LEVEL II SCOUR ANALYSIS FOR BRIDGE 46 (BRIDTH00050046) on TOWN HIGHWAY 5, crossing the NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-311

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

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By SCOTT A. OLSON and DONALD L. SONG

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Pembroke, New Hampshire

1996

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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	VTAT	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 46 (BRIDTH00050046) ON TOWN HIGHWAY 5, CROSSING NORTH BRANCH OTTAUQUECHEE RIVER, BRIDGEWATER, VERMONT

By Scott A. Olson and Donald L. Song

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00050046 on town highway 5 crossing the North Branch Ottauquechee River, Bridgewater, 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, gleaned from Vermont Agency of Transportation (VTAOT) files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Bridgewater. The 5.61-mi² drainage area is a predominantly rural and forested basin. In the vicinity of the study site, the banks are forested. Town highway 5 parallels the upstream left bank.

In the study area, the North Branch Ottauquechee River has a sinuous channel with a slope of approximately 0.015 ft/ft, an average channel top width of 48 ft and an average channel depth of 6 ft. The predominant channel bed materials are gravel and cobble with a median grain size (D_{50}) of 66.2 mm (0.217 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 2 and 3, 1994, indicated that the reach was stable.

The town highway 5 crossing of North Branch Ottauquechee River is a 40-ft-long, one-lane bridge consisting of a 34-ft steel-beam span, supported by vertical abutments with no wingwalls (Vermont Agency of Transportation, written communication, August 25, 1994). The left abutment is stone; the right abutment is log cribwork with type-2 stone fill (less than 36 inches diameter) along its base. Type-2 stone fill has also been placed on the upstream and downstream sides of the road embankments, except the upstream left which has type-3 (less than 48 inches diameter). The channel is skewed approximately 60 degrees; the opening-skew-to-roadway is 30 degrees. Additional details describing conditions at the site are included in the Level II Summary, Appendix D, and Appendix E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993).

Total scour at a highway crossing is comprised of three components: 1) long-term 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 these computed results follow.

Contraction scour for all modelled flows was 0.0 ft. Abutment scour ranged from 5.7 ft to 7.7 ft. with the worst-case abutment scour occurring at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated depths, are presented in tables 1 and 2. A cross-section of the computed scour at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1993, p. 22). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.

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

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

LEVEL II SUMMARY

Structure Number BRIDTH00050046 **Stream** N. Br. Ottawaquechee R.
County Windsor **Road** TH5 **District** 04

Description of Bridge

Bridge length 40 **ft** **Bridge width** 14 **ft** **Max span length** 34 **ft**
Alignment of bridge to road (on curve or straight) slight curve
Abutment type vertical **Embankment type** vertical
Stone fill on abutment? yes, right **Date of inspection** 11/2/94
Type-2 stone fill is along the right abutment and at the road
Description of stone fill
embankments on the right upstream side and the left and right downstream sides. Type- 3 stone fill
is on the left upstream road embankment.
The left abutment is laid-up stone. The right abutment
is log cribbing with stone in gaps.

Is bridge skewed to flood flow according to Y **' survey?** 60 **Angle**
There is only a moderate bend to the channel at the bridge, however the bridge abutments are not
aligned with the channel. Opening skew to roadway is 30 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	<u>11/02/94</u>	<u>0</u>	<u>0</u>
Level II	<u>11/03/94</u>	<u>-</u>	<u>-</u>
Potential for debris			

November 2-3, 1994. The abutments are not aligned with the channel.

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

Description of the Geomorphic Setting

General topography The bridge is in a steep, narrow valley with moderate relief and little or no flood plains

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

Date of inspection 11/02/94

DS left: Steep valley wall

DS right: Moderate sloping channel bank to town highway 05, then steep valley wall.

US left: Steep channel bank to town highway 05, then steep valley wall.

US right: Steep valley wall.

