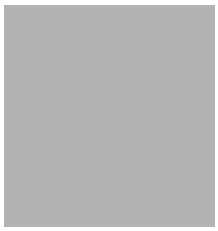
LEVEL II SCOUR ANALYSIS FOR BRIDGE 6 (IRASTH00050006) on TOWN HIGHWAY 5, crossing the BLACK RIVER, IRASBURG, VERMONT

U.S. Geological Survey
Open-File Report 96-193



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

LEVEL II SCOUR ANALYSIS FOR BRIDGE 6 (IRASTH00050006) on TOWN HIGHWAY 5, crossing the BLACK RIVER, IRASBURG, VERMONT

By SCOTT A. OLSON

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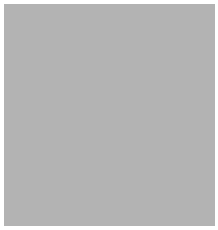

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

Pembroke, New Hampshire

1996

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

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

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Federal Center
Denver, CO 80225

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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 6 (IRASTH00050006) ON TOWN HIGHWAY 5, CROSSING THE BLACK RIVER, IRASBURG, VERMONT

By **Scott A. Olson**

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure IRASTH00050006 on town highway 5 crossing the Black River, Irasburg, 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.

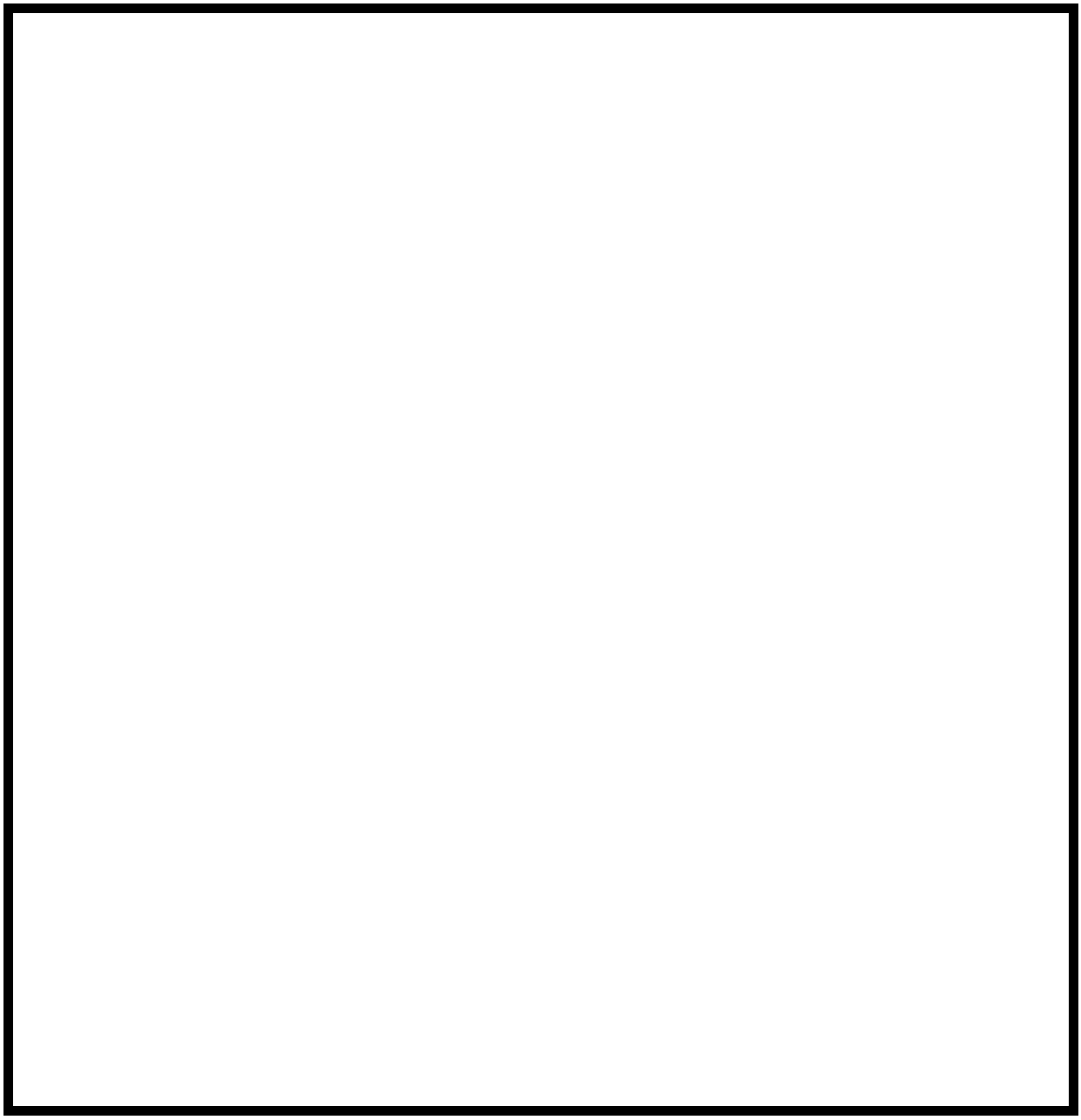
The site is in the New England Upland physiographic province of north-central Vermont. The 91.1-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the left and right banks are forested and a residence is located on the downstream left overbank.

