LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (WORCTH00200028) on TOWN HIGHWAY 20, crossing MINISTER BROOK, WORCESTER, VERMONT

Open-File Report 98-526

Prepared in cooperation with

VERMONT AGENCY OF TRANSPORTATION

and

FEDERAL HIGHWAY ADMINISTRATION

U.S. Department of the Interior
U.S. Geological Survey

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By ERICK M. BOEHMLER AND ROBERT H. FLYNN

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Pembroke, New Hampshire

1998

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

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 28 (WORCTH00200028) ON TOWN HIGHWAY 20, CROSSING MINISTER BROOK, WORCESTER, VERMONT

By **Erick M. Boehmler and Robert H. Flynn**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure WORCTH00200028 on Town Highway 20 crossing Minister Brook, Worcester, 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 (FHWA, 1993). Results of a Level I scour investigation also are included in appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in appendix D.

The site is in the New England Upland section of the New England physiographic province in north-central Vermont. The 4.68-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is forest except for the right bank upstream. Surface cover on the right bank upstream consists of pasture beyond a narrow strip of trees along the brook.

In the study area, Minister Brook has an incised, sinuous channel with a slope of approximately 0.08 ft/ft, an average channel top width of 37 ft and an average bank height of 4 ft. The channel bed material ranges from sand to boulders with a median grain size (D_{50}) of 103 mm (0.337 ft). The geomorphic assessment at the time of the Level I and Level II site visit on July 17, 1996, indicated that the reach was stable.

The Town Highway 20 crossing of Minister Brook is a 30-ft-long, one-lane bridge consisting of one 27-foot steel-beam span (Vermont Agency of Transportation, written communication, October 13, 1995). The opening length of the structure parallel to the bridge face is 22.8 ft. The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is zero degrees.

A scour hole 1.0 ft deeper than the mean thalweg depth was observed at the downstream end of the left abutment and along the left bank from 35 feet upstream to the bridge during the Level I assessment. Scour protection measures at the site included type-1 (less than 12 inches diameter) and type-2 (less than 36 inches diameter) stone fill. Type-1 stone fill was observed along the right abutment, the right wingwalls, and discontinuously along the upstream right bank. Type-2 stone fill was observed along the left abutment, the left wingwalls, the left bank upstream, and the left and right banks downstream. Additional details describing conditions at the site are included in the Level II Summary and appendices
D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995) for the 100- and 500-year discharges. In addition, the incipient roadway-overtopping discharge was determined and analyzed as another potential worst-case scour scenario. Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 0.1 ft. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 3.3 to 6.1 ft. The worst-case abutment scour occurred at the 100-year discharge for the left abutment and at the 500-year discharge for the right abutment. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results.” Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and Davis, 1995, p. 46). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

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 WORCTH00200028 ***Stream*** Minister Brook

County Washington ***Road*** TH 20 ***District*** 6

Description of Bridge

Bridge length 30 ***ft*** ***Bridge width*** 15.9 ***ft*** ***Max span length*** 27 ***ft***

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

Abutment type Vertical, concrete ***Embankment type*** Sloping

Stone fill on abutment? Yes ***Date of inspection*** 7/17/96

Description of stone fill Type-1 along the right abutment and right wingwalls upstream and downstream and type-2 along the left abutment and the left wingwalls upstream and downstream.

Abutments and wingwalls are concrete. There is a one foot deep scour hole along the downstream end of the left abutment. The footings of the right and left abutments are exposed one-half to one foot.

Yes

20 Yes

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

There is a mild channel bend in the upstream reach. The scour holes have developed in the location where the flow impacts the left abutment.

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	7/17/96	0	0
Level II	7/17/96	0	0

Potential for debris High. Some debris was observed lodged along the left abutment and there is significant tree cover along the upstream banks.

None were observed on 7/17/96.

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

Description of the Geomorphic Setting

General topography The channel is located in a moderate relief valley with narrow flood plains and steep valley walls.

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

Date of inspection 7/17/96

DS left: Steep channel bank to a moderately sloped overbank

DS right: Steep channel bank and valley wall

US left: Steep channel bank and valley wall

US right: Steep channel bank and a moderately sloped overbank

Description of the Channel

Average top width 37 ft ***Average depth*** 4 ft

Predominant bed material Cobbles / Boulders ***Bank material*** Cobbles / Boulders

Perennial but flashy, sinuous, and locally anabranched with semi-alluvial channel boundaries.

7/17/96

Vegetative co

Trees

DS left: Trees

DS right: Trees and grass

US left: Trees and grass on the overbank

US right:

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

None were observed on 7/17/96

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 4.68 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

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

Is drainage area considered rural or urban? Rural ***Describe any significant urbanization***: -

Is there a USGS gage on the stream of interest? No

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi²***

Is there a lake/p No -

Calculated Discharges

Q100 1,160 ***ft³/s*** ***Q500*** 1,760 ***ft³/s***

The 100- and 500-year discharges are based on a drainage area relationship [(4.68/8.3)exp 0.67] with flood frequency estimates available from the Flood Insurance Study for the Town of Worcester (FEMA, 1977) for Minister Brook at the confluence with the North Branch Winooski River. The drainage area above the confluence is 8.3 square miles. These drainage area adjusted discharges were within a range defined by flood frequency curves derived from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887). Each curve was extended graphically to the 500-year event.

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 upstream end of the left abutment (elev. 500.22 ft, arbitrary survey datum). RM2 is a chiseled X on top of the downstream end of the right abutment (elev. 500.24 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXIT1	-67	2	Initial conditions section (Templated from EXTEM)
EXITX	-23	2	Exit Section
EXTEM	-23	1	Exit Section as surveyed (Used as a template)
FULLV	0	2	Downstream Full-valley section (Templated from EXTEM)
BRIDG	0	1	Bridge section
RDWAY	10	1	Road Grade section
APPR1	40	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). The analyses reported herein reflect conditions existing at the site at the time of the study. Furthermore, in the development of the model it was necessary to assume no accumulation of debris or ice at the site. 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 and Schneider (1989). Final adjustments to the values were made during the modeling of the reach. Channel "n" values for the reach ranged from 0.043 to 0.070, and overbank "n" values ranged from 0.047 to 0.075.

Critical depth at the downstream-most section (EXIT1) was assumed as the starting water surface. Normal depth was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was 0.0765 ft/ft, which was estimated from thalweg points surveyed downstream. The normal water surface was within 0.7 feet of the critical water surface for each discharge modeled. Thus, the critical water surface was assumed to be a satisfactory starting water surface.

The approach section (APPR1) was surveyed one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location provides a consistent method for determining scour variables.

Culvert routines provided with WSPRO are not fully integrated. Therefore, it was necessary to develop individual ratings for the culvert and bridge to model this multiple-opening situation. The ratings were combined to determine the quantity of the total discharge diverted from the bridge through the culvert. The combined ratings indicate the culvert diverts 250 cfs, 430 cfs, and 330 cfs of the total discharge for the 100-year, 500-year, and incipient roadway-overtopping peak discharges respectively. Each discharge modeled at the bridge was reduced by the flow through the culvert for the model provided in appendices A and B.

For the 100-year discharge, WSPRO assumes critical depth at the bridge section. A supercritical model was developed for this discharge. After analyzing both the supercritical and subcritical profiles, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumption of critical depth at the bridge is satisfactory solutions.

Bridge Hydraulics Summary

Average bridge embankment elevation 500.7 ***ft***
Average low steel elevation 498.7 ***ft***

100-year discharge 1,160 ***ft³/s***
Water-surface elevation in bridge opening 495.6 ***ft***
Road overtopping? No ***Discharge over road*** -- ***ft³/s***
Area of flow in bridge opening 84 ***ft²***
Average velocity in bridge opening 10.9 ***ft/s***
Maximum WSPRO tube velocity at bridge 13.5 ***ft/s***

Water-surface elevation at Approach section with bridge 498.1
Water-surface elevation at Approach section without bridge 496.5
Amount of backwater caused by bridge 1.6 ***ft***

500-year discharge 1,760 ***ft³/s***
Water-surface elevation in bridge opening 498.7 ***ft***
Road overtopping? Yes ***Discharge over road*** 76 ***ft³/s***
Area of flow in bridge opening 155 ***ft²***
Average velocity in bridge opening 8.6 ***ft/s***
Maximum WSPRO tube velocity at bridge 10.4 ***/s***

Water-surface elevation at Approach section with bridge 500.6
Water-surface elevation at Approach section without bridge 497.1
Amount of backwater caused by bridge 3.5 ***ft***

Incipient overtopping discharge 1,540 ***ft³/s***
Water-surface elevation in bridge opening 498.7 ***ft***
Area of flow in bridge opening 155 ***ft²***
Average velocity in bridge opening 7.8 ***ft/s***
Maximum WSPRO tube velocity at bridge 9.5 ***ft/s***

Water-surface elevation at Approach section with bridge 500.1
Water-surface elevation at Approach section without bridge 496.9
Amount of backwater caused by bridge 3.2 ***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 Davis, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the scour depths are shown graphically in figure 8.

Contraction scour for the 100-year discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). At this site, the 500-year and incipient-overtopping discharges resulted in unsubmerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Thus, contraction scour for these discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146). The streambed armoring depths computed suggest that armoring will not limit the depth of contraction scour.

For comparison, contraction scour for the discharges resulting in orifice flow also was computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Furthermore, for the 500-year and incipient-overtopping discharges, contraction scour was computed by substituting estimates for the depth of flow at the downstream bridge face in the contraction scour equations. Results with respect to these alternative computations are provided in appendix F.

