LEVEL II SCOUR ANALYSIS FOR BRIDGE 20 (IRASTH00080020) on TOWN HIGHWAY 8, crossing the BLACK RIVER, IRASBURG, VERMONT

U.S. Geological Survey
Open-File Report 96-154

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

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By SCOTT A. OLSON

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Pembroke, New Hampshire

1996

U.S. DEPARTMENT OF THE INTERIOR
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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 20 (IRASTH00080020) ON TOWN HIGHWAY 8, 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 IRASTH00080020 on town highway 8 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, was 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 Irasburg. The 110-mi^2 drainage area is in a predominantly rural basin. In the vicinity of the study site, the left bank surface cover is pasture and row crops and the right bank is covered by shrub and brush and is adjacent to woods.

In the study area, the Black River has a sinuous channel with a slope of approximately 0.002 ft/ft, an average channel top width of 90 ft and an average channel depth of 5 ft. The predominant channel bed material is gravel and cobbles (D_{50} is 49.7 mm or 0.163 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 laterally unstable.

The town highway 8 crossing of the Black River is a 88-ft-long, one-lane covered bridge consisting of one 80-foot span (Vermont Agency of Transportation, written commun., August 2, 1994). The bridge is supported by vertical, concrete abutments with wingwalls on the upstream and downstream sides of the right abutment. The right abutment has stone fill protection. The channel is skewed approximately 25 degrees to the opening while the opening-skew-to-roadway is zero 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). 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, 1986

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 IRASTH00080020 ***Stream*** Black River

County Orleans ***Road*** TH008 ***District*** 09

Description of Bridge

Bridge length 88 ***ft*** ***Bridge width*** 22 ***ft*** ***Max span length*** 80 ***ft***

Alignment of bridge to road (on curve or straight) sharp curve at right road approach

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

Stone fill on abutment? on right ***Date of inspection*** 10/4/94

Description of stone fill Type-2 stone fill on right abutment, upstream right wingwall, and the upstream and downstream sides of the right road approach. Type-3 stone fill on upstream side of the left road approach.

Brief description of piers/abutments

Is bridge skewed to flood flow according to Y ***survey?*** Y ***Angle*** 25

The river severely curves at the approach to the bridge. This curve results in a skew of 25 degrees and in the flow impacting the right abutment also at approximately 25 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	10/4/94	0	0
Level II	10/4/94	--	--

Potential for debris Accumulation potential is moderate due to sharp bend just upstream of the bridge.

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

On 10/4/94 it was noted that flood flows will impact the right abutment heavily and may cause pile-up of water and increase scour.

Description of the Geomorphic Setting

General topography Moderate relief valley with wide flood plains and no apparent incision of the channel.

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

Date of inspection 10/4/94

DS left: wide flood plain

DS right: steep valley wall

US left: two-lane gravel road, then wide flood plain

US right: narrow flood plain, then steep valley wall

Description of the Channel

Average top width 90 ***ft*** ***Average depth*** 5 ***ft***

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

sinuous, with flood plains. Stream boundaries are alluvial and semi-alluvial and are laterally unstable

10/4/94

Vegetative co Pasture and row crops

DS left: Shrub and brush with forest further from river

DS right: Pasture

US left: Shrub and brush

US right: N

Do banks appear stable? 10/4/94--In the downstream channel a cut-bank is noted along the left bank as well as a mid-channel bar.

date of observation.

08/16/94--None

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 110 ***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 3,800 ***ft³/s*** ***Q500*** 4,460 ***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 [(110/122) to the 0.8 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 Add 265.4 feet to VTAOT datum.

Description of reference marks used to determine USGS datum. RM1 is a chiseled **X** on top of the downstream end of the left abutment wall with an arbitrary survey elevation of 1008.62 feet.

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT2	-121	1	Downstream section
EXIT1	-39	1	Exit section
FV	0	2	Downstream Full-valley section (Templated from EXIT1)
BRIDG	0	1	Bridge section
RDWAY	10	1	Road Grade section
APPR1	110	1	Approach section

[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 0.040 to 0.045, and overbank "n" values ranged from 0.035 to 0.095.