In the study area, the Black River has an incised, sinuous channel with a slope of approximately 0.05 ft/ft, an average channel top width of 116 ft and an average bank-full channel depth of 2.8 ft. The predominant channel bed material is cobble (D_{50} is 240 mm or 0.789 ft). The geomorphic assessment at the time of the Level I and Level II site visit on October 4, 1994, indicated that the reach was stable.

The town highway 5 crossing of the Black River is a 70-ft-long, two-lane bridge consisting of one 65-foot clear span (Vermont Agency of Transportation, written commun., August 2, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. There is also a retaining wall along the upstream side of the road embankments. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is 15 degrees.

A scour hole 3.0 ft deeper than the mean thalweg depth was observed along the right abutment. The scour hole was 27 feet long, 15 feet wide, and was 2.5 feet below the abutment footing at the time of the Level I assessment. This right abutment had numerous cracks and had settled. 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.

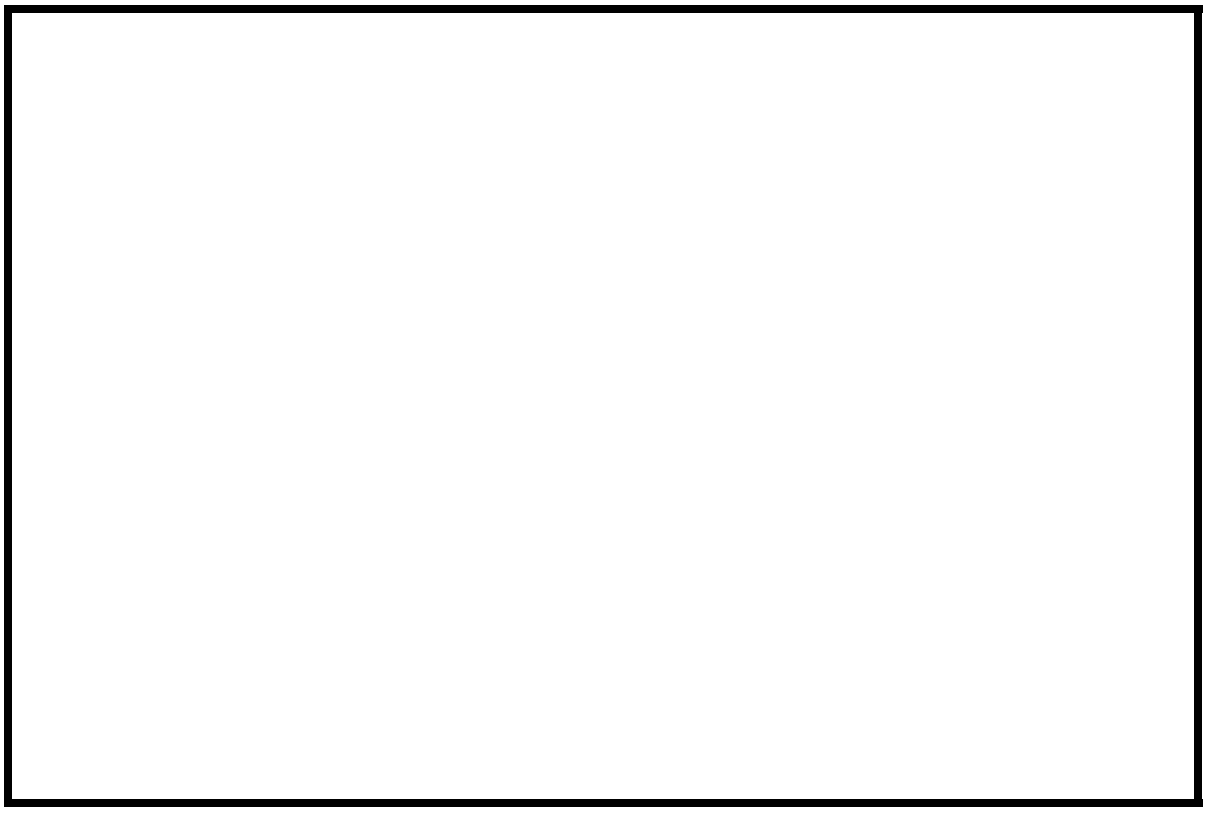


Irasburg, VT. Quadrangle, 1:24,000, 1968

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 IRASTH00050006 ***Stream*** Black River

County Orleans ***Road*** TH005 ***District*** 09

Description of Bridge

Bridge length 70 ***ft*** ***Bridge width*** 21.4 ***ft*** ***Max span length*** 65 ***ft***

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

Abutment type concrete ***Embankment type*** retaining wall then sloped

Stone fill on abutment? no ***Date of inspection*** 10/04/94

Description of stone fill type I stone fill at ends on downstream wingwalls.