Abutment scour was computed by use of the Froehlich equation (Richardson and Davis, 1995, p. 48, equation 28). 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-year discharge	500-year discharge	Incipient overtopping discharge
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.1	0.0	0.0
Depth to armoring	12.4	44.5	36.5
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	100-year discharge	500-year discharge	Incipient overtopping discharge
Abutment scour			
Left abutment	6.1	5.6	5.8
Right abutment	3.3	5.0	4.1
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-year discharge	500-year discharge	Incipient overtopping discharge
		(D_{50} in feet)	
Abutments:			
Left abutment	1.5	1.8	1.7
Right abutment	1.5	1.8	1.7
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

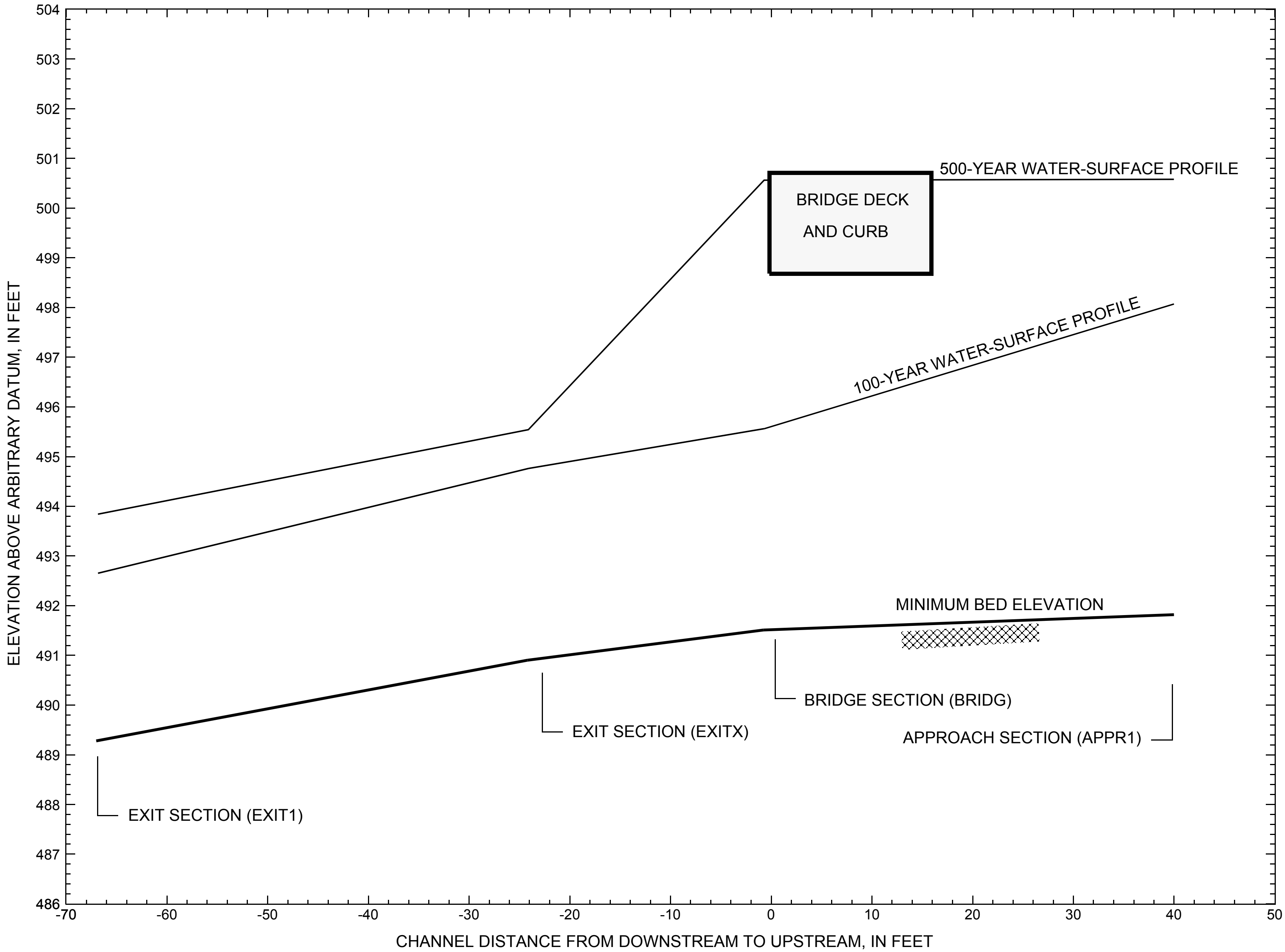

Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont.

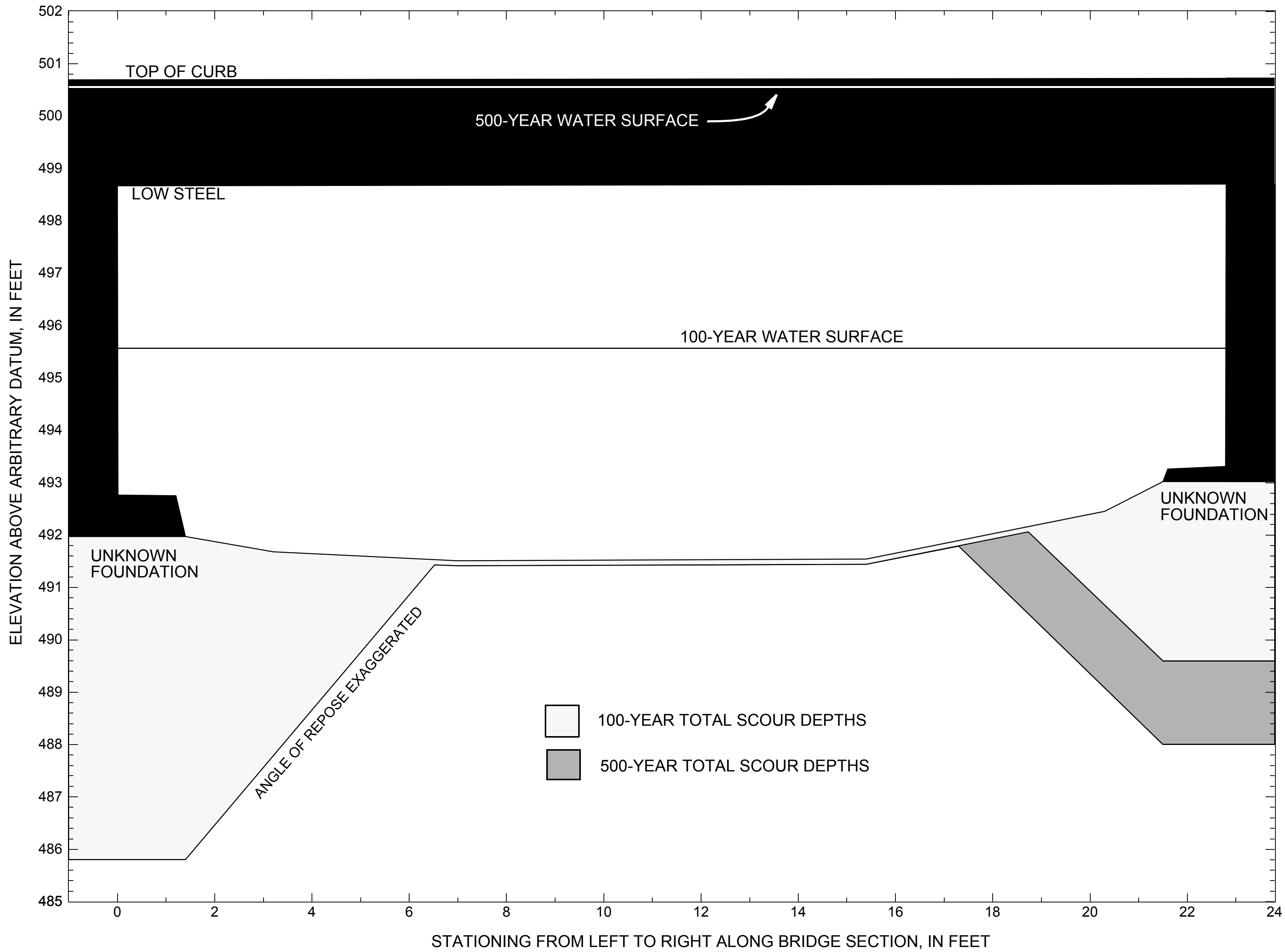

Figure 8. Scour elevations for the 100- and 500-year discharges at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, 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/pile 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-year discharge is 1,160 cubic-feet per second											
Left abutment	0.0	--	498.7	--	492.0	0.1	6.1	--	6.2	485.8	--
Right abutment	22.8	--	498.7	--	493.0	0.1	3.3	--	3.4	489.6	--

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 WORCTH00200028 on Town Highway 20, crossing Minister Brook, Worcester, 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/pile 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-year discharge is 1,760 cubic-feet per second											
Left abutment	0.0	--	498.7	--	492.0	0.0	5.6	--	5.6	486.4	--
Right abutment	22.8	--	498.7	--	493.0	0.0	5.0	--	5.0	488.0	--

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

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U.S. Geological Survey, 1968, Mount Worcester, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Aerial photography, 1966, Contour interval, 20 feet, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File worc028.1.wsp
T2        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
T3        Town Highway 20 over Minister Brook, Worcester, VT
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*           1160.0   1760.0
Q            910.0
WS          492.28
*
XT   EXTEM     -23
GR         -111.4, 502.13    -76.8, 494.83    -35.5, 494.85     -8.5, 494.54
GR           -2.4, 492.36      0.0, 491.16      3.6, 491.17      8.8, 490.90
GR           14.0, 491.32     20.6, 491.15     25.6, 491.23     27.7, 492.18
GR           32.8, 494.39     33.0, 502.13
*
XS   EXIT1     -67  * * *  0.0385
GT
N           0.067        0.070
SA                  -8.5
*
XS   EXITX     -23  * * *  0.0385
GT
*
XS   FULLV       0  * * *   0.0276
GT
*
*              SRD     LSEL    XSSKEW
BR   BRIDG      0    498.68       0.0
GR            0.0, 498.67      0.0, 492.76      1.2, 492.75
GR            1.4, 491.97      3.2, 491.68      7.0, 491.51     12.8, 491.52
GR           15.4, 491.54     20.3, 492.45     21.5, 493.02     21.6, 493.26
GR           22.8, 493.31     22.8, 498.70      0.0, 498.67
*
*        BRTYPE  BRWDTH        WWANGL    WWWID
CD            1      27.4 * *      56.8      5.2
N           0.043
*
*              SRD    EMBWID   IPAVE
XR   RDWAY      10      15.9      2
GR         -216.3, 508.06   -168.0, 505.50    -77.1, 501.15    -25.1, 500.48
GR           -1.9, 500.18     -1.9, 500.69      0.0, 500.69     23.0, 500.72
GR           24.9, 500.72     25.0, 500.07     67.8, 500.11     73.4, 500.09
GR          117.5, 501.35    177.5, 504.64    238.0, 509.69
*
AS   APPR1      40
GR         -100.9, 513.40    -72.7, 509.90    -59.5, 504.69    -26.1, 499.58
GR           -9.3, 500.20      0.0, 493.93      2.2, 492.25      6.3, 492.01
GR            9.1, 491.82     12.8, 491.99     15.9, 493.02     17.4, 493.89
GR           23.6, 497.73     31.2, 498.68     46.4, 498.14     55.3, 497.24
GR           61.8, 492.43     65.5, 492.06     68.4, 492.07     70.1, 491.91
GR           71.6, 492.09     76.7, 497.19    126.9, 501.25    138.2, 504.44
GR          216.4, 507.84
*
N           0.067        0.060        0.047
SA                   -9.3         76.7
*
HP 1 BRIDG 495.56 1 495.56
HP 2 BRIDG 495.56 * * 910
HP 1 APPR1 498.07 1 498.07
HP 2 APPR1 498.07 * * 1160
*
EX
ER
```

