3     1558    123022    422    423                        16976
    502.95          2345    238212    544    548  1.44    -75    467    23019
1
   HP 2 APPRO   502.95 * * 3930
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      55.

          WSEL     LEW     REW    AREA        K        Q    VEL
        502.95   -76.4   467.4  2344.7  238212.    3930.   1.68

 X STA.       -76.4      -28.6       -6.1        1.4        7.1       12.4
   A(I)            139.5      110.4       76.7       66.9       63.8
   V(I)             1.41       1.78       2.56       2.94       3.08
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 X STA.        12.4       17.7       23.6       30.3       37.6       53.7
   A(I)             63.6       65.8       68.8       70.7      103.5
   V(I)             3.09       2.98       2.86       2.78       1.90

 X STA.        53.7       93.9      140.8      189.7      236.0      274.9
   A(I)            149.9      158.8      163.1      159.0      148.9
   V(I)             1.31       1.24       1.20       1.24       1.32

 X STA.       274.9      306.5      337.5      370.3      409.2      467.4
   A(I)            135.0      137.4      140.2      149.9      172.8
   V(I)             1.46       1.43       1.40       1.31       1.14
1
   *
   HP 1 BRIDG   500.10 1 500.10
     CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1      375     66884     39     55                          6609
    500.10           375     66884     39     55  1.00      0     39     6609
1
   HP 2 BRIDG   500.10 * * 2621
     VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

          WSEL     LEW     REW    AREA        K        Q    VEL
        500.10     0.0    39.0   375.4   66884.    2621.   6.98

 X STA.         0.0        4.3        6.5        8.3       10.0       11.6
   A(I)             36.0       22.4       18.8       17.2       16.7
   V(I)             3.64       5.86       6.98       7.63       7.83

 X STA.        11.6       13.0       14.5       15.9       17.4       18.8
   A(I)             15.6       15.8       15.3       15.2       15.2
   V(I)             8.42       8.30       8.55       8.63       8.61

 X STA.        18.8       20.2       21.7       23.2       24.8       26.4
   A(I)             15.1       15.3       15.5       16.0       16.5
   V(I)             8.69       8.57       8.47       8.20       7.95

 X STA.        26.4       28.2       30.1       32.2       34.6       39.0
   A(I)             17.0       17.3       19.0       21.1       34.4
   V(I)             7.71       7.55       6.89       6.20       3.80
1
   HP 1 APPRO   501.07 1 501.07
     CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      55.

      WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
              1       78      4519     50     50                           560
              2      486     68793     62     65                          7689
              3      771     38556    415    415                          5962
    501.07          1335    111868    527    530  1.90    -66    460     8751
1
   HP 2 APPRO   501.07 * * 2621
     VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      55.

          WSEL     LEW     REW    AREA        K        Q    VEL
        501.07   -66.8   460.0  1334.9  111868.    2621.   1.96

 X STA.       -66.8      -12.6       -2.9        1.5        5.3        8.9
   A(I)             92.4       55.1       40.3       36.7       35.5
   V(I)             1.42       2.38       3.25       3.57       3.69

 X STA.         8.9       12.1       15.5       19.0       22.8       26.9
   A(I)             33.3       34.3       34.0       35.1       36.2
   V(I)             3.93       3.82       3.85       3.73       3.62

 X STA.        26.9       31.7       36.7       43.4       88.8      179.2
   A(I)             38.1       39.1       45.7      100.6      134.5
   V(I)             3.44       3.36       2.87       1.30       0.97

 X STA.       179.2      256.2      301.2      337.7      380.5      460.0
   A(I)            124.7      101.1       92.7      100.1      125.4
   V(I)             1.05       1.30       1.41       1.31       1.05
1
   *
   EX
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WSPRO OUTPUT FILE (continued)

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+++ BEGINNING PROFILE CALCULATIONS --   3

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

EXITX:XS   ******   -104     1575  0.09 *****  500.68  496.06    2900  500.59
       -36 ******    462   129690  1.67 ***** *******    0.25    1.84

FULLV:FV       37   -104     1561  0.09  0.02  500.70 *******    2900  500.61
         0     37    462   128163  1.68  0.00    0.00    0.26    1.86
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                              "APPRO"     KRATIO =  0.68

APPRO:AS       55    -62     1069  0.23  0.04  500.80 *******    2900  500.56
        55     55    458    86868  2.04  0.07   -0.02    0.48    2.71
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                         WS3N,LSEL =   500.61     500.40

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

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

BRIDG:BR       37      0      386  0.86 *****  501.27  495.98    2868  500.41
         0 ******     39    48948  1.00 ***** *******    0.42    7.42

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000  500.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.    41.  0.01  0.07  501.99    0.00     34.  501.87

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:     34.    48.   -69.   -21.   0.6   0.3   2.6   2.4   0.4   2.6
   RT:      0.    36.    95.   130.   0.1   0.0   1.7   6.7   0.2   2.6

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

APPRO:AS       34    -73     1797  0.07  0.06  502.01  497.09    2900  501.94
        55     55    463   163822  1.65  0.00    0.00    0.20    1.61