Brief description of bridge (abutments, piers, etc.) Abutments are concrete with wingwalls. The right abutment has cracked and settled due to undermining.

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

Moderate: The skew angle of the stream to the bridge is 20 degrees. Opening skew to roadway is 15 degrees and the right abutment is attacked at approximately 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	10/04/94	0	0
Level II	same	-	-

Potential for debris Moderate, due to trees on the banks and information on ice jamming problems from a local resident.

Describe any features near or at the bridge that may affect flow (include observation date) October 4, 1994: Some logs and other debris existed upstream of the bridge. There are also numerous trees growing within the “bankfull” channel. Additional debris could affect flow.

Description of the Geomorphic Setting

General topography The bridge is over an incised river with little or no flood plains. The channel has numerous bedrock outcrops.

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

Date of inspection 10/04/94

DS left: moderately steep high bank

DS right: mildly sloping bank

US left: moderately steep high bank to roadway

US right: steep valley wall

Description of the Channel

Average top width 116 ft ***Average depth*** 2.8 ft

Predominant bed material cobbles ***Bank material*** cobbles

Channel type sinuous and incised, with little or no flood plains.

10/04/94

Vegetative co forested with a residence on the high overbank

DS left: forested

DS right: forested

US left: forested

US right: Y

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

On 10/04/94, there were several logs in the channel. Furthermore, there are numerous trees growing within the "bankfull" channel.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 99.1 ***mi²***

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, Vermont

USGS gage number 04296000

Gage drainage area 122 ***mi²***

Is there a lake/p No

Calculated Discharges

Q100 3,530 ***ft³/s*** ***Q500*** 4,150 ***ft³/s***

Discharges are based on analysis of the continuous record from the Black River gage. The computed 100-year and 500-year discharges at the gage were reduced by a drainage area relationship [(99.1/122) to the 0.7 power] to determine the discharges at the bridge site.

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 box on the US right guardrail and has an arbitrary elevation of 500.62 feet. RM2 is a chiseled "X" in the top of the base of the concrete downstream guardrail. It is on the road side of the guardrail and at left end of the bridge. The arbitrary elevation is 500.50 feet.

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-73	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	12	1	Road Grade section
APPR	89	2	Modelled Approach section (Templated from APPRO)
APPRO	117	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 0.050 to 0.055, and overbank "n" values were 0.075.

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

The surveyed approach section (APPRO) was moved along the approach channel slope (0.028 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.

The modeled 100- and 500-year discharges do not overtop the roadway embankments or the bridge deck.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.4 *ft*
Average low steel elevation 496.5 *ft*

100-year discharge 3,530 ft^3/s
Water-surface elevation in bridge opening 490.5 *ft*
Road overtopping? N *Discharge over road* N/A ft^3/s
Area of flow in bridge opening 329 ft^2
Average velocity in bridge opening 10.7 *ft/s*
Maximum WSPRO tube velocity at bridge 13.6 *ft/s*

Water-surface elevation at Approach section with bridge 492.8
Water-surface elevation at Approach section without bridge 492.0
Amount of backwater caused by bridge 0.8 *ft*

500-year discharge 4,150 ft^3/s
Water-surface elevation in bridge opening 490.7 *ft*
Road overtopping? N *Discharge over road* N/A ft^3/s
Area of flow in bridge opening 341 ft^2
Average velocity in bridge opening 12.2 *ft/s*
Maximum WSPRO tube velocity at bridge 15.4 *ft/s*

Water-surface elevation at Approach section with bridge 493.7
Water-surface elevation at Approach section without bridge 492.5
Amount of backwater caused by bridge 1.2

Incipient overtopping discharge -- ft^3/s
Water-surface elevation in bridge opening -- *ft*
Area of flow in bridge opening -- ft^2
Average velocity in bridge opening -- *ft/s*
Maximum WSPRO tube velocity at bridge -- *ft/s*

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

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18). For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). 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	0.0	0.0	--
Depth to armoring	2.9	6.9	--
Left overbank	--	--	--
Right overbank			
Local scour:			
Abutment scour	13.8	15.6	--
Left abutment	14.4	15.4	--
Right abutment			
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:	2.2	2.3	--
Left abutment	2.2	2.3	--
Right abutment	--	--	--
Piers:	--	--	--
Pier 1	--	--	--
Pier 2			