```
T1        U.S. Geological Survey WSPRO Input File worc028.2.wsp
T2        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
T3        Town Highway 20 over Minister Brook, Worcester, VT
*
J1         * * 0.005
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*           1760.0   1540.0
Q           1410.0   1210.0
WS          491.15   490.92
*
XT   EXTEM    -23
GR         -111.4, 502.13    -76.8, 494.83    -35.5, 494.85     -8.5, 494.54
GR           -2.4, 492.36      0.0, 491.16      3.6, 491.17      8.8, 490.90
GR           14.0, 491.32     20.6, 491.15     25.6, 491.23     27.7, 492.18
GR           32.8, 494.39     33.0, 502.13
*            70.8, 488.67     73.1, 488.08     76.5, 488.50     88.3, 489.58
*            97.0, 494.39    106.6, 498.36    122.7, 498.25
*
XS   EXIT1    -67  * * *  0.0385
GT
N           0.067        0.070       0.075       0.070
SA                  -8.5        32.8        59.4
*
XS   EXITX    -23  * * *  0.0385
GT
*
XS   FULLV      0  * * *   0.0276
GT
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0    498.68      0.0
GR            0.0, 498.67      0.0, 492.76      1.2, 492.75
GR            1.4, 491.97      3.2, 491.68      7.0, 491.51     12.8, 491.52
GR           15.4, 491.54     20.3, 492.45     21.5, 493.02     21.6, 493.26
GR           22.8, 493.31     22.8, 498.70      0.0, 498.67
*
*        BRTYPE  BRWDTH        WWANGL    WWWID
CD          1      27.4 * *     56.8      5.2
N           0.043
*
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     10      15.9     2
GR         -216.3, 508.06   -168.0, 505.50    -77.1, 501.15    -25.1, 500.48
GR           -1.9, 500.18     -1.9, 500.69      0.0, 500.69     23.0, 500.72
GR           24.9, 500.72     25.0, 500.07     67.8, 500.11     73.4, 500.09
GR          117.5, 501.35    177.5, 504.64    238.0, 509.69
*
*
AS   APPR1     40          0.
GR         -100.9, 513.40    -72.7, 509.90    -59.5, 504.69    -26.1, 499.58
GR           -9.3, 500.20      0.0, 493.93      2.2, 492.25      6.3, 492.01
GR            9.1, 491.82     12.8, 491.99     15.9, 493.02     17.4, 493.89
GR           23.6, 497.73     31.2, 498.68     46.4, 498.14     55.3, 497.24
GR           61.8, 492.43     65.5, 492.06     68.4, 492.07     70.1, 491.91
GR           71.6, 492.09     76.7, 497.19    126.9, 501.25    138.2, 504.44
GR          216.4, 507.84
*
N           0.067        0.060        0.047
SA                   -9.3         76.7
*
HP 1 BRIDG 498.70 1 498.70
HP 2 BRIDG 498.70 * * 1331
HP 1 BRIDG 496.17 1 496.17
HP 2 RDWAY 500.56 * * 76
HP 1 APPR1 500.58 1 500.58
HP 2 APPR1 500.58 * * 1760
*
HP 1 BRIDG 498.70 1 498.70
HP 2 BRIDG 498.70 * * 1210
HP 1 BRIDG 495.93 1 495.93
HP 1 APPR1 500.12 1 500.12
HP 2 APPR1 500.12 * * 1540
*
EX
ER
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APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File worc028.1.wsp
        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
        Town Highway 20 over Minister Brook, Worcester, VT
           *** RUN DATE & TIME: 07-02-98  13:08

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1      84.    5883.   23.    29.                         908.
   495.56           84.    5883.   23.    29.  1.00     0.    23.    908.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       495.56     0.0    22.8    83.6    5883.     910.  10.89

X STA.         0.0        3.1        4.0        4.9        5.8        6.6
  A(I)             10.5        3.4        3.5        3.5        3.5
  V(I)             4.34      13.23      12.97      13.15      13.10

X STA.         6.6        7.5        8.3        9.2       10.1       10.9
  A(I)              3.4        3.5        3.4        3.5        3.5
  V(I)            13.44      13.04      13.25      12.95      12.95

X STA.        10.9       11.8       12.7       13.5       14.4       15.2
  A(I)              3.5        3.5        3.5        3.5        3.4
  V(I)            13.07      13.08      12.93      13.06      13.47

X STA.        15.2       16.1       17.1       18.1       19.2       22.8
  A(I)              3.5        3.5        3.6        3.9        9.9
  V(I)            12.86      12.84      12.55      11.79       4.57

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             2     227.   12449.   62.    69.                        2464.
             3       5.      88.   11.    11.                          18.
   498.07          232.   12536.   73.    80.  1.02    -6.    88.   2320.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.07    -6.1    87.6   231.8   12536.    1160.   5.00

X STA.        -6.1        1.3        3.0        4.5        5.9        7.3
  A(I)             19.0        9.3        8.7        8.7        8.7
  V(I)             3.06       6.25       6.63       6.69       6.64

X STA.         7.3        8.8       10.2       11.7       13.2       14.5
  A(I)              8.9        8.8        9.0        9.3        7.3
  V(I)             6.49       6.57       6.43       6.25       7.99

X STA.        14.5       15.6       61.5       63.1       64.7       66.2
  A(I)              6.1       45.5        9.4        9.2        8.9
  V(I)             9.47       1.27       6.15       6.31       6.50