Normal depth was assumed at the downstream-most section (EXIT2) for 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 water-surface slope on the day of the field inspection.

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

Bridge Hydraulics Summary

Average bridge embankment elevation 1008.0 *ft*
Average low steel elevation 1005.1 *ft*

100-year discharge 3,800 *ft^3/s*
Water-surface elevation in bridge opening 1000.5 *ft*
Road overtopping? no *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 526 *ft^2*
Average velocity in bridge opening 7.23 *ft/s*
Maximum WSPRO tube velocity at bridge 9.11 *ft/s*

Water-surface elevation at Approach section with bridge 1001.6
Water-surface elevation at Approach section without bridge 1000.9
Amount of backwater caused by bridge 0.7 *ft*

500-year discharge 4,460 *ft^3/s*
Water-surface elevation in bridge opening 1000.8 *ft*
Road overtopping? no *Discharge over road* -- *ft^3/s*
Area of flow in bridge opening 542 *ft^2*
Average velocity in bridge opening 8.23 *ft/s*
Maximum WSPRO tube velocity at bridge 10.38 *ft/s*

Water-surface elevation at Approach section with bridge 1002.3
Water-surface elevation at Approach section without bridge 1001.2
Amount of backwater caused by bridge 1.1

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 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.

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 the same as 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	--	--	--
Clear-water scour	0.0	0.0	--
Depth to armoring	0.5	1.2	--
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
Abutment scour			
Left abutment	15.9	17.3	--
Right abutment	13.5	14.8	--
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	1.4	1.8	--
Right abutment	1.4	1.8	--
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