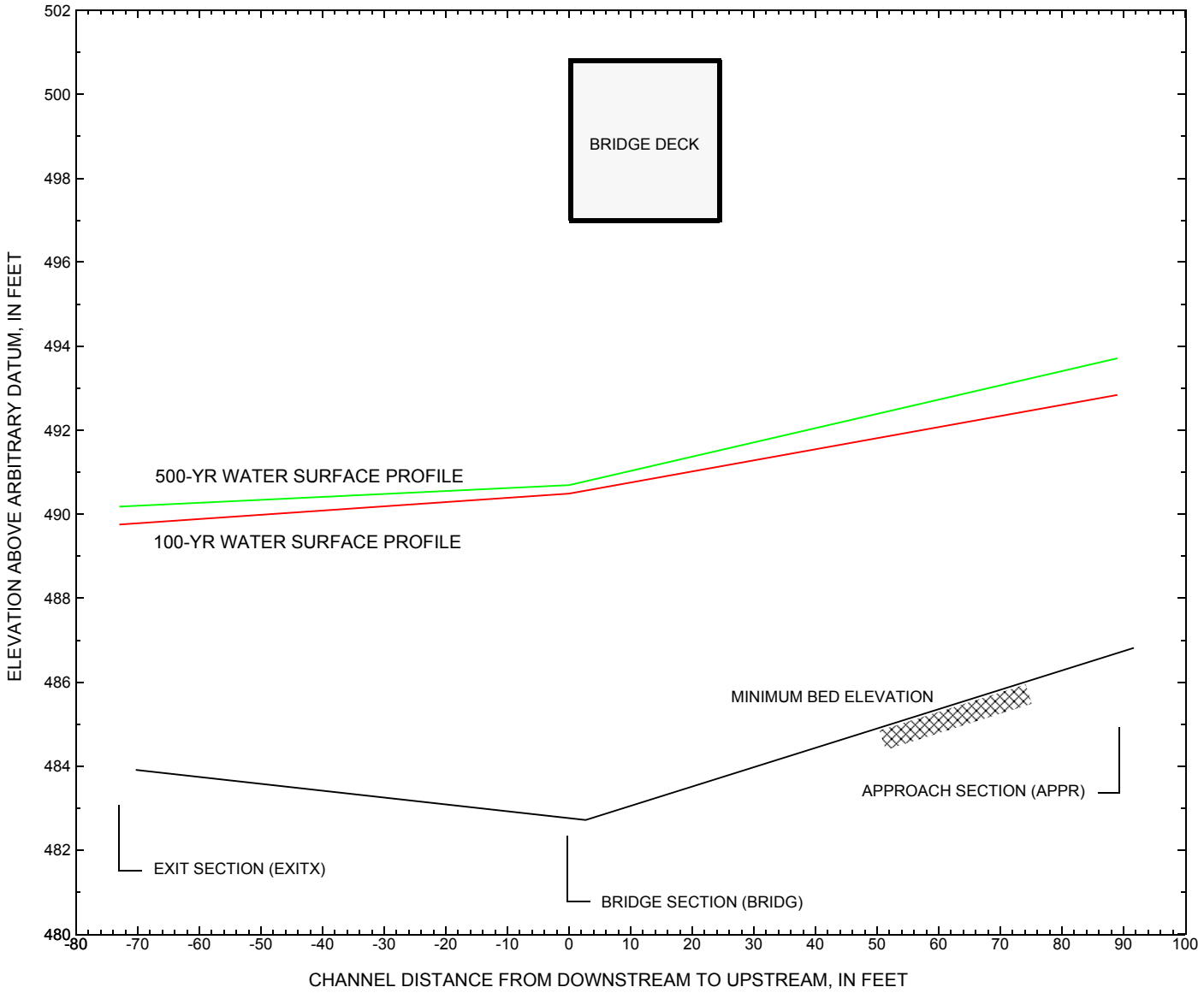


Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure IRASTH00050006 on town highway 5, crossing the Black River, Irasburg, Vermont.