X STA.        66.2       67.7       69.2       70.6       72.2       87.6
  A(I)              9.1        8.7        8.7        9.3       19.1
  V(I)             6.40       6.68       6.65       6.21       3.04
```

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WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V060188            MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File worc028.2.wsp
        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
        Town Highway 20 over Minister Brook, Worcester, VT
           *** RUN DATE & TIME: 07-02-98  12:52

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1     155.   10334.    0.    58.                           0.
   498.70          155.   10334.    0.    58.  1.00     0.    23.      0.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.70     0.0    22.8   154.8   10334.    1331.   8.60

X STA.         0.0         2.9         3.8         4.7         5.6         6.6
  A(I)             18.4         6.5         6.5         6.6         6.6
  V(I)             3.62       10.17       10.32       10.14       10.14

X STA.         6.6         7.5         8.4         9.3        10.2        11.1
  A(I)              6.4         6.6         6.6         6.6         6.6
  V(I)            10.42       10.11       10.04       10.15       10.15

X STA.        11.1        12.1        13.0        13.9        14.8        15.7
  A(I)              6.6         6.6         6.5         6.6         6.5
  V(I)            10.03       10.03       10.28       10.12       10.20

X STA.        15.7        16.7        17.6        18.7        19.7        22.8
  A(I)              6.7         6.6         6.8         6.9        17.7
  V(I)             9.98       10.09        9.72        9.59        3.76

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1      97.    7397.   23.    30.                        1144.
   496.17           97.    7397.   23.    30.  1.00     0.    23.   1144.

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = RDWAY;  SRD =      10.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.56   -31.3    89.8    32.2     346.      76.   2.36

X STA.       -31.3        -9.8        -4.0        26.8        29.5        32.2
  A(I)              3.0         1.8         1.7         1.3         1.3
  V(I)             1.28        2.08        2.24        2.88        2.91

X STA.        32.2        35.1        38.1        41.1        44.1        47.2
  A(I)              1.4         1.4         1.4         1.4         1.4
  V(I)             2.70        2.68        2.68        2.63        2.65

X STA.        47.2        50.3        53.4        56.5        59.7        62.7
  A(I)              1.5         1.4         1.5         1.5         1.4
  V(I)             2.62        2.63        2.62        2.60        2.81

X STA.        62.7        65.7        68.9        71.8        74.8        89.8
  A(I)              1.4         1.4         1.3         1.4         3.2
  V(I)             2.75        2.69        2.88        2.74        1.17

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1      15.     244.   23.    23.                          67.
             2     433.   29786.   86.    94.                        5511.
             3      71.    3195.   42.    42.                         525.
   500.58          519.   33225.  151.   159.  1.08   -33.   119.   5239.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.58   -32.6   118.6   518.8   33225.    1760.   3.39

X STA.       -32.6         0.2         2.7         4.9         7.1         9.2
  A(I)             48.7        19.8        18.4        18.7        18.3
  V(I)             1.81        4.44        4.78        4.70        4.80

X STA.         9.2        11.4        13.6        16.2        19.7        38.9
  A(I)             18.6        19.3        20.2        22.5        49.3
  V(I)             4.72        4.56        4.35        3.92        1.78

X STA.        38.9        55.7        60.4        63.0        65.3        67.5
  A(I)             44.3        25.1        20.8        19.0        19.1
  V(I)             1.98        3.50        4.23        4.63        4.62

X STA.        67.5        69.7        71.9        75.9        84.0       118.6
  A(I)             18.5        18.8        25.1        25.7        48.4
  V(I)             4.75        4.69        3.50        3.43        1.82
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WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V060188           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File worc028.2.wsp
        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
        Town Highway 20 over Minister Brook, Worcester, VT
           *** RUN DATE & TIME: 07-02-98  12:52

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1     155.   10334.    0.    58.                           0.
   498.70          155.   10334.    0.    58.  1.00     0.    23.       0.

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

         WSEL     LEW     REW    AREA        K        Q    VEL
       498.70     0.0    22.8   154.8   10334.    1210.   7.82

X STA.         0.0        2.9        3.8        4.7        5.6        6.6
  A(I)            18.4        6.5        6.5        6.6        6.6
  V(I)            3.29       9.24       9.38       9.22       9.21

X STA.         6.6        7.5        8.4        9.3       10.2       11.1
  A(I)             6.4        6.6        6.6        6.6        6.6
  V(I)            9.48       9.19       9.12       9.23       9.23

X STA.        11.1       12.1       13.0       13.9       14.8       15.7
  A(I)             6.6        6.6        6.5        6.6        6.5
  V(I)            9.12       9.12       9.34       9.20       9.27

X STA.        15.7       16.7       17.6       18.7       19.7       22.8
  A(I)             6.7        6.6        6.8        6.9       17.7
  V(I)            9.07       9.18       8.84       8.71       3.42

    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1      92.    6790.   23.    30.                        1049.
   495.93           92.    6790.   23.    30.  1.00     0.    23.    1049.

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

     WSEL  SA#     AREA        K  TOPW   WETP  ALPH    LEW    REW     QCR
             1       5.      45.   18.    18.                          14.
             2     393.   25415.   86.    94.                        4776.
             3      53.    2166.   36.    36.                         365.
   500.12          451.   27626.  140.   148.  1.06   -30.   113.    4462.

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPR1;  SRD =      40.

         WSEL     LEW     REW    AREA        K        Q    VEL
       500.12   -29.6   112.9   451.3   27626.    1540.   3.41

X STA.       -29.6        0.7        2.9        5.0        7.0        9.0
  A(I)            37.8       16.7       16.6       16.2       16.1
  V(I)            2.04       4.61       4.64       4.76       4.79

X STA.         9.0       10.9       13.0       15.3       18.1       22.6
  A(I)            16.3       16.8       17.4       19.1       19.7
  V(I)            4.71       4.58       4.43       4.03       3.91

X STA.        22.6       56.6       60.6       63.0       65.1       67.2
  A(I)            69.1       21.3       17.7       16.7       16.8
  V(I)            1.11       3.61       4.34       4.60       4.58

X STA.        67.2       69.2       71.2       73.9       81.2      112.9
  A(I)            16.5       15.8       19.1       24.6       40.7
  V(I)            4.66       4.86       4.03       3.13       1.89
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WSPRO OUTPUT FILE (continued)

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WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V060188             MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File worc028.1.wsp
        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
        Town Highway 20 over Minister Brook, Worcester, VT
           *** RUN DATE & TIME: 07-02-98  13:08

 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1":  USED WSI = CRWS.
                           WSI,CRWS =    492.36     492.65

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

EXIT1:XS   ******    -8.     101.  1.26 *****  493.91  492.65    910.  492.65
      -65. ******    33.    3898.  1.00 ***** *******    1.00    9.00

 ===125 FR# EXCEEDS FNTEST AT SECID "EXITX":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.92     494.76     494.26

 ===110 WSEL NOT FOUND AT SECID "EXITX":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   492.15     502.13    0.50

 ===115 WSEL NOT FOUND AT SECID "EXITX":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   492.15     502.13     494.26

EXITX:XS      42.   -28.     124.  0.86  1.72  495.63  494.26    910.  494.76
      -23.    42.    33.    5189.  1.03  0.00    0.00    0.92    7.35

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.15     495.50     494.90

 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   494.26     502.76    0.50

 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   494.26     502.76     494.90

FULLV:FV      23.   -77.     132.  0.80  0.67  496.30  494.90    910.  495.50
        0.    23.    33.    5497.  1.08  0.00    0.01    1.16    6.92
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR1:AS      40.    -4.     147.  0.59  0.81  497.11 *******    910.  496.52
       40.    40.    76.    7422.  1.00  0.00    0.00    0.60    6.18
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                  SECID "BRIDG"      Q,CRWS =     910.     495.56

            <<<<<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      23.     0.      84.  1.84 *****  497.40  495.56    910.  495.56
        0.    23.    23.    5893.  1.00 ***** *******    1.00   10.88

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  498.68 ****** ****** ******

    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      13.    -6.     232.  0.25  0.25  498.31  495.40    910.  498.07
       40.    23.    88.   12522.  1.02  0.65    0.00    0.39    3.93

      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.715  0.523    5979.     3.    26.   497.94

                    <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW      Q        K      AREA     VEL   WSEL
   EXIT1:XS     -65.    -8.    33.    910.    3898.     101.    9.00  492.65
   EXITX:XS     -23.   -28.    33.    910.    5189.     124.    7.35  494.76
   FULLV:FV       0.   -77.    33.    910.    5497.     132.    6.92  495.50
   BRIDG:BR       0.     0.    23.    910.    5893.      84.   10.88  495.56
   RDWAY:RG      10.**************      0.******************    2.00********
   APPR1:AS      40.    -6.    88.    910.   12522.     232.    3.93  498.07

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR1:AS       3.    26.    5979.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
   EXIT1:XS    492.65    1.00  489.28  500.51************  1.26  493.91  492.65
   EXITX:XS    494.26    0.92  490.90  502.13  1.72  0.00  0.86  495.63  494.76
   FULLV:FV    494.90    1.16  491.53  502.76  0.67  0.00  0.80  496.30  495.50
   BRIDG:BR    495.56    1.00  491.51  498.70************  1.84  497.40  495.56
   RDWAY:RG  ***************  500.07  509.69**********************************
   APPR1:AS    495.40    0.39  491.82  513.40  0.25  0.65  0.25  498.31  498.07
  ER
```
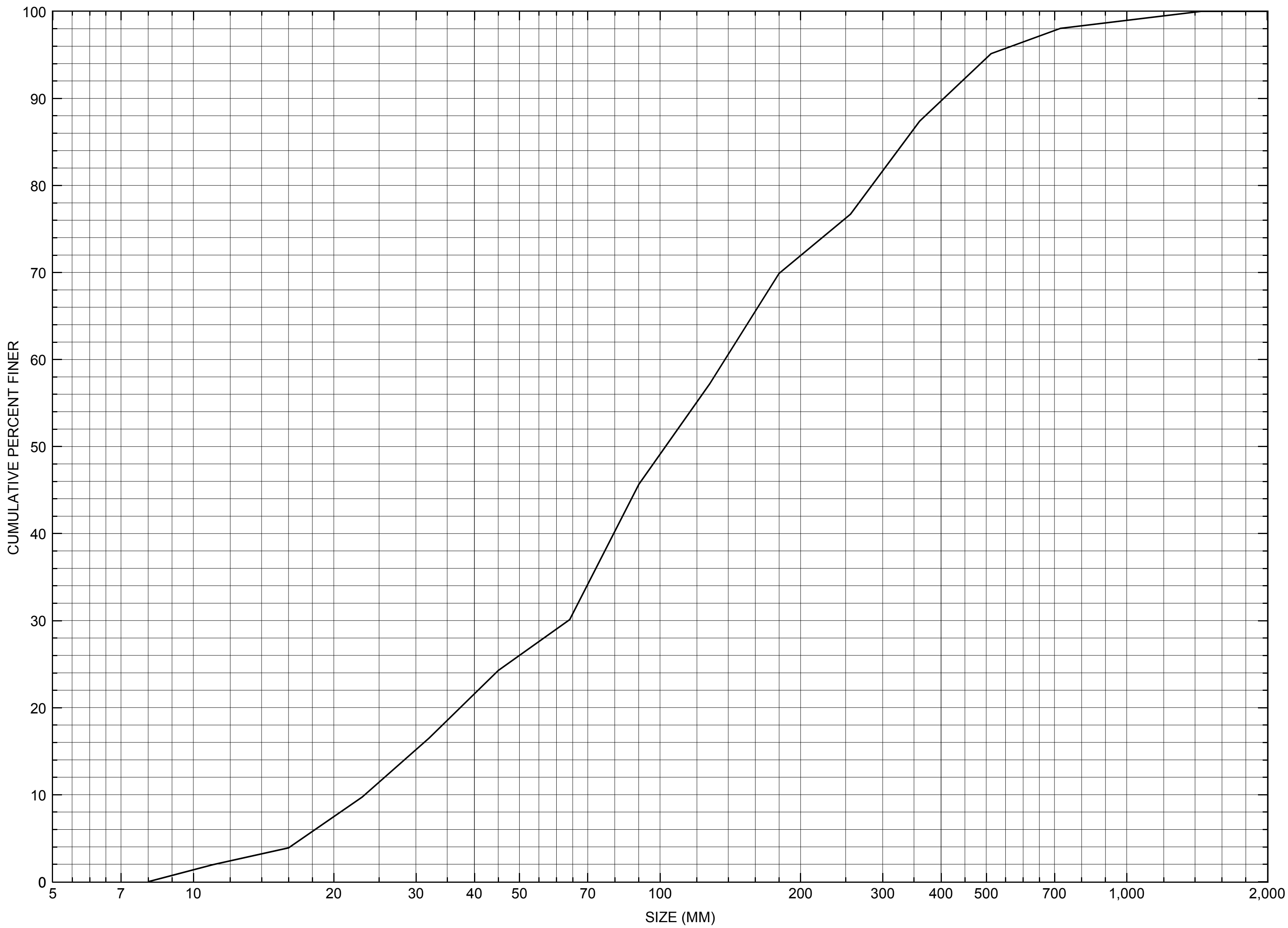