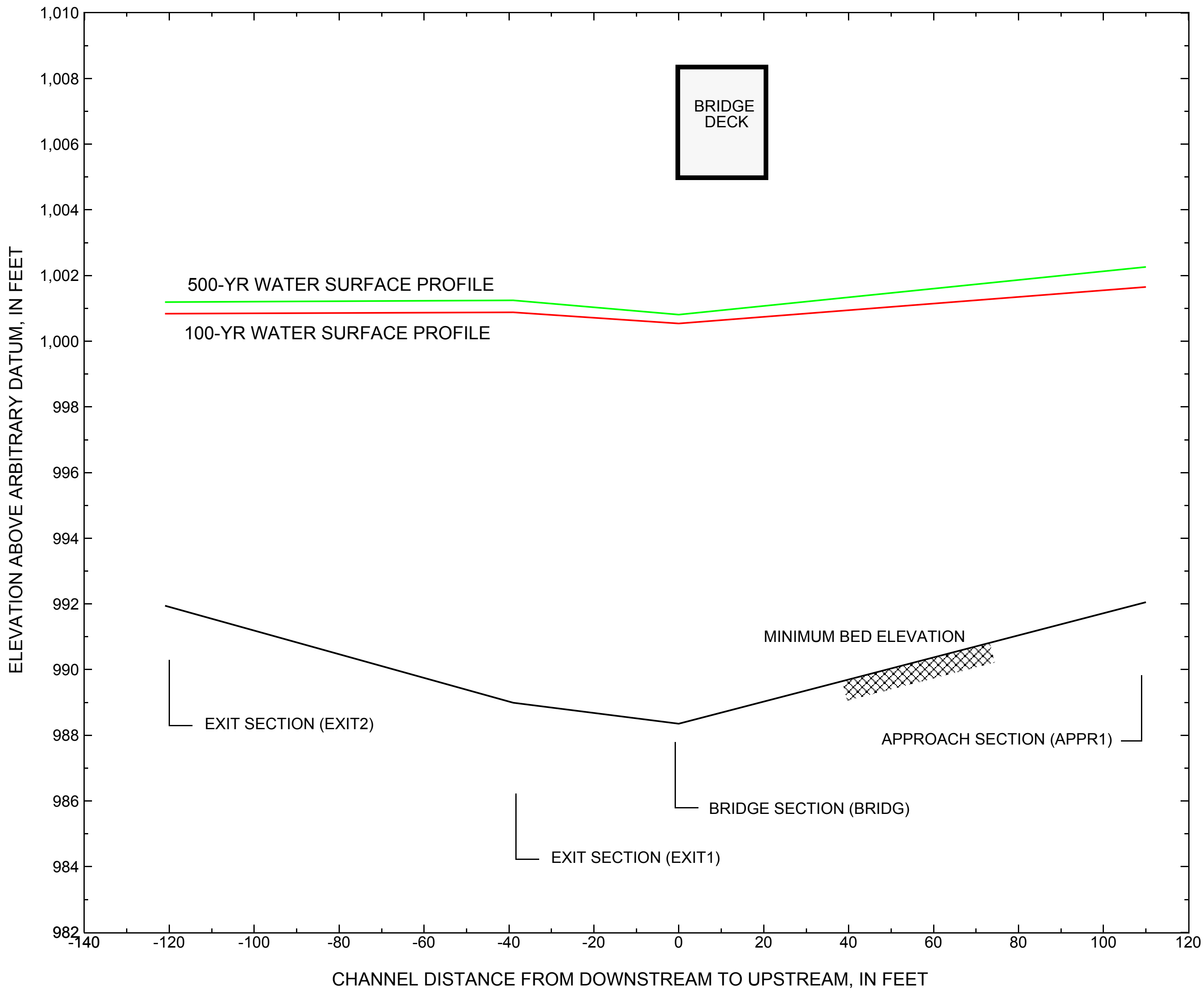

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure IRASTH00080020 on town highway 8, crossing the Black River, Irasburg, Vermont.