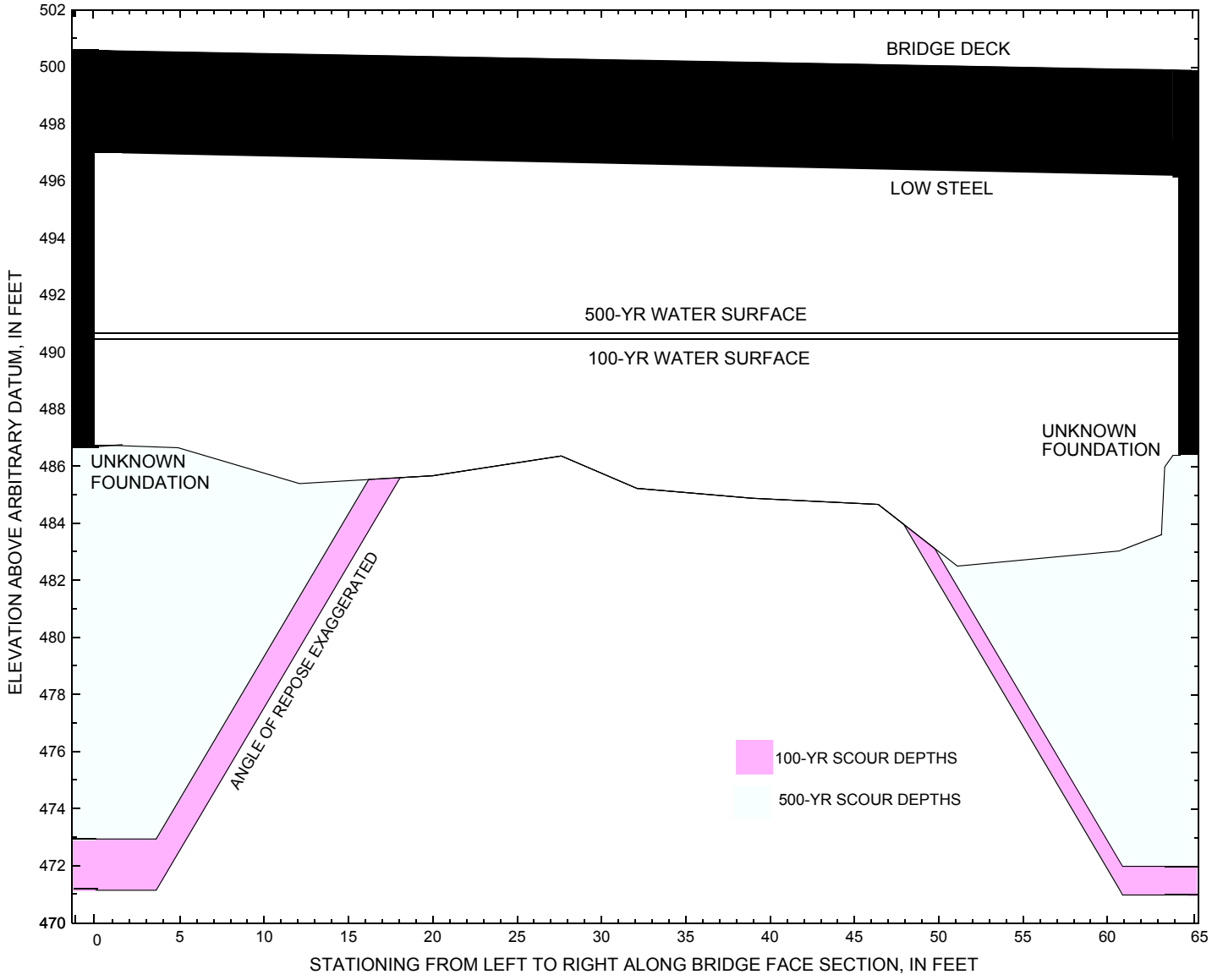


Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure IRASTH00050006 on town highway 5, crossing the Black River, Irasburg, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure IRASTH00050006 on Town Highway 5, crossing the Black River, Irasburg, 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 3,530 cubic-feet per second											
Left abutment	0.0	--	497.0	--	486.8	0.0	13.8	--	13.8	473.0	--
Right abutment	64.1	--	496.1	--	486.4	0.0	14.4	--	14.4	472.0	--

[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 IRASTH00050006 on Town Highway 5, crossing the Black River, Irasburg, 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 4,150 cubic-feet per second											
Left abutment	0.0	--	497.0	--	486.8	0.0	15.6	--	15.6	471.2	--
Right abutment	64.1	--	496.1	--	486.4	0.0	15.4	--	15.4	471.0	--

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

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Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

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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, Irasburg, 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          U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras0006.wsp
T2          CREATED ON 21-APR-95 FOR IRASTH00050006 USING FILE iras0006.dca
T3          IRAS006 IN IRASBURG, VT OVER THE BLACK RIVER
*
J3          6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           3530 4150
SK          0.015 0.015
*
XS   EXITX    -73
GR          -89.6, 503.75    -68.6, 497.82    -48.8, 494.85    -27.0, 490.42
GR          -10.9, 486.67      0.0, 485.91      7.9, 484.71     13.4, 483.95
GR           18.2, 483.71     29.5, 483.84     39.3, 484.02     52.7, 485.73
GR           52.7, 485.74     59.4, 487.01     67.0, 487.74     89.2, 489.32
GR          114.5, 490.23    136.4, 499.60    136.9, 500.38
N              0.052        0.075
SA                  67.0
*
XS   FULLV    0 * * * 0.01
*
BR   BRIDG   0 496.96 20
GR           0.0, 496.96      0.6, 486.76      4.9, 486.67     12.1, 485.41
GR          20.0, 485.69     27.6, 486.38     32.1, 485.24     38.9, 484.90
GR          46.4, 484.68     51.1, 482.52     60.7, 483.05     63.2, 483.62
GR          63.4, 485.99     63.9, 486.40     64.1, 496.06      0.0, 496.96
N            0.050
CD          1 35 * * 47.5 10
*
XR   RDWAY    12 21.4 2
GR          -95.1, 501.88    -48.7, 500.87     -5.9, 499.96     -5.7, 500.72
GR           0.0, 500.09      0.0, 500.84      0.5, 503.65      2.7, 503.64
GR          34.6, 503.44     67.8, 503.67     69.9, 503.60     70.0, 500.60
GR          70.0, 499.98    144.3, 500.34
BP          -5.7
*
XT   APPRO    117
GR         -107.6, 501.75    -87.1, 498.63    -75.8, 496.09    -59.3, 492.62
GR          -31.7, 491.04    -15.2, 490.50      0.0, 489.05     14.7, 487.87
GR           33.4, 487.41     43.1, 488.45     47.5, 490.01     54.3, 489.37
GR           64.2, 488.15     71.0, 488.95     71.8, 488.94     77.6, 492.43
GR           92.9, 505.98
*
AS   APPR      89
GT           -0.79
N            0.075        0.055
SA                -15.
BP           0
*
HP 1 BRIDG    490.49 1 490.49
HP 2 BRIDG    490.49 * * 3530
HP 1 APPR     492.84 1 492.84
HP 2 APPR     492.84 * * 3530
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
          U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras0006.wsp
          CREATED ON 21-APR-95 FOR IRASTH00050006 USING FILE iras0006.dca
          IRAS006 IN IRASBURG, VT OVER THE BLACK RIVER
           *** RUN DATE & TIME: 04-21-95  11:04
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     329.   27340.    60.    71.                       4377.
   490.49         329.   27340.    60.    71.  1.00     0.    64.   4377.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       490.49     0.4    64.0   328.8   27340.    3530.  10.74
X STA.          0.4         7.5        11.8        15.3        19.0        22.8
  A(I)              25.7        18.4        16.8        17.0        16.5
  V(I)              6.86        9.58       10.49       10.36       10.68