WSPRO OUTPUT FILE (continued)

```
 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1":  USED WSI = CRWS.
                               WSI,CRWS =   491.15     493.84

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

EXIT1:XS   ******   -80.     206.  0.94 *****  494.78  493.84   1410.  493.84
      -67. ******    33.    8645.  1.29 ***** *******    1.01    6.83

 ===125 FR# EXCEEDS FNTEST AT SECID "EXITX":  TRIALS CONTINUED.
               FNTEST,FR#,WSEL,CRWS =  0.80    1.42     495.13     495.54
 ===110 WSEL NOT FOUND AT SECID "EXITX":  REDUCED DELTAY.
                    WSLIM1,WSLIM2,DELTAY =   493.34     502.13    0.50
 ===115 WSEL NOT FOUND AT SECID "EXITX":  USED WSMIN = CRWS.
                    WSLIM1,WSLIM2,CRWS =   493.34     502.13     495.54
 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
               ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "EXITX"
                    WSBEG,WSEND,CRWS =   495.54     502.13     495.54

EXITX:XS      44.   -80.     206.  0.94 *****  496.47  495.54   1410.  495.54
      -23.    44.    33.    8645.  1.29 ***** *******    1.01    6.83

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
               FNTEST,FR#,WSEL,CRWS =  0.80    1.03     496.15     496.17
 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                    WSLIM1,WSLIM2,DELTAY =   495.04     502.76    0.50
 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                    WSLIM1,WSLIM2,CRWS =   495.04     502.76     496.17
 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
               ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "FULLV"
                    WSBEG,WSEND,CRWS =   496.17     502.76     496.17

FULLV:FV      23.   -80.     206.  0.94 *****  497.11  496.17   1410.  496.17
        0.    23.    33.    8645.  1.29 ***** *******    1.01    6.83
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR1:AS      40.    -5.     175.  1.01  0.98  498.12 *******   1410.  497.11
       40.    40.    77.    9424.  1.00  0.04    0.00    0.75    8.04
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
            WS3,WSIU,WS1,LSEL =   496.82     499.75     499.94     498.68

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

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

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

BRIDG:BR      23.     0.     155.  1.15 *****  499.85  496.63   1331.  498.70
        0. ******    23.   10334.  1.00 ***** *******    0.58    8.59

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.466  0.000  498.68 ****** ****** ******

   XSID:CODE     SRD   FLEN    HF   VHD      EGL     ERR       Q    WSEL
  RDWAY:RG       10.    24.  0.04  0.12  500.66    0.00     76.  500.56

          Q    WLEN    LEW     REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
  LT:    12.    29.   -31.     -2.   0.4   0.2   2.2   2.2   0.3   2.7
  RT:    64.    65.    25.     90.   0.5   0.4   2.9   2.4   0.5   2.7

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

APPR1:AS      13.   -33.     518.  0.12  0.12  500.70  496.36   1410.  500.58
       40.    22.   119.   33193.  1.08  0.66    0.00    0.27    2.72

       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
   EXIT1:XS      -67.   -80.    33.   1410.    8645.     206.    6.83  493.84
   EXITX:XS      -23.   -80.    33.   1410.    8645.     206.    6.83  495.54
   FULLV:FV        0.   -80.    33.   1410.    8645.     206.    6.83  496.17
   BRIDG:BR        0.     0.    23.   1331.   10334.     155.    8.59  498.70
   RDWAY:RG       10.*******    12.     76.******************    2.00  500.56
   APPR1:AS       40.   -33.   119.   1410.   33193.     518.    2.72  500.58

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR1:AS  **********************

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX     HF     HO  VHD      EGL    WSEL
   EXIT1:XS    493.84    1.01  489.21  500.44************  0.94  494.78  493.84
   EXITX:XS    495.54    1.01  490.90  502.13************  0.94  496.47  495.54
   FULLV:FV    496.17    1.01  491.53  502.76************  0.94  497.11  496.17
   BRIDG:BR    496.63    0.58  491.51  498.70************  1.15  499.85  498.70
   RDWAY:RG  ***************  500.07  509.69  0.04******  0.12  500.66  500.56
   APPR1:AS    496.36    0.27  491.82  513.40  0.12  0.66  0.12  500.70  500.58
```

```
WSPRO         FEDERAL HIGHWAY ADMINISTRATION - U. S. GEOLOGICAL SURVEY
V060188           MODEL  FOR  WATER-SURFACE  PROFILE  COMPUTATIONS

        U.S. Geological Survey WSPRO Input File worc028.2.wsp
        Hydraulic analysis for structure WORCTH00200028   Date: 17-JUL-97
        Town Highway 20 over Minister Brook, Worcester, VT
           *** RUN DATE & TIME: 07-02-98  12:52

 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1":  USED WSI = CRWS.
                          WSI,CRWS =    490.92     493.60

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

EXIT1:XS   ******   -79.     179.  0.90 *****  494.50  493.60   1210.  493.60
      -67. ******    33.    7371.  1.27 ***** *******    1.06    6.75

 ===125 FR# EXCEEDS FNTEST AT SECID "EXITX":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.47     494.92     495.30
 ===110 WSEL NOT FOUND AT SECID "EXITX":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   493.10     502.13     0.50
 ===115 WSEL NOT FOUND AT SECID "EXITX":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    493.10     502.13     495.30
 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
              ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "EXITX"
                   WSBEG,WSEND,CRWS =    495.30     502.13     495.30

EXITX:XS      44.   -79.     179.  0.90 *****  496.19  495.30   1210.  495.30
      -23.    44.    33.    7371.  1.27 ***** *******    1.06    6.75

 ===125 FR# EXCEEDS FNTEST AT SECID "FULLV":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.07     495.92     495.93
 ===110 WSEL NOT FOUND AT SECID "FULLV":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   494.80     502.76     0.50
 ===115 WSEL NOT FOUND AT SECID "FULLV":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =    494.80     502.76     495.93

FULLV:FV      23.   -79.     179.  0.90  0.62  496.83  495.93   1210.  495.93
        0.    23.    33.    7371.  1.27  0.00    0.02    1.06    6.75
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPR1:AS      40.    -4.     166.  0.83  0.91  497.74 *******   1210.  496.92
       40.    40.    76.    8734.  1.00  0.00    0.01    0.69    7.30
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   496.33     499.01     499.24     498.68
 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

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

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

BRIDG:BR      23.     0.     155.  0.95 *****  499.65  496.33   1209.  498.70
        0. ******    23.   10334.  1.00 ***** *******    0.53    7.81

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.443  0.000  498.68 ****** ****** ******

    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      13.   -30.     451.  0.12  0.12  500.24  496.00   1210.  500.12
       40.    22.   113.   27598.  1.06  0.66    0.00    0.27    2.68

       M(G)   M(K)        KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ******   500.07

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>

  FIRST USER DEFINED TABLE.

    XSID:CODE     SRD     LEW     REW       Q        K      AREA     VEL    WSEL
   EXIT1:XS      -67.    -79.     33.   1210.     7371.      179.    6.75  493.60
   EXITX:XS      -23.    -79.     33.   1210.     7371.      179.    6.75  495.30
   FULLV:FV        0.    -79.     33.   1210.     7371.      179.    6.75  495.93
   BRIDG:BR        0.      0.     23.   1209.    10334.      155.    7.81  498.70
   RDWAY:RG       10.**************      0.        0.         0.    2.00********
   APPR1:AS       40.    -30.    113.   1210.    27598.      451.    2.68  500.12

    XSID:CODE   XLKQ   XRKQ       KQ
   APPR1:AS   ***********************

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS      FR#    YMIN    YMAX     HF    HO   VHD      EGL    WSEL
   EXIT1:XS    493.60     1.06  489.21  500.44************  0.90  494.50  493.60
   EXITX:XS    495.30     1.06  490.90  502.13************  0.90  496.19  495.30
   FULLV:FV    495.93     1.06  491.53  502.76  0.62  0.00  0.90  496.83  495.93
   BRIDG:BR    496.33     0.53  491.51  498.70************  0.95  499.65  498.70
   RDWAY:RG  ***************  500.07  509.69************  0.12  500.19********
   APPR1:AS    496.00     0.27  491.82  513.40  0.12  0.66  0.12  500.24  500.12
  ER
  NORMAL  END  OF  WSPRO  EXECUTION.
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure WORCTH00200028, in Worcester, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number **WORCTH00200028**

General Location Descriptive

Data collected by *(First Initial, Full last name)* **L**. **Medalie**

Date *(MM/DD/YY)* **10** / **13** / **95**

Highway District Number *(I - 2; nn)* **06**