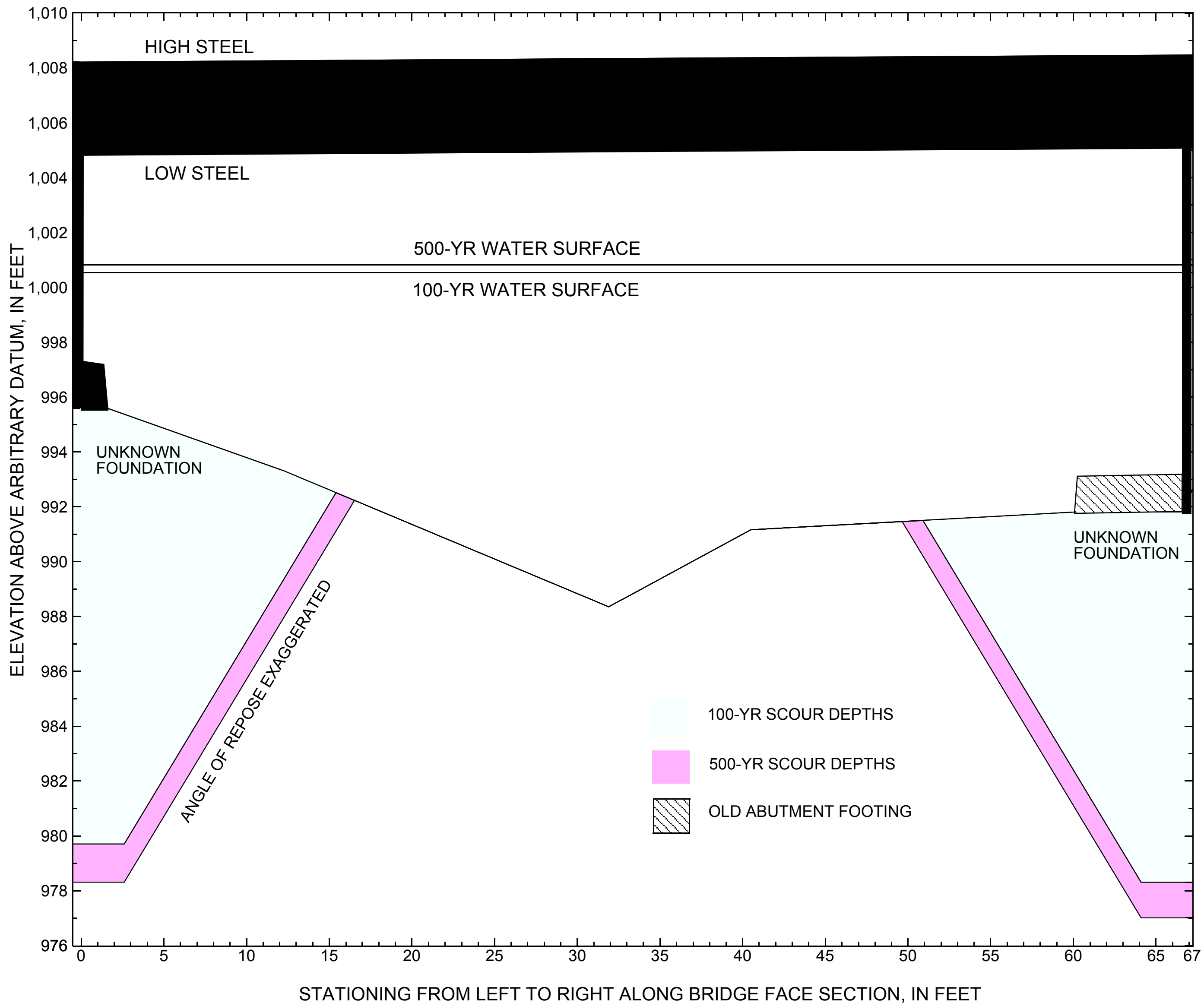

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure IRASTH00080020 on town highway 8, crossing the Black River, Irasburg, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure IRASTH00080020 on Town Highway 8, 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 3,800 cubic-feet per second											
Left abutment	0.0	739.4	1004.8	--	995.6	0.0	15.9	--	15.9	979.7	--
Right abutment	66.7	--	1005.3	--	991.8	0.0	13.5	--	13.5	978.3	--

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure IRASTH00080020 on Town Highway 8, 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 4,460 cubic-feet per second											
Left abutment	0.0	739.4	1004.8	--	995.6	0.0	17.3	--	17.3	978.3	--
Right abutment	66.7	--	1005.3	--	991.8	0.0	14.8	--	14.8	977.0	--

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

SELECTED REFERENCES

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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 iras020.wsp
T2        CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
T3        HYDRAULIC ANALYSIS OF IRAS020 OVER THE BLACK RIVER IN COVENTRY, VT
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
*          Discharges from the log Pearson type 3 analysis of
*          gage data from station 04296000 Black River at Coventry, VT
*          and adjusted by drainage area relationship
*
Q          3800 4460
SK         0.0005 0.0005
*
*           Valley slope determined from survey data between exit and appr.
*
*           Since EXIT1 had been surveyed through as deep section, EXIT2 was
*           surveyed.  EXIT2 consisted of only the channel geometry so the
*           overbank sections of EXIT1 were appended to EXIT2.  EXIT2 is
*           shallower and better represents the river for starting
*           step-backwater analysis.
*
XS   EXIT2    -121
GR            0.0,1003.48     23.1,1001.22     23.6,1001.21     72.6,1000.11
GR          141.3, 997.90    207.0, 997.05    267.6, 996.96    318.7, 996.93
GR          376.9, 999.11    399.7, 999.16    418.6,1000.46    484.1, 999.68
GR          577.6, 998.80    594.0, 993.34    599.4, 992.04    614.3, 992.88
GR          629.2, 991.94    654.9, 993.15    671.7, 998.80    686.7,1001.08
GR          704.0,1006.87    723.8,1006.58    727.8,1006.03    732.3,1008.24
N           0.035  0.045  0.045
SA              577.6   671.7
*
XS   EXIT1    -39
GR            0.0,1003.48     23.1,1001.22     23.6,1001.21     72.6,1000.11
GR          141.3, 997.90    207.0, 997.05    267.6, 996.96    318.7, 996.93
GR          376.9, 999.11    399.7, 999.16    418.6,1000.46    484.1, 999.68
GR          577.6, 998.80    594.0, 993.34    607.3, 990.96    616.7, 988.99
GR          621.6, 989.24    628.5, 990.37    637.5, 991.82    648.9, 993.19
GR          665.7, 998.80    680.7,1001.08    698.0,1006.87    717.8,1006.58
GR          721.8,1006.03    726.3,1008.24
N            0.035  0.045  0.045
SA              577.6  665.7
*
XS   FULLV   0 * * * 0.002
*
BR   BRIDG   0 1005.1 25.0
GR            0.0,1004.77      0.0,997.23       1.3, 997.28      1.5, 995.61
GR           12.2, 993.32     31.9, 988.35     40.5, 991.16     60.2, 991.81
GR           60.4, 993.12     66.6, 993.22     66.7,1005.34      0.0,1004.77
CD           1 27 * 1008 45 0
N            0.040
*
XR   RDWAY     10 22 2
```