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

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -37.  -105.   462.   2900.  129690.    1575.    1.84  500.59
   FULLV:FV       0.  -105.   462.   2900.  128163.    1561.    1.86  500.61
   BRIDG:BR       0.     0.    39.   2868.   48948.     386.    7.42  500.41
   RDWAY:RG       8.*******    34.     34.*********       0.    2.00  501.87
   APPRO:AS      55.   -74.   463.   2900.  163822.    1797.    1.61  501.94

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS  ***********************
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    496.06    0.25  489.30  504.45************  0.09  500.68  500.59
   FULLV:FV  ********    0.26  489.34  504.49  0.02  0.00  0.09  500.70  500.61
   BRIDG:BR    495.98    0.42  489.35  500.41************  0.86  501.27  500.41
   RDWAY:RG  ****************  501.28  506.07  0.01******  0.07  501.99  501.87
   APPRO:AS    497.09    0.20  490.67  503.88  0.06  0.00  0.07  502.01  501.94
1

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

EXITX:XS   ******   -109     1969  0.09 *****  501.37  498.87    3930  501.28
       -36 ******    464   175615  1.49 ***** *******    0.23    2.00
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 FULLV:FV       37   -109     1955  0.09  0.02  501.40 *******    3930  501.30
         0     37    464   173875  1.49  0.00    0.00    0.23    2.01
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 APPRO:AS       55    -67     1441  0.21  0.04  501.48 *******    3930  501.27
        55     55    461   122847  1.84  0.06   -0.01    0.40    2.73
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                        WS3N,LSEL =   501.30     500.40

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

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

 BRIDG:BR       37      0      386  1.06 *****  501.47  496.39    3183  500.41
         0 ******     39    48948  1.00 ***** *******    0.46    8.24

      TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   6.  0.800  0.000  500.40 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
    RDWAY:RG       8.    41.  0.01  0.06  503.00    0.00    736.  502.72

              Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
    LT:    349.   115.   -96.    19.   1.4   0.7   4.5   4.2   1.0   3.0
    RT:    387.   238.    19.   256.   0.7   0.4   3.5   3.9   0.7   2.8

 ===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                             WSEL,YLT,YRT =   502.95      502.2      503.9

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

 APPRO:AS       34    -75     2346  0.06  0.07  503.02  498.30    3930  502.95
        55     61    467   238462  1.44  0.00    0.00    0.17    1.67

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

                       <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
   FIRST USER DEFINED TABLE.

     XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
    EXITX:XS     -37.  -110.   464.   3930.  175615.    1969.    2.00  501.28
    FULLV:FV       0.  -110.   464.   3930.  173875.    1955.    2.01  501.30
    BRIDG:BR       0.     0.    39.   3183.   48948.     386.    8.24  500.41
    RDWAY:RG       8.*******   349.    736.*****************    2.00  502.72
    APPRO:AS      55.   -76.   467.   3930.  238462.    2346.    1.67  502.95

     XSID:CODE   XLKQ   XRKQ       KQ
    APPRO:AS  ***********************
1
  SECOND USER DEFINED TABLE.

     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
    EXITX:XS    498.87    0.23  489.30  504.45************  0.09  501.37  501.28
    FULLV:FV  ********    0.23  489.34  504.49  0.02  0.00  0.09  501.40  501.30
    BRIDG:BR    496.39    0.46  489.35  500.41************  1.06  501.47  500.41
    RDWAY:RG  ****************  501.28  506.07  0.01******  0.06  503.00  502.72
    APPRO:AS    498.30    0.17  490.67  503.88  0.07  0.00  0.06  503.02  502.95
1

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

 EXITX:XS   ******   -102     1455  0.09 *****  500.47  495.70    2621  500.38
       -36 ******    462   117165  1.74 ***** *******    0.26    1.80

 FULLV:FV       37   -102     1441  0.09  0.02  500.49 *******    2621  500.40
         0     37    462   115726  1.74  0.00    0.00    0.27    1.82
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
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 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                          "APPRO"     KRATIO =  0.67

APPRO:AS       55    -60      957  0.24  0.04  500.59 *******    2621  500.35
        55     55    457    77468  2.08  0.08   -0.02    0.51    2.74
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   500.10     501.01     501.07     500.40

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

 ===250 INSUFFICIENT HEAD FOR PRESSURE FLOW.
                       YU/Z,WSIU,WS = 1.09     501.26     501.32

 ===270 REJECTED 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       37      0      375  0.99  0.04  501.09  495.68    2621  500.10
         0     37     39    66834  1.31  0.58    0.00    0.45    6.99

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  0.873 ******  500.40 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG       8.        <<<<<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       34    -66     1334  0.11  0.06  501.18  496.80    2621  501.07
        55     53    460   111805  1.90  0.03    0.00    0.30    1.96

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.925  0.513   54479.     3.    42.   501.05