County *(FIPS county code; I - 3; nnn)* **023**

Town *(FIPS place code; I - 4; nnnnn)* **86125**

Mile marker *(I - 11; nnn.nnn)* **000000**

Waterway *(I - 6)* **MINISTER BROOK**

Road Name *(I - 7):* **-**

Route Number **C3020**

Vicinity *(I - 9)* **0.1 MI TO JCT W CL3 TH3**

Topographic Map **Mount.Worcester**

Hydrologic Unit Code: **02010003**

Latitude *(I - 16; nnnn.n)* **44237**

Longitude *(i - 17; nnnnn.n)* **72355**

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* **10122000281220**

Maintenance responsibility *(I - 21; nn)* **03**

Maximum span length *(I - 48; nnnn)* **0027**

Year built *(I - 27; YYYY)* **1919**

Structure length *(I - 49; nnnnnn)* **000030**

Average daily traffic, ADT *(I - 29; nnnnnn)* **000030**

Deck Width *(I - 52; nn.n)* **159**

Year of ADT *(I - 30; YY)* **91**

Channel & Protection *(I - 61; n)* **5**

Opening skew to Roadway *(I - 34; nn)* **00**

Waterway adequacy *(I - 71; n)* **4**

Operational status *(I - 41; X)* **B**

Underwater Inspection Frequency *(I - 92B; XYY)* **N**

Structure type *(I - 43; nnn)* **302**

Year Reconstructed *(I - 106)* **0000**

Approach span structure type *(I - 44; nnn)* **000**

Clear span (*nnn.n ft*) **24**

Number of spans *(I - 45; nnn)* **001**

Vertical clearance from streambed (*nnn.n ft*) **5**

Number of approach spans *(I - 46; nnnn)* **0000**

Waterway of full opening (*nnn.n* ft^2) **120**

Comments:

According to the structural inspection report dated 7/14/95, the structure has a wooden deck with wood post guard rails and the superstructure consists of 5 I-beam stringers. Minor cracks are noted on the abutments and wingwalls. No footings are exposed and no undermining is noted. Channel scour is described as normal. The boulder-lined embankments show signs of past flooding. A bar consisting of mainly boulders is noted at the right abutment and debris is minor. Stone fill is noted as good around the abutments. Hydraulic adequacy is described as possibly narrow. The abutments are laid-up river boulders with concrete caps. The inspection report dated 10/18/93 states that the **(continued on page 34)**

Bridge Hydrologic Data

Is there hydrologic data available? **Y** *if No, type ctrl-n h* VTAOT Drainage area *(mi^2)*: **4.96**

Terrain character: **Hilly to mountainous, mostly forested**

Stream character & type: -

Streambed material: -

Discharge Data *(cfs)*: $Q_{2.33}$ **400** Q_{10} **800** Q_{25} **1080**
Q_{50} **1280** Q_{100} **1480** Q_{500} -

Record flood date *(MM / DD / YY)*: - / - / - Water surface elevation *(ft)*: -

Estimated Discharge *(cfs)*: - Velocity at Q - *(ft/s)*: -

Ice conditions *(Heavy, Moderate, Light)* : - Debris *(Heavy, Moderate, Light)*: -

The stage increases to maximum highwater elevation (*Rapidly, Not rapidly*): -

The stream response is (*Flashy, Not flashy*): -

Describe any significant site conditions upstream or downstream that may influence the stream's stage: **This hydraulic report is for the combined flow through structures 24 and 28, from a 1979 report. Bridge 24 is an overflow for bridge 28. Until 1979, bridge 24 was a 16.5 by 8 ft bridge. It was washed out in a flood. Currently, it is a 4 ft corrugated, galvanized metal pipe.**
Bridge 28 is on the main channel and bridge 24 is on an overflow/side channel.

Watershed storage area (*in percent*): - %

The watershed storage area is: - (*1-mainly at the headwaters; 2- uniformly distributed; 3-immediatly upstream oi the site*)

Water Surface Elevation Estimates for Existing Structure:

Peak discharge frequency	$Q_{2.33}$	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Water surface elevation (*ft*))	-	**485.7**	**486.4**	**486.8**	**487.1**
Velocity (*ft / sec*)	**487.4**	-	-	-	-

Long term stream bed changes: -

Is the roadway overtopped below the Q_{100}? (*Yes, No, Unknown*): **U** Frequency: -

Relief Elevation (*ft*): - Discharge over roadway at Q_{100} (*ft^3/ sec*): -

Are there other structures nearby? (*Yes, No, Unknown*): **U** *If No or Unknown, type ctrl-n os*

Upstream distance (*miles*): - Town: - Year Built: -

Highway No. : - Structure No. : - Structure Type: -

Clear span (*ft*): - Clear Height (*ft*): - Full Waterway (*ft^2*): -

Downstream distance (*miles*): **1** Town: **Worcester** Year Built: **1960**

Highway No. : **TH 21** Structure No. : **26** Structure Type: **steel beam**

Clear span (*ft*): **19** Clear Height (*ft*): **7** Full Waterway (ft^2): **133**

Comments:

left abutment, in general, appears to be quite unstable.

Water surface elevations above are design elevations for a proposed 15 x 6 foot bridge to replace existing bridge 24.
Notes in hydraulics folder indicate a WSPRO analysis was done on this bridge in 1979.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **4.68** mi^2 Lake/pond/swamp area **0** mi^2

Watershed storage *(ST)* **0** %

Bridge site elevation **1180** ft Headwater elevation **3642** ft

Main channel length **3.53** mi

10% channel length elevation **1300** ft 85% channel length elevation **2640** ft

Main channel slope *(S)* **506.13** ft / mi

Watershed Precipitation Data

Average site precipitation **-** in Average headwater precipitation **-** in

Maximum 2yr-24hr precipitation event *(I24,2)* **-** in

Average seasonal snowfall *(Sn)* **-** ft

Bridge Plan Data

Are plans available? N *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: - / -

Project Number -   Minimum channel bed elevation: -

Low superstructure elevation: USLAB - DSLAB - USRAB - DSRAB -

Benchmark location description:

No benchmark information was available

Reference Point (*MSL, Arbitrary, Other*): -   Datum (*NAD27, NAD83, Other*): -

Foundation Type: 4 (*1-Spreadfooting; 2-Pile; 3- Gravity; 4-Unknown*)

If 1: Footing Thickness -   Footing bottom elevation: -

If 2: Pile Type: - (*1-Wood; 2-Steel or metal; 3-Concrete*)   Approximate pile driven length: -

If 3: Footing bottom elevation: -

Is boring information available? N *If no, type ctrl-n bi*   Number of borings taken: -

Foundation Material Type: 3 (*1-regolith, 2-bedrock, 3-unknown*)

Briefly describe material at foundation bottom elevation or around piles:

No foundation material information was available.

Comments:

No plans.

Cross-sectional Data

Is cross-sectional data available? Y *If no, type ctrl-n xs*

Source (*FEMA, VTAOT, Other*)? VTAOT

Comments: **This cross section is the upstream face. The low chord elevations are from the survey log done for this report on 7/17/96. The low chord to bed length data are from the sketch attached to a bridge inspection report dated 10/18/93.**

Station	0	3	8	13	24	-	-	-	-	-	-
Feature	LAB				RAB	-	-	-	-	-	-
Low chord elevation	498.7	498.7	498.7	498.8	498.8	-	-	-	-	-	-
Bed elevation	492.8	491.9	492.9	493.7	494.8	-	-	-	-	-	-
Low chord to bed	5.9	6.8	5.8	5.1	4.0	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

Source (*FEMA, VTAOT, Other*)? -

Comments:

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low chord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low chord to bed	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

U. S. Geological Survey
Bridge Field Data Collection and Processing Form

Qa/Qc Check by: **RB** Date: **09/13/96**
Computerized by: **RB** Date: **09/13/96**
Reviewd by: **EMB** Date: **6/30/98**

Structure Number **WORCTH00200028**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **R. FLYNN** Date *(MM/DD/YY)* **07** / **17** / 19**96**

2. Highway District Number **06** Mile marker **000**

County **WASHINGTON (023)** Town **WORCESTER (86125)**

Waterway *(I - 6)* **Minister Brook** Road Name **Kimball Road**

Route Number **TH 20** Hydrologic Unit Code: **02010003**

3. Descriptive comments:

This bridge is located 0.1 mile from the junction with TH 3.

B. Bridge Deck Observations

4. Surface cover... LBUS **6** RBUS **4** LBDS **6** RBDS **6** Overall **6**
*(2b us,ds,lb,rb: **1**- Urban; **2**- Suburban; **3**- Row crops; **4**- Pasture; **5**- Shrub- and brushland; **6**- Forest; **7**- Wetland)*

5. Ambient water surface... US **2** UB **2** DS **2** *(**1**- pool; **2**- riffle)*

6. Bridge structure type **1** *(**1**- single span; **2**- multiple span; **3**- single arch; **4**- multiple arch; **5**- cylindrical culvert; **6**- box culvert; or **7**- other)*

7. Bridge length **30** *(feet)* Span length **27** *(feet)* Bridge width **15.9** *(feet)*

Road approach to bridge:

8. LB **2** RB **2** *(**0** even, **1**- lower, **2**- higher)*

9. LB **2** RB **2** *(**1**- Paved, **2**- Not paved)*

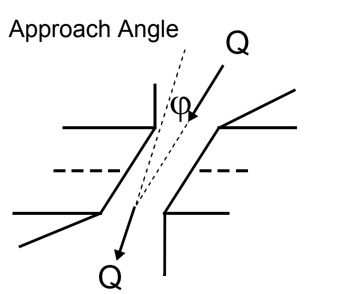
10. Embankment slope (*run / rise in feet / foot*):
US left **--** US right **--**

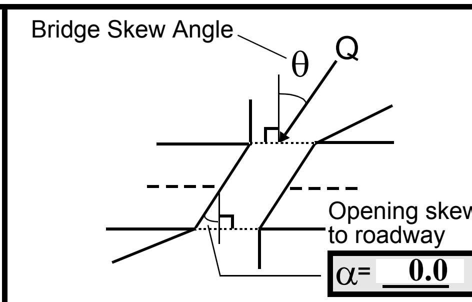
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	2	1	2	1
RBUS	2	1	2	1
RBDS	2	1	2	1
LBDS	2	1	2	1

*Bank protection types: **0**- none; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*
*Erosion: **0** - none; **1**- channel erosion; **2**- road wash; **3**- both; **4**- other*