```
GR           0.0,1007.01     73.5,1004.89    170.1,1004.47    256.1,1003.55
GR         355.2,1003.22    460.6,1002.68    499.9,1003.21    567.1,1005.99
GR         594.5,1007.29    623.4,1008.17    673.2,1007.90    710.0,1008.55
GR         727.3,1008.27    753.8,1007.54    756.0,1005.87    762.6,1013.47
BP         623.4
*


AS   APPR1    110
GR        -553.7,1007.0    -480.2,1004.9    -383.6,1004.5
GR        -297.6,1003.6    -198.5, 1003.2    -93.1, 1002.7    -53.8, 1003.2
GR           0.0,1004.85     18.0, 999.24     36.0, 998.65     40.7, 996.15
GR          52.7, 993.38     72.8, 992.14     79.5, 992.05     99.7, 992.15
GR         120.1, 993.36    128.6, 995.55    158.9, 996.72    183.3, 995.95
GR         209.1, 998.97    263.1,1003.54    291.8,1012.07
N          0.065 0.045 0.095
SA           36.0   128.6
BP         40.7
*
HP 1 BRIDG  1000.54 1 1000.54
HP 2 BRIDG  1000.54 * * 3800
HP 1 APPR1  1001.65 1 1001.65
HP 2 APPR1  1001.65 * * 3800
*
HP 1 BRIDG  1000.81 1 1000.81
HP 2 BRIDG  1000.81 * * 4460
HP 1 APPR1  1002.26 1 1002.26
HP 2 APPR1  1002.26 * * 4460
*
EX
ER
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras020.wsp
        CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
        HYDRAULIC ANALYSIS OF IRAS020 OVER THE BLACK RIVER IN COVENTRY, VT
           *** RUN DATE & TIME: 04-20-95  14:45
    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      526.   71649.    60.    75.                        8797.
  1000.54           526.   71649.    60.    75.  1.00     0.    67.   8797.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1000.54     0.0    66.7   525.6   71649.    3800.   7.23

X STA.         0.0         9.1        14.0        17.8        20.8        23.5
  A(I)             44.0        31.5        27.9        25.1        23.9
  V(I)             4.32        6.04        6.81        7.57        7.96

X STA.        23.5        26.0        28.2        30.2        32.2        34.1
  A(I)             23.0        22.2        21.3        20.9        21.1
  V(I)             8.25        8.55        8.92        9.11        9.00

X STA.        34.1        36.3        38.7        41.3        44.1        46.8
  A(I)             21.3        22.5        22.7        23.5        23.2
  V(I)             8.92        8.43        8.35        8.07        8.19

X STA.        46.8        49.8        52.8        56.1        59.8        66.7
  A(I)             24.2        25.1        26.3        29.6        46.2
  V(I)             7.84        7.58        7.21        6.42        4.11

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPR1;  SRD =     110.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1       58.    2264.    26.    26.                         494.
             2      781.  106125.    93.    94.                       12866.
             3      447.   17610.   112.   112.                        5069.
  1001.65          1286.  125999.   231.   232.  1.65    10.   241.  13435.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =     110.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1001.65    10.3   240.8  1286.2  125999.    3800.   2.95

X STA.        10.3        44.9        52.3        58.0        63.2        68.2
  A(I)            103.1        53.9        48.2        46.1        45.0
  V(I)             1.84        3.53        3.94        4.12        4.22