Description of the Channel

Average top width 48 [#] gravel and cobbles **Average depth** 6 [#] cobble-boulder

Predominant bed material channel with only slight sinuosity. **Bank material** Narrow, incised

Vegetative cover Forested 11/02/94

DS left: Forested

DS right: Forested

US left: Forested

US right: Y

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

11/2/94--None.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 5.61 *mi*²

Percentage of drainage area in physiographic provinces: (approximate)

<i>Physiographic province</i>	<i>Percent of drainage area</i>
<u>Green Mountain Prov.</u>	<u>100</u>

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

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

USGS gage description

USGS gage number

Gage drainage area *mi*² No

Is there a lake/p

<u>1,580</u>	Calculated Discharges	<u>2,230</u>
<i>Q100</i>	<i>ft</i> ³ / <i>s</i>	<i>Q500</i>
	<i>ft</i> ³ / <i>s</i>	

Q100 and Q500 were determined by use of an area relationship [(5.6/5.0) to the 0.7 power] with flood frequency estimates at bridge 33 on the North Branch Ottauquechee River with a drainage area of 5.0 square miles. The Q100 discharge at bridge 33 (1460 cfs,) was available from VTAOT (VTAOT, written communication, May 1995). The Q500 discharge at bridge 33 (2060 cfs) was based upon a weighted average of several empirical methods applicable for a drainage of this size in this region (Talbot, 1887; Potter, 1957a; Potter, 1957b; Johnson and Tasker, 1974; Federal Highway Administration, 1983; Richardson and others, 1983).

Description of the Water-Surface Profile Model (WSPRO) Analysis

Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans) USGS survey

Datum tie between USGS survey and VTAOT plans Not applicable.

Description of reference marks used to determine USGS datum. RM1 is a carved X in the top a wood deck plank at the upstream right corner of the bridge deck (elev. 4999.01 ft, arbitrary datum). RM2 is a carved X in the top a wood deck plank at the downstream left corner of the bridge deck (elev. 4999.41 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

¹ <i>Cross-section</i>	<i>Section Reference Distance (SRD) in feet</i>	² <i>Cross-section development</i>	<i>Comments</i>
EXITX	-34	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	7	1	Road Grade section
APPRO	41	2	Modelled Approach section (Templated from APTEM)
APTEM	66	1	Approach section as surveyed (Used as a template)

¹ For location of cross-sections see plan-view sketch included with Level I field form, Appendix E.
For more detail on how cross-sections were developed see WSPRO input file.

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The analysis reported herein reflects 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, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel "n" values for the reach ranged from 0.050 to 0.060, and overbank "n" values were 0.045.

Normal depth at the exit section (EXITX) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the User's manual for WSPRO (Shearman, 1990). The slope used was 0.0145 ft/ft which was determined from surveyed thalweg points downstream of the bridge.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.035 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.

Bridge Hydraulics Summary

Average bridge embankment elevation 4999.5 ft
 Average low steel elevation 4997.7 ft

100-year discharge 1,580 ft³/s
 Water-surface elevation in bridge opening 4997.9 ft
 Road overtopping? Y Discharge over road 72 ft/s
 Area of flow in bridge opening 174 ft²
 Average velocity in bridge opening 8.7 ft/s
 Maximum WSPRO tube velocity at bridge 10.1 ft/s

Water-surface elevation at Approach section with bridge 4999.6
 Water-surface elevation at Approach section without bridge 4998.5
 Amount of backwater caused by bridge 1.1 ft

500-year discharge 2,230 ft³/s
 Water-surface elevation in bridge opening 4997.9 ft
 Road overtopping? Y Discharge over road 782 ft/s
 Area of flow in bridge opening 174 ft²
 Average velocity in bridge opening 8.3 ft/s
 Maximum WSPRO tube velocity at bridge 9.8 ft/s

Water-surface elevation at Approach section with bridge 5000.4
 Water-surface elevation at Approach section without bridge 4999.6
 Amount of backwater caused by bridge 0.8 ft

Incipient overtopping discharge 1,470 ft³/s
 Water-surface elevation in bridge opening 4997.2 ft
 Area of flow in bridge opening 174 ft²
 Average velocity in bridge opening 9.1 ft/s
 Maximum WSPRO tube velocity at bridge 11.3 ft/s

Water-surface elevation at Approach section with bridge 4998.1
 Water-surface elevation at Approach section without bridge 4998.3
 Amount of backwater caused by bridge N/A 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 7.

The 100-year and 500-year discharges resulted in submerged 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). Therefore, contraction scour for these two discharges was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). Contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equations 18 and 19) for the incipient road over-flow discharge. The results of Laursen's clear-water contraction scour for the 100-year and 500-year events were also computed and can be found in appendix F. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

The total scour depth computed at the right abutment for the 100-yr discharge was greater than that for the 500-yr discharge. Therefore, only the scour for the 100-year event is shown in figure 8. The incipient overtopping model resulted in the worst-case total scour at the right abutment.