*Erosion Severity: **0** - none; **1**- slight; **2**- moderate; **3**- severe*

Channel approach to bridge (BF):

15. Angle of approach: **40** 16. Bridge skew: **20**





17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **1**
Range? **5** feet **US** *(US, UB, DS)* to **30** feet **US**

Channel impact zone 2: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **0**
Range? **5** feet **DS** *(US, UB, DS)* to **30** feet **DS**

*Impact Severity: **0**- none to very slight; **1**- Slight; **2**- Moderate; **3**- Severe*

18. Bridge Type: **1a**

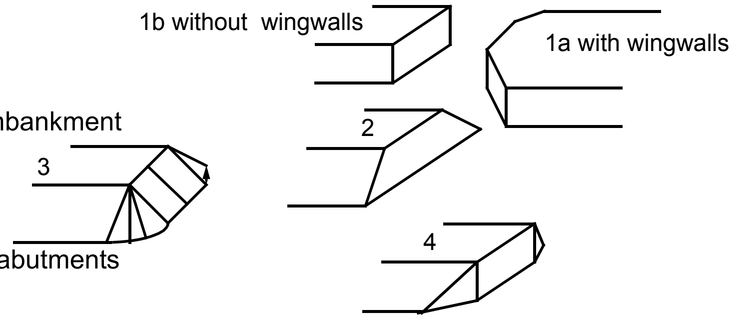
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls parallel to abut. face

3- Spill through abutments

4- Sloping embankment, vertical wingwalls and abutments
Wingwall angle less than 90°.



19. Bridge Deck Comments (surface cover variations, measured bridge and span lengths, bridge type variations, approach overflow width, etc.)

This is a new bridge. According to the right bank landowner, it was constructed in 1994. The deck is 2 by 8 inch wood beams, which have been placed with the 2 inch side facing up and down and the length in the direction of flow. The bridge has 4 by 4 inch wooden curbs and guardrails both US and DS. Wingwalls have an angle less than 90 degrees, but the ends of the wingwalls do not go below low chord. A 6 ft culvert is located on the right bank about 46 ft from the right abutment. The stream is divided between these two structures with most of the flow going through the bridge. There is no scour along the channel with the culvert.

4. There is a strip of trees along the immediate bank then a horse pasture and barn on the upstream right bank.

5. The water is pooled at the US bridge face and is riffled upstream from the upstream face.

7. The bridge dimensions provided on the previous page are from the VTAOT files. The bridge length, span length, and bridge width measured were 27.2, 23.2, and 16.1 ft respectively.

C. Upstream Channel Assessment

20. SRD	21. Bank height (BF) LB	21. Bank height (BF) RB	22. Bank angle (BF) LB	22. Bank angle (BF) RB	26. % Veg. cover (BF) LB	26. % Veg. cover (BF) RB	27. Bank material (BF) LB	27. Bank material (BF) RB	28. Bank erosion (BF) LB	28. Bank erosion (BF) RB
24.0	6.5			4.0	3	3	54	45	1	2

23. Bank width **35.0** 24. Channel width **30.0** 25. Thalweg depth **33.0** 29. Bed Material **452**

30 .Bank protection type: LB **2** RB **1** 31. Bank protection condition: LB **1** RB **2**

SRD - Section ref. dist. to US face *% Vegetation (Veg) cover:* ***1****- 0 to 25%;* ***2****- 26 to 50%;* ***3****- 51 to 75%;* ***4****- 76 to 100%*
Bed and bank Material: ***0****- organics;* ***1****- silt / clay, < 1/16mm;* ***2****- sand, 1/16 - 2mm;* ***3****- gravel, 2 - 64mm;* ***4****- cobble, 64 - 256mm;* ***5****- boulder, > 256mm;* ***6****- bedrock;* ***7****- manmade*
Bank Erosion: ***0****- not evident;* ***1****- light fluvial;* ***2****- moderate fluvial;* ***3****- heavy fluvial / mass wasting*
Bank protection types: ***0****- absent;* ***1****- < 12 inches;* ***2****- < 36 inches;* ***3****- < 48 inches;* ***4****- < 60 inches;* ***5****- wall / artificial levee*
Bank protection conditions: ***1****- good;* ***2****- slumped;* ***3****- eroded;* ***4****- failed*

32. Comments (bank material variation, minor inflows, protection extent, etc.):

28. The right bank is not as well protected as the left bank and some tree roots are exposed.

30. Placed protection along the left bank and the right bank extends to 80 ft US with natural protection intermittent as far as can be seen, greater than 500 ft US.

33. Point/Side bar present? N (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: - 35. Mid-bar width: -

36. Point bar extent: - feet - (US, UB) to - feet - (US, UB, DS) positioned - %LB to - %RB

37. Material: -

38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):

NO POINT BARS

39. Is a cut-bank present? N (Y or if N type ctrl-n cb) 40. Where? - (LB or RB)

41. Mid-bank distance: - 42. Cut bank extent: - feet - (US, UB) to - feet - (US, UB, DS)

43. Bank damage: - (1- eroded and/or creep; 2- slip failure; 3- block failure)

44. Cut bank comments (eg. additional cut banks, protection condition, etc.):

NO CUT BANKS

45. Is channel scour present? Y (Y or if N type ctrl-n cs) 46. Mid-scour distance: 18

47. Scour dimensions: Length 35 Width 5 Depth : 1 Position 0 %LB to 50 %RB

48. Scour comments (eg. additional scour areas, local scouring process, etc.):

Scour is from the US bridge face to 35 ft US.

49. Are there major confluences? N (Y or if N type ctrl-n mc) 50. How many? -

51. Confluence 1: Distance - 52. Enters on - (LB or RB) 53. Type - (1- perennial; 2- ephemeral)

Confluence 2: Distance - Enters on - (LB or RB) Type - (1- perennial; 2- ephemeral)

54. Confluence comments (eg. confluence name):

NO MAJOR CONFLUENCES

D. Under Bridge Channel Assessment

55. Channel restraint (BF)? LB 2 RB ____ (1- natural bank; 2- abutment; 3- artificial levee)

56. Height (BF) LB	RB	57 Angle (BF) LB	RB	61. Material (BF) LB	RB	62. Erosion (BF) LB	RB
17.5		2.0		2	7	7	-

58. Bank width (BF) - 59. Channel width - 60. Thalweg depth 90.0 63. Bed Material -

*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*

*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*

64. Comments (bank material variation, minor inflows, protection extent, etc.):

4532

63. The bed material under the bridge is primarily cobbles and gravel at the US end of the right abutment and cobbles and boulders in mid-channel and along the left abutment.

65. **Debris and Ice** Is there debris accumulation? ____ *(Y or N)* 66. Where? Y ____ *(1- Upstream; 2- At bridge; 3- Both)*

67. Debris Potential 3 ____ *(1- Low; 2- Moderate; 3- High)* 68. Capture Efficiency 3 ____ *(1- Low; 2- Moderate; 3- High)*

69. Is there evidence of ice build-up? 3 ___ *(Y or N)* Ice Blockage Potential N ____ *(1- Low; 2- Moderate; 3- High)*

70. Debris and Ice Comments:

1

67. There are trees and brush on the US banks and at the left abutment.

68. Large rocks and steep slopes US make the capture efficiency high.

Abutments	71. Attack ∠(BF)	72. Slope ∠ (Qmax)	73. Toe loc. (BF)	74. Scour Condition	75. Scour depth	76. Exposure depth	77. Material	78. Length
LABUT		40	90	2	2	1	0.5	90.0
RABUT	1	0	90			2	2	23.0

Pushed: LB or RB *Toe Location (Loc.): 0- even, 1- set back, 2- protrudes*
Scour cond.: 0- not evident; 1- evident (comment); 2- footing exposed; 3-undermined footing; 4- piling exposed; 5- settled; 6- failed
Materials: *1-* Concrete; *2-* Stone masonry or drywall; *3-* steel or metal; *4-* wood

79. Abutment comments (eg. undermined penetration, unusual scour processes, debris, etc.):

0

0.5

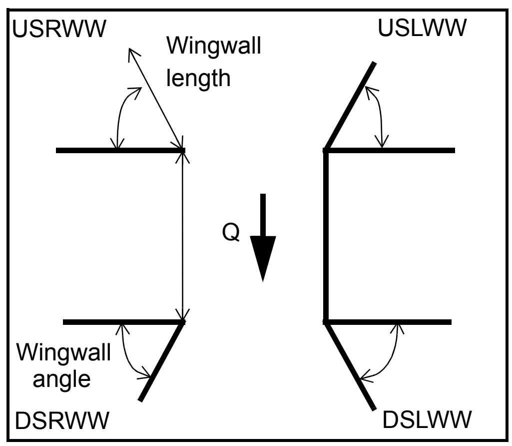
1

Protection along both abutment footings is in good condition. Scour is evident at the DS end of the left abutment. The left abutment footing is exposed 1 ft at the DS end and 0.5 ft at the US end. The right abutment footing is exposed 0.5 ft at the DS end.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						23.0	
USRWW:	Y		1		0	1.5	
DSLWW:	-		-		Y	19.5	
DSRWW:	1		0		-	19.5	

Wingwall materials: 1- Concrete; 2- Stone masonry or drywall; 3- steel or metal; 4- wood



82. **Bank / Bridge Protection**:

Location	USLWW	USRWW	LABUT	RABUT	LB	RB	DSLWW	DSRWW
Type	-	2	Y	0	1	1	1	1
Condition	Y	0	1	0.5	1	1	1	1
Extent	1	0.5	2	2	1	2	1	-

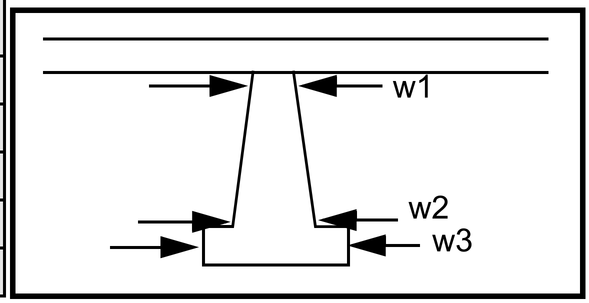
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
-
-
-
-
-
2
1
1
1
1
1

Piers:

84. Are there piers? **82.** *(Y or if N type ctrl-n pr)*

85. Pier no.	width (w) feet			elevation (e) feet		
	w1	w2	w3	e@w1	e@w2	e@w3
Pier 1		**9.5**		**60.0**	**50.0**	**10.0**
Pier 2		**8.5**	**8.0**	**35.0**	**60.0**	-
Pier 3	-	-	-	-	-	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	**The**	**e it**	**.**	-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	**DS**	**meet**		-	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	**left**	**s the**		-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	**wing**	**dow**		-	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	**wall**	**nstre**		-	*Y- yes; N- no*
91. Attack ∠ (BF)	**foot-**	**am**		-	
92. Pushed	**ing is**	**end**		-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	**expo**	**of**		-	
95. Cross-members	**sed**	**the**		-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	**most**	**left**		-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	**ly**	**abut**		-	
98. Exposure depth	**wher**	**ment**	**N**	-	

99. Pier comments (eg. undermined penetration, protection and protection extent, unusual scour processes, etc.):
-
-
-
-
-
-
-
-
-
-

E. Downstream Channel Assessment

100.

SRD	Bank height (BF) LB	Bank height (BF) RB	Bank angle (BF) LB	Bank angle (BF) RB	% Veg. cover (BF) LB	% Veg. cover (BF) RB	Bank material (BF) LB	Bank material (BF) RB	Bank erosion (BF) LB	Bank erosion (BF) RB
-	-			-	-	-	-	-	-	-

Bank width (BF) - Channel width - Thalweg depth - Bed Material -

Bank protection type (Qmax): LB - RB - Bank protection condition: LB - RB -