X STA.        68.2        72.9        77.4        81.9        86.4        90.9
  A(I)             43.9        42.8        43.4        42.8        42.7
  V(I)             4.32        4.44        4.38        4.44        4.45

X STA.        90.9        95.3        99.8       104.4       109.3       114.4
  A(I)             42.5        42.4        43.7        43.7        45.2
  V(I)             4.47        4.48        4.35        4.35        4.20

X STA.       114.4       119.8       126.7       147.5       175.2       240.8
  A(I)             46.0        51.3       120.5       143.1       195.8
  V(I)             4.13        3.71        1.58        1.33        0.97

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras020.wsp
        CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
        HYDRAULIC ANALYSIS OF IRAS020 OVER THE BLACK RIVER IN COVENTRY, VT
           *** RUN DATE & TIME: 04-20-95  14:45
    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
             1      542.   75035.    60.    76.                        9210.
  1000.81           542.   75035.    60.    76.  1.00     0.    67.   9210.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1000.81     0.0    66.7   541.9   75035.    4460.   8.23

X STA.         0.0         9.1        13.8        17.6        20.7        23.4
  A(I)             46.2        31.2        28.9        26.0        24.7
  V(I)             4.83        7.15        7.71        8.59        9.04

X STA.        23.4        25.9        28.1        30.2        32.1        34.1
  A(I)             23.8        22.9        21.9        21.5        21.8
  V(I)             9.38        9.73       10.16       10.38       10.22

X STA.        34.1        36.3        38.6        41.2        44.0        46.8
  A(I)             22.2        22.8        23.4        24.2        23.9
  V(I)            10.04        9.78        9.52        9.20        9.33

X STA.        46.8        49.8        52.8        56.1        59.8        66.7
```

```
  A(I)             25.0       25.9       27.2       30.5       48.0
  V(I)             8.93       8.62       8.21       7.30       4.65


    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPR1;  SRD =     110.
     WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1      74.    3252.    28.    28.                         691.
            2     837.  119226.    93.    94.                       14287.
            3     518.   21568.   119.   120.                        6122.
  1002.26        1430.  144047.   240.   242.  1.68     8.   248.  15273.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =     110.

         WSEL     LEW     REW    AREA        K        Q    VEL
      1002.26     8.3   248.0  1429.6  144047.    4460.   3.12
X STA.        8.3       43.5       51.3       57.2       62.6       67.7
  A(I)           115.4       59.7       52.8       50.5       49.3
  V(I)            1.93       3.73       4.23       4.41       4.53

X STA.       67.7       72.7       77.3       81.9       86.5       91.0
  A(I)            48.9       46.6       47.2       46.6       46.5
  V(I)            4.56       4.78       4.72       4.78       4.79

X STA.       91.0       95.7      100.4      105.1      110.1      115.5
  A(I)            47.2       47.1       46.8       48.9       49.9
  V(I)            4.73       4.74       4.77       4.56       4.47

X STA.      115.5      121.1      128.4      151.6      178.1      248.0
  A(I)            50.7       56.2      145.3      153.8      220.2
  V(I)            4.40       3.97       1.53       1.45       1.01

        U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras020.wsp
        CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
        HYDRAULIC ANALYSIS OF IRAS020 OVER THE BLACK RIVER IN COVENTRY, VT
           *** RUN DATE & TIME: 04-20-95  14:45

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

EXIT2:XS   ******    40.    1895.  0.08 ***** 1000.92  997.97   3800. 1000.84
     -121. ******   685.  169776.  1.21 ***** *******    0.23    2.01

EXIT1:XS      82.    38.    1948.  0.07  0.04 1000.96 *******   3800. 1000.88
      -39.    82.   679.  181936.  1.26  0.00    0.00    0.22    1.95

FULLV:FV      39.    41.    1909.  0.08  0.02 1000.98 *******   3800. 1000.90
        0.    39.   679.  177071.  1.27  0.00    0.00    0.23    1.99
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPR1"     KRATIO =  0.59