                       <<<<<END OF BRIDGE COMPUTATIONS>>>>>
1
   FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -37.  -103.   462.   2621.  117165.    1455.    1.80  500.38
   FULLV:FV       0.  -103.   462.   2621.  115726.    1441.    1.82  500.40
   BRIDG:BR       0.     0.    39.   2621.   66834.     375.    6.99  500.10
   RDWAY:RG       8.**************      0.*********       0.    2.00********
   APPRO:AS      55.   -67.   460.   2621.  111805.    1334.    1.96  501.07

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       3.    42.   54479.
1
 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    495.70    0.26  489.30  504.45************  0.09  500.47  500.38
   FULLV:FV  ********    0.27  489.34  504.49  0.02  0.00  0.09  500.49  500.40
   BRIDG:BR    495.68    0.45  489.35  500.41  0.04  0.58  0.99  501.09  500.10
   RDWAY:RG  ****************  501.28  506.07************  0.09  501.40********
   APPRO:AS    496.80    0.30  490.67  503.88  0.06  0.03  0.11  501.18  501.07
  ER

1  NORMAL  END  OF  WSPRO  EXECUTION.
```
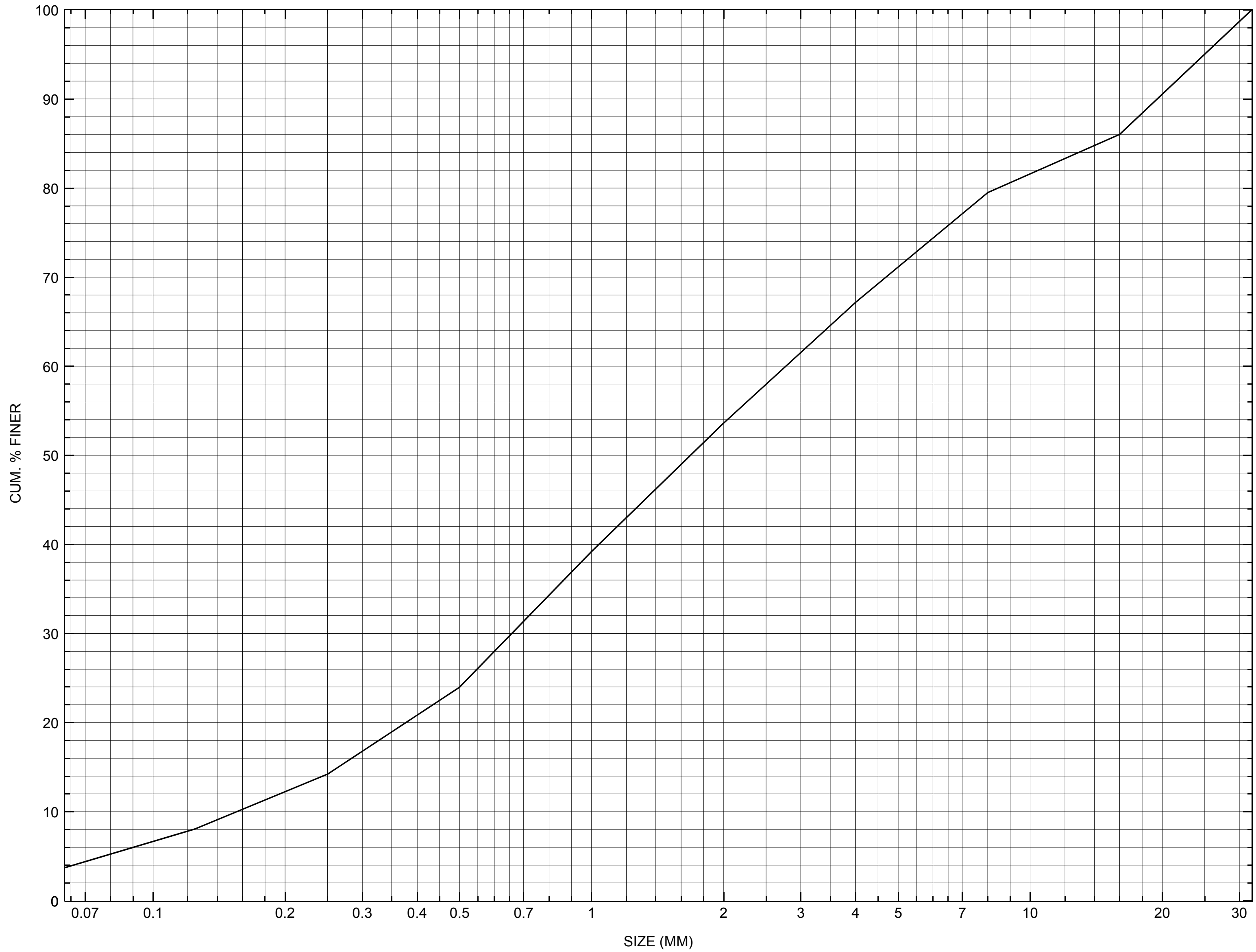

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a channel composite sample at the approach cross-section for structure ALBATH00250030, in Albany, Vermont.

APPENDIX D:

HISTORICAL DATA FORM