X STA.         22.8        27.1        31.2        34.4        37.4        40.3
  A(I)              17.9        17.4        15.7        15.2        15.1
  V(I)              9.87       10.13       11.25       11.62       11.69

X STA.         40.3        43.0        45.7        48.3        50.3        52.1
  A(I)              14.8        14.5        14.8        13.7        13.0
  V(I)             11.96       12.16       11.93       12.85       13.58

X STA.         52.1        53.8        55.7        57.7        59.9        64.0
  A(I)              12.9        13.7        14.2        15.8        25.6
  V(I)             13.64       12.93       12.42       11.18        6.89

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =      89.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     100.    3181.    49.    49.                        809.
            2     452.   34382.    94.    96.                       5622.
   492.84         552.   37563.   143.   145.  1.16   -64.    79.   5704.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =      89.
         WSEL     LEW     REW    AREA        K        Q    VEL
       492.84   -64.1    79.0   551.7   37563.    3530.   6.40
X STA.        -64.1       -26.8       -12.0        -4.4         1.5         6.5
  A(I)              65.1        44.7        28.7        26.3        24.3
  V(I)              2.71        3.95        6.15        6.71        7.26

X STA.          6.5        10.9        14.9        18.7        22.4        25.9
  A(I)              23.3        22.5        22.1        21.8        21.4
  V(I)              7.58        7.86        7.99        8.11        8.25

X STA.         25.9        29.5        32.9        36.6        40.6        45.5
  A(I)              21.6        21.2        22.2        22.7        24.6
  V(I)              8.18        8.32        7.94        7.77        7.16

X STA.         45.5        52.8        58.7        63.4        68.4        79.0
  A(I)              28.7        26.2        23.9        26.2        34.2
  V(I)              6.15        6.73        7.39        6.74        5.15
```

WSPRO OUTPUT FILE (continued)

```
          U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras0006.wsp
          CREATED ON 21-APR-95 FOR IRASTH00050006 USING FILE iras0006.dca
          IRAS006 IN IRASBURG, VT OVER THE BLACK RIVER
           *** RUN DATE & TIME: 04-21-95  11:04
    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     341.   28908.    60.    71.                       4617.
   490.69          341.   28908.    60.    71.  1.00     0.    64.   4617.

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       490.69     0.4    64.0   340.8   28908.    4150.  12.18
X STA.          0.4         7.5        11.7        15.2        18.8        22.6
  A(I)              26.8        19.0        17.4        17.2        17.6
  V(I)              7.75       10.91       11.95       12.09       11.78

X STA.         22.6        26.7        30.9        34.0        37.1        39.9
  A(I)              17.8        18.0        16.3        16.1        15.5
  V(I)             11.66       11.51       12.75       12.91       13.41

X STA.         39.9        42.7        45.4        48.0        50.1        51.9
  A(I)              15.1        15.3        15.1        14.3        13.8
  V(I)             13.76       13.57       13.73       14.52       15.05

X STA.         51.9        53.7        55.6        57.6        59.9        64.0
  A(I)              13.5        14.2        14.8        16.4        26.8
  V(I)             15.42       14.61       14.04       12.63        7.76

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPR ;  SRD =      89.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1     144.    5565.    53.    53.                       1350.
             2     534.   45013.    95.    97.                       7186.
   493.71          678.   50578.   148.   151.  1.17   -68.    80.   7625.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPR ;  SRD =      89.
         WSEL     LEW     REW    AREA        K        Q    VEL
       493.71   -68.2    79.9   678.4   50578.    4150.   6.12
X STA.        -68.2       -33.3       -17.9        -8.6        -1.9         3.5
  A(I)              76.5        56.5        39.4        32.9        29.9
  V(I)              2.71        3.67        5.27        6.31        6.94