APPR1:AS     110.    13.    1113.  0.29  0.09 1001.17 *******   3800. 1000.88
      110.   110.   232.  104927.  1.60  0.11    0.00    0.34    3.41
         <<<<<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      39.     0.     526.  1.12  0.04 1001.66  996.78   3800. 1000.54
        0.    39.    67.   71644.  1.38  0.66    0.00    0.51    7.23

     TYPE PPCD FLOW      C     P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  0.853 ****** 1005.10 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD      EGL      ERR       Q    WSEL
   RDWAY:RG      10.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR1:AS      83.    10.    1287.  0.22  0.14 1001.88  997.05   3800. 1001.65
      110.    90.   241.  126097.  1.65  0.08    0.01    0.28    2.95
```

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      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.695  0.301   87927.    56.   123.  1001.57

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

   XSID:CODE    SRD    LEW    REW       Q         K     AREA     VEL    WSEL
  EXIT2:XS    -121.    40.   685.   3800.  169776.    1895.    2.01 1000.84
  EXIT1:XS     -39.    38.   679.   3800.  181936.    1948.    1.95 1000.88
  FULLV:FV       0.    41.   679.   3800.  177071.    1909.    1.99 1000.90
  BRIDG:BR       0.     0.    67.   3800.   71644.     526.    7.23 1000.54
  RDWAY:RG      10.**************      0.*****************    2.00********
  APPR1:AS     110.    10.   241.   3800.  126097.    1287.    2.95 1001.65
   XSID:CODE   XLKQ   XRKQ       KQ
   APPR1:AS      56.   123.   87927.
 SECOND USER DEFINED TABLE.

   XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
  EXIT2:XS    997.97    0.23  991.94 1008.24************  0.08 1000.92 1000.84
  EXIT1:XS  ********    0.22  988.99 1008.24  0.04  0.00  0.07 1000.96 1000.88
  FULLV:FV  ********    0.23  989.07 1008.32  0.02  0.00  0.08 1000.98 1000.90
  BRIDG:BR    996.78    0.51  988.35 1005.34  0.04  0.66  1.12 1001.66 1000.54
  RDWAY:RG  *************** 1002.68 1013.47**********************************
  APPR1:AS    997.05    0.28  992.05 1012.07  0.14  0.08  0.22 1001.88 1001.65