*SRD - Section ref. dist. to US face % Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

Comments (eg. bank material variation, minor inflows, protection extent, etc.):
-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

101. Is a drop structure present? N *(Y or N, if N type ctrl-n ds)* 102. Distance: - feet

103. Drop: - feet 104. Structure material: O *(**1**- steel sheet pile; **2**- wood pile; **3**- concrete; **4**- other)*

105. Drop structure comments (eg. downstream scour depth):

PIERS

106. Point/Side bar present? _____ *(Y or N. if N type ctrl-n pb)* Mid-bar distance: ______ Mid-bar width: ______

Point bar extent: ______ feet 3 *(US, UB, DS)* to 3 feet 542 *(US, UB, DS)* positioned 542 %LB to 1 %RB

Material: 2

Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

452
2
2
1

Is a cut-bank present? 1 *(Y or if N type ctrl-n cb)* Where? The *(LB or RB)* Mid-bank distance: re is

Cut bank extent: a feet lar *(US, UB, DS)* to ge feet am *(US, UB, DS)*

Bank damage: ou *(**1**- eroded and/or creep; **2**- slip failure; **3**- block failure)*

Cut bank comments (eg. additional cut banks, protection condition, etc.):

nt of debris on the left and right banks.
The protection along the banks extends to 100 ft DS.

Is channel scour present? _____ *(Y or if N type ctrl-n cs)* Mid-scour distance: _______

Scour dimensions: Length ______ Width ______ Depth: _____ Positioned ____ %LB to ____ %RB

Scour comments (eg. additional scour areas, local scouring process, etc.):

Are there major confluences? N *(Y or if N type ctrl-n mc)* How many? -

Confluence 1: Distance NO Enters on DR *(LB or RB)* Type OP *(**1**- perennial; **2**- ephemeral)*

Confluence 2: Distance STR Enters on UC *(LB or RB)* Type TU *(**1**- perennial; **2**- ephemeral)*

Confluence comments (eg. confluence name):

RE

F. Geomorphic Channel Assessment

107. Stage of reach evolution _____

1- *Constructed*
2- *Stable*
3- *Aggraded*
4- *Degraded*
5- *Laterally unstable*
6- *Vertically and laterally unstable*

108. Evolution comments *(Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors)*:

N
-
-
-
-
-
-
-
-
-
NO POINT BARS

109. G. Plan View Sketch

point bar	debris	flow	stone wall
cut-bank	rip rap or stone fill	cross-section	other wall
scour hole		ambient channel	

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number:	WORCTH00200028	Town:	Worcester
Road Number:	TH 20	County:	Washington
Stream:	Minister Brook		

Initials EMB Date: 7/2/98 Checked: RLB

Analysis of contraction scour, live-bed or clear water?

Critical Velocity of Bed Material (converted to English units)
Vc=11.21*y1^0.1667*D50^0.33 with Ss=2.65
(Richardson and Davis, 1995, p. 28, eq. 16)

Approach Section Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	1160	1760	1540
Main Channel Area, ft2	227	433	393
Left overbank area, ft2	0	15	5
Right overbank area, ft2	5	71	53
Top width main channel, ft	62	86	86
Top width L overbank, ft	0	23	18
Top width R overbank, ft	11	42	36
D50 of channel, ft	0.337	0.337	0.337
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	3.7	5.0	4.6
y1, average depth, LOB, ft	ERR	0.7	0.3
y1, average depth, ROB, ft	0.5	1.7	1.5
Total conveyance, approach	12536	33225	27626
Conveyance, main channel	12449	29786	25415
Conveyance, LOB	0	244	45
Conveyance, ROB	88	3195	2166
Percent discrepancy, conveyance	-0.0080	0.0000	0.0000
Qm, discharge, MC, cfs	1151.9	1577.8	1416.7
Ql, discharge, LOB, cfs	0.0	12.9	2.5
Qr, discharge, ROB, cfs	8.1	169.2	120.7
Vm, mean velocity MC, ft/s	5.1	3.6	3.6
Vl, mean velocity, LOB, ft/s	ERR	0.9	0.5
Vr, mean velocity, ROB, ft/s	1.6	2.4	2.3
Vc-m, crit. velocity, MC, ft/s	9.7	10.2	10.0
Vc-l, crit. velocity, LOB, ft/s	ERR	ERR	ERR
Vc-r, crit. velocity, ROB, ft/s	ERR	ERR	ERR

Results

Live-bed(1) or Clear-Water(0) Contraction Scour?			
Main Channel	0	0	0

Armoring
Dc=[(1.94*V^2)/(5.75*log(12.27*y/D90))^2]/[0.03*(165-62.4)]
Depth to Armoring=3*(1/Pc-1)

(Federal Highway Administration, 1993)

Downstream bridge face property	100-yr	500-yr	Other Q
Q, discharge thru bridge MC, cfs	910	1331	1210
Main channel area (DS), ft2	83.6	97	92
Main channel width (normal), ft	22.8	22.8	22.8
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	22.8	22.8	22.8
D90, ft	1.3302	1.3302	1.3302
D95, ft	1.6687	1.6687	1.6687
Dc, critical grain size, ft	0.9659	1.4131	1.3365
Pc, Decimal percent coarser than Dc	0.189	0.087	0.099
Depth to armoring, ft	12.43	44.49	36.49

Clear Water Contraction Scour in MAIN CHANNEL

y2 = (Q2^2/(131*Dm^(2/3)*W2^2))^(3/7)   Converted to English Units
ys=y2-y_bridge
(Richardson and Davis, 1995, p. 32, eq. 20, 20a)

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	1160	1760	1540
(Q) discharge thru bridge, cfs	910	1331	1210
Main channel conveyance	5883	10334	10334
Total conveyance	5883	10334	10334
Q2, bridge MC discharge,cfs	910	1331	1210
Main channel area, ft2	84	155	155
Main channel width (normal), ft	22.8	22.8	22.8
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	22.8	22.8	22.8
y_bridge (avg. depth at br.), ft	3.67	6.79	6.79
Dm, median (1.25*D50), ft	0.42125	0.42125	0.42125
y2, depth in contraction,ft	3.73	5.17	4.77
ys, scour depth (y2-ybridge), ft	0.07	-1.62	-2.02

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation   Hb+Ys=Cq*qbr/Vc
Cq=1/Cf*Cc   Cf=1.5*Fr^0.43 (<=1)   Cc=SQRT[0.10(Hb/(ya-w)-0.56)]+0.79 (<=1)
Umbrell pressure flow equation
(Hb+Ys)/ya=1.1021*[(1-w/ya)*(Va/Vc)]^0.6031
(Richardson and Davis, 1995, p. 144-146)

	Q100	Q500	OtherQ
Q, total, cfs	1160	1760	1540
Q, thru bridge MC, cfs	910	1331	1210
Vc, critical velocity, ft/s	9.68	10.21	10.05
Va, velocity MC approach, ft/s	5.07	3.64	3.60
Main channel width (normal), ft	22.8	22.8	22.8
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	22.8	22.8	22.8
qbr, unit discharge, ft2/s	39.9	58.4	53.1
Area of full opening, ft2	83.6	154.8	154.8
Hb, depth of full opening, ft	3.67	6.79	6.79
Fr, Froude number, bridge MC	0	0.58	0.53
Cf, Fr correction factor (<=1.0)	0.00	1.00	1.00
**Area at downstream face, ft2	N/A	97	92
**Hb, depth at downstream face, ft	ERR	4.25	4.04
**Fr, Froude number at DS face	ERR	1.17	1.15
**Cf, for downstream face (<=1.0)	N/A	1.00	1.00
Elevation of Low Steel, ft	498.68	498.68	498.68
Elevation of Bed, ft	495.01	491.89	491.89
Elevation of Approach, ft	0	500.58	500.12
Friction loss, approach, ft	0	0.12	0.12
Elevation of WS immediately US, ft	0.00	500.46	500.00
ya, depth immediately US, ft	-495.01	8.57	8.11
Mean elevation of deck, ft	500.7	500.7	500.7
w, depth of overflow, ft (>=0)	0.00	0.00	0.00
Cc, vert contrac correction (<=1.0)	ERR	0.94	0.96
**Cc, for downstream face (<=1.0)	ERR	0.79	0.79
Ys, scour w/Chang equation, ft	N/A	-0.72	-1.27
Ys, scour w/Umbrell equation, ft	N/A	-1.72	-1.97

**=for UNsubmerged orifice flow using estimated downstream bridge face properties.

**Ys, scour w/Chang equation, ft	N/A	2.98	2.65
**Ys, scour w/Umbrell equation, ft	ERR	0.82	0.78

In UNsubmerged orifice flow, an adjusted scour depth using the Laursen equation results and the estimated downstream bridge face properties can also be computed (ys=y2-ybridgeDS)

y2, from Laursen's equation, ft	3.73	5.17	4.77
WSEL at downstream face, ft	--	496.63	496.33
Depth at downstream face, ft	N/A	4.25	4.04
Ys, depth of scour (Laursen), ft	N/A	0.92	0.73

Abutment Scour

Froehlich's Abutment Scour
$Ys/Y1 = 2.27*K1*K2*(a'/Y1)^{0.43}*Fr1^{0.61}+1$
(Richardson and Davis, 1995, p. 48, eq. 28)

Characteristic	Left Abutment 100 yr Q	500 yr Q	Other Q	Right Abutment 100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	1160	1760	1540	1160	1760	1540
a', abut.length blocking flow, ft	6.1	32.6	29.6	3.5	8.4	8.4
Ae, area of blocked flow ft2	15.7	42.7	36.9	6.34	18.6	17.1
Qe, discharge blocked abut.,cfs	47.8	--	75.2	8.05	--	18.94
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	3.04	1.81	2.04	1.27	1.78	1.11
ya, depth of f/p flow, ft	2.57	1.31	1.25	1.81	2.21	2.04
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)						
K1	0.82	0.82	0.82	0.82	0.82	0.82
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00
Fr, froude number f/p flow	0.334	0.261	0.322	0.166	0.211	0.137
ys, scour depth, ft	6.13	5.59	5.78	3.31	5.04	4.11

HIRE equation (a'/ya > 25)
$ys = 4*Fr^{0.33}*y1*K/0.55$
(Richardson and Davis, 1995, p. 49, eq. 29)

a'(abut length blocked, ft)	6.1	32.6	29.6	3.5	8.4	8.4
y1 (depth f/p flow, ft)	2.57	1.31	1.25	1.81	2.21	2.04
a'/y1	2.37	24.89	23.74	1.93	3.79	4.13
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.33	0.26	0.32	0.17	0.21	0.14
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	ERR	ERR	ERR
vertical w/ ww's	ERR	ERR	ERR	ERR	ERR	ERR
spill-through	ERR	ERR	ERR	ERR	ERR	ERR

Abutment riprap Sizing

Isbash Relationship
$D50=y*K*Fr^2/(Ss-1)$ and $D50=y*K*(Fr^2)^{0.14}/(Ss-1)$
(Richardson and Davis, 1995, p112, eq. 81,82)

Characteristic	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	1	1	1	1	1	1
y, depth of flow in bridge, ft	3.67	4.25	4.04	3.67	4.25	4.04
Median Stone Diameter for riprap at: left abutment				right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	ERR	ERR	ERR	ERR	ERR
Fr>0.8 (vertical abut.)	1.53	1.78	1.69	1.53	1.78	1.69