X STA.          3.5         8.5        12.8        16.9        20.9        24.8
  A(I)              29.6        27.3        27.2        26.4        26.8
  V(I)              7.01        7.60        7.63        7.85        7.73

X STA.         24.8        28.6        32.3        36.1        40.4        45.4
  A(I)              26.4        26.0        26.6        28.0        29.6
  V(I)              7.85        7.99        7.81        7.41        7.01

X STA.         45.4        52.5        58.4        63.4        68.5        79.9
  A(I)              34.1        31.2        29.6        31.4        43.1
  V(I)              6.09        6.65        7.02        6.61        4.81
```

WSPRO OUTPUT FILE (continued)

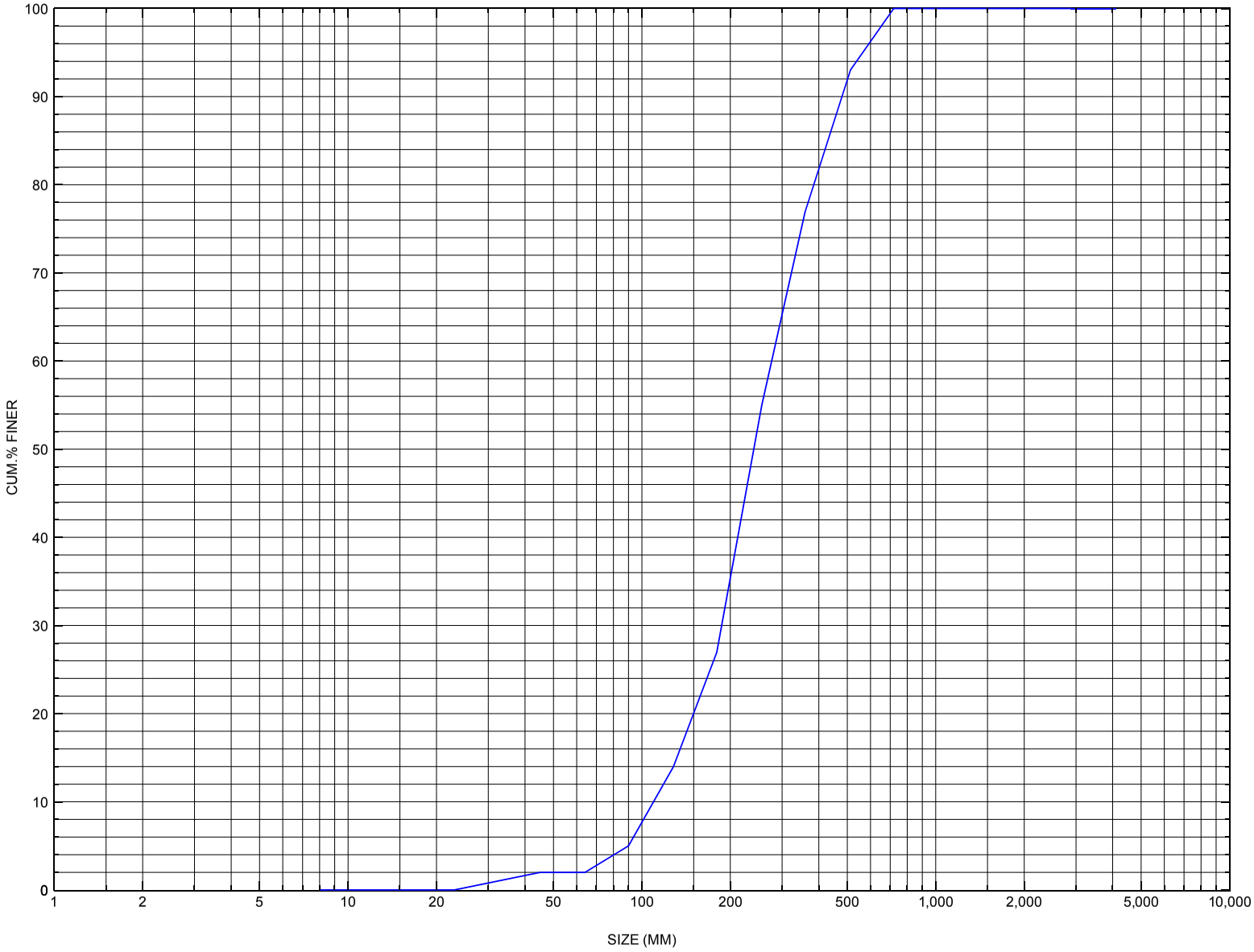
```
          U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras0006.wsp
          CREATED ON 21-APR-95 FOR IRASTH00050006 USING FILE iras0006.dca
          IRAS006 IN IRASBURG, VT OVER THE BLACK RIVER
           *** RUN DATE & TIME: 04-21-95  11:04