       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras020.wsp
       CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
       HYDRAULIC ANALYSIS OF IRAS020 OVER THE BLACK RIVER IN COVENTRY, VT
          *** RUN DATE & TIME: 04-20-95  14:45

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

EXIT2:XS   ******    24.    2125.  0.08 ***** 1001.27  998.24   4460. 1001.19
     -121. ******   687.  199299.  1.17 ***** *******    0.22    2.10

EXIT1:XS      82.    23.    2177.  0.08  0.04 1001.31 *******   4460. 1001.24
      -39.    82.   681.  211837.  1.22  0.00    0.00    0.22    2.05

FULLV:FV      39.    25.    2137.  0.08  0.02 1001.34 *******   4460. 1001.25
        0.    39.   681.  206515.  1.22  0.00    0.00    0.23    2.09
        <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPR1"     KRATIO =  0.55

APPR1:AS     110.    12.    1186.  0.36  0.09 1001.56 *******   4460. 1001.21
      110.   110.   236.  113677.  1.62  0.14    0.00    0.37    3.76
        <<<<<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      39.     0.     542.  1.44  0.05 1002.25  997.38   4460. 1000.81
        0.    39.    67.   75041.  1.37  0.89    0.00    0.57    8.23

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****    1.  0.855 ****** 1005.10 ****** ****** ******

   XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
  RDWAY:RG      10.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPR1:AS      83.     8.    1429.  0.25  0.17 1002.51  997.48   4460. 1002.26
      110.    90.   248.  143933.  1.68  0.10    0.00    0.29    3.12

      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.702  0.319   97945.    57.   123.  1002.17

                   <<<<<END OF BRIDGE COMPUTATIONS>>>>>
       U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE iras020.wsp
       CREATED ON 19-APR-95 FOR BRIDGE IRASTH00080020 USING FILE iras020.dca
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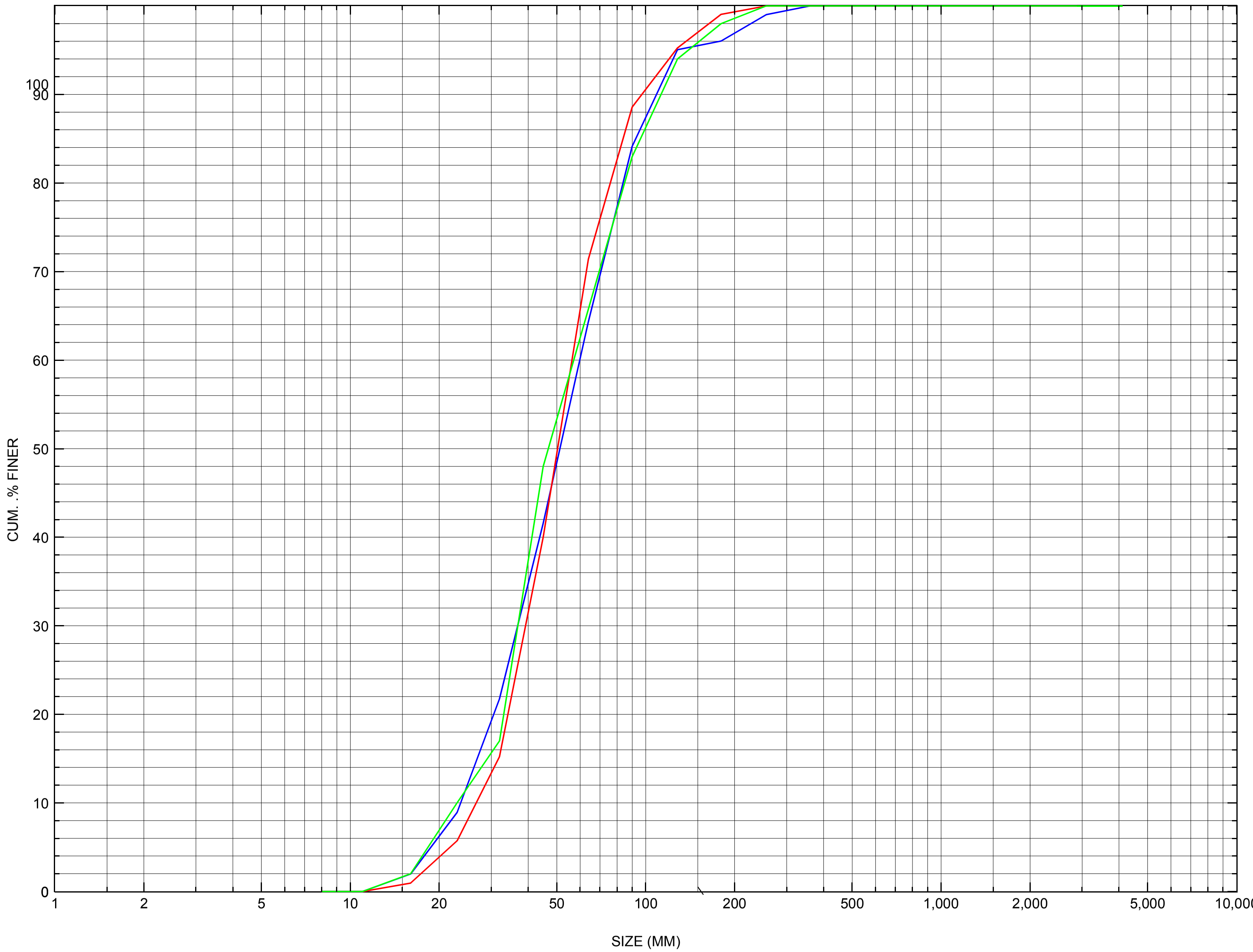
APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution at the approach cross-section for structure IRASTH00080020, in Irasburg, Vermont.

APPENDIX D:

HISTORICAL DATA FORM