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

EXITX:XS   ******   -24.     411.  1.26 *****  491.01  489.17   3530.  489.75
      -73. ******   101.   28810.  1.10 ***** *******    0.87    8.58

FULLV:FV      73.   -26.     475.  0.98  0.92  491.94 *******   3530.  490.96
        0.    73.   114.   34394.  1.14  0.00    0.01    0.76    7.43
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPR ":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.85     492.05     491.58

 ===110 WSEL NOT FOUND AT SECID "APPR ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   490.46     505.19    0.50

 ===115 WSEL NOT FOUND AT SECID "APPR ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   490.46     505.19     491.58

APPR :AS      89.   -60.     441.  1.15  1.18  493.20  491.58   3530.  492.05
       89.    89.    78.   27333.  1.15  0.08    0.00    0.85    8.00
         <<<<<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

BRIDG:BR      73.     0.     329.  1.79  1.21  492.28  489.76   3530.  490.49
        0.    73.    64.   27329.  1.00  0.06   -0.01    0.81   10.74

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  496.96 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF    VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      12.         <<<<<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      54.   -64.     551.  0.74  0.73  493.58  491.58   3530.  492.84
       89.    57.    79.   37514.  1.16  0.58    0.01    0.62    6.40

      M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
     0.540  0.302   26063.   -12.    52.   492.23

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -73.   -24.   101.   3530.   28810.     411.    8.58  489.75
   FULLV:FV       0.   -26.   114.   3530.   34394.     475.    7.43  490.96
   BRIDG:BR       0.     0.    64.   3530.   27329.     329.   10.74  490.49
   RDWAY:RG      12.**************      0.******************    2.00********
   APPR :AS      89.   -64.    79.   3530.   37514.     551.    6.40  492.84

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR :AS     -12.    52.   26063.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    489.17    0.87  483.71  503.75************  1.26  491.01  489.75
   FULLV:FV  ********    0.76  484.44  504.48  0.92  0.00  0.98  491.94  490.96
   BRIDG:BR    489.76    0.81  482.52  496.96  1.21  0.06  1.79  492.28  490.49
   RDWAY:RG  ***************** 499.96  503.67**********************************
   APPR :AS    491.58    0.62  486.62  505.19  0.73  0.58  0.74  493.58  492.84
```

WSPRO OUTPUT FILE (continued)

```
          U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras0006.wsp
          CREATED ON 21-APR-95 FOR IRASTH00050006 USING FILE iras0006.dca
          IRAS006 IN IRASBURG, VT OVER THE BLACK RIVER
           *** RUN DATE & TIME: 04-21-95  11:04

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

EXITX:XS   ******   -26.     469.  1.39 *****  491.57  489.62   4150.  490.18
      -73. ******   113.   33853.  1.14 ***** *******    0.91    8.85

FULLV:FV      73.   -28.     542.  1.06  0.91  492.49 *******   4150.  491.43
        0.    73.   116.   40632.  1.16  0.00    0.00    0.75    7.66
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPR ":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    0.83     492.49     492.00

 ===110 WSEL NOT FOUND AT SECID "APPR ":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   490.93     505.19    0.50

 ===115 WSEL NOT FOUND AT SECID "APPR ":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   490.93     505.19     492.00

APPR :AS      89.   -62.     503.  1.22  1.14  493.72  492.00   4150.  492.50
       89.    89.    79.   32957.  1.16  0.08    0.01    0.83    8.24
         <<<<<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

BRIDG:BR      73.     0.     341.  2.30  1.28  493.00  490.30   4150.  490.69
        0.    73.    64.   28945.  1.00  0.15    0.00    0.90   12.17

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  496.96 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      12.         <<<<<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      54.   -68.     678.  0.68  0.68  494.39  492.00   4150.  493.71
       89.    57.    80.   50527.  1.17  0.72    0.01    0.55    6.12

       M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
      0.549  0.328   33864.   -12.    52.   493.25

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -73.   -26.   113.   4150.   33853.     469.    8.85  490.18
   FULLV:FV       0.   -28.   116.   4150.   40632.     542.    7.66  491.43
   BRIDG:BR       0.     0.    64.   4150.   28945.     341.   12.17  490.69
   RDWAY:RG      12.**************      0.******************    2.00********
   APPR :AS      89.   -68.    80.   4150.   50527.     678.    6.12  493.71

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR :AS     -12.    52.   33864.

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS      FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITX:XS    489.62    0.91  483.71  503.75************  1.39  491.57  490.18
   FULLV:FV  ********    0.75  484.44  504.48  0.91  0.00  1.06  492.49  491.43
   BRIDG:BR    490.30    0.90  482.52  496.96  1.28  0.15  2.30  493.00  490.69
   RDWAY:RG  ***************  499.96  503.67**********************************
   APPR :AS    492.00    0.55  486.62  505.19  0.68  0.72  0.68  494.39  493.71
```

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution at the approach cross-section for structure IRASTH00050006, in Irasburg, Vermont.

APPENDIX D:

HISTORICAL DATA FORM