Scour Results

<i>Contraction scour:</i>	<i>100-yr discharge</i>	<i>500-yr discharge</i>	<i>Incipient overtopping discharge</i>
	<i>(Scour depths in feet)</i>		

Main channel

<i>Live-bed scour</i>	--	--	--
	0.0	0.0	0.0
<i>Clear-water scour</i>	2.4	1.8	3.8
<i>Depth to armoring</i>	--	--	--
<i>Left overbank</i>	--	--	--
<i>Right overbank</i>	--	--	--

Local scour:

<i>Abutment scour</i>	6.0	7.7	6.7
<i>Left abutment</i>	7.0	5.7	7.6
<i>Right abutment</i>			
<i>Pier scour</i>	--	--	--
<i>Pier 1</i>	--	--	--
<i>Pier 2</i>	--	--	--
<i>Pier 3</i>	--	--	--

Riprap Sizing

	<i>100-yr discharge</i>	<i>500-yr discharge</i>	<i>Incipient overtopping discharge</i>
	<i>(D₅₀ in feet)</i>		
<i>Abutments:</i>	1.6	1.6	1.6
<i>Left abutment</i>	1.6	1.6	1.6
<i>Right abutment</i>	--	--	--
<i>Piers:</i>	--	--	--
<i>Pier 1</i>	--	--	--
<i>Pier 2</i>	--	--	--

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure [BRIDTH00050046](#) on town highway 5, crossing the [North Branch Ottauquechee River, Bridgewater, Vermont](#).

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure [BRIDTH00050046](#) on town highway 5, crossing the [North Branch Ottaquechee River, Bridgewater, Vermont](#).

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00050046 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, 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 1,580 cubic-feet per second											
Left abutment	0.0	--	4997.9	--	4991.8	0.0	6.0	--	6.0	4985.8	--
Right abutment	31.7	--	4997.4	--	4992.8	0.0	7.0	--	7.0	4985.8	--

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 BRIDTH00050046 on Town Highway 5, crossing the North Branch Ottauquechee River, Bridgewater, 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 2,230 cubic-feet per second											
Left abutment	0.0	--	4997.9	--	4991.8	0.0	7.7	--	7.7	4984.1	--
Right abutment	31.7	--	4997.4	--	4992.8	0.0	5.7	--	5.7	4987.1	--

¹. Measured along the face of the most constricting side of the bridge.

². Arbitrary datum for this study.

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APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```

T1      U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid046.wsp
T2      CREATED ON 31-AUG-95 FOR BRIDGE BRIDTH00050046 USING FILE brid046.dca
T3      HYDRAULIC ANALYSIS OF BRID046    SAO
J1      * * 0.002
J3      6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
*      Incipient overflow discharge requires different model input
*      at the approach section because if the left overbank is
*      overtopped then the roadway WILL be overtopped. Thus, for
*      incipient overtopping model station 0.0 was used as a control point.
Q      1580 2230
SK      0.0145 0.0145
*
XS      EXITX      -34
GR      -57.0,5006.66      -15.3,4996.22      -5.8,4993.68      0.0,4992.04
GR      3.3,4991.37      9.0,4991.27      14.1,4991.06      18.8,4991.94
GR      40.3,4997.25      53.9,4999.35      63.8,4999.77      77.6,4999.27
GR      109.3,5000.90      127.0,5010.56
N      0.060      0.045
SA      54.
*
XS      FULLV      0 * * * 0.021
*
BR      BRIDG      0 4997.7 30
GR      0.0,4997.92      0.4,4991.75      3.7,4991.73      10.0,4991.00
GR      19.5,4990.33      24.5,4990.52      24.9,4991.80      31.2,4992.77
GR      31.7,4997.41      0.0,4997.92
N      0.050
CD      1 13.5
*
XR      RDWAY      7 14.0 2
GR      -104.6,5011.00      -84.0,5004.90      -69.6,5003.79      -57.1,5001.43
GR      -45.3,4998.56      -31.5,4999.02      -14.6,4999.79      0.0,4999.71
GR      39.9,4999.29      61.3,4999.61      97.5,4999.77      111.4,4999.27
GR      143.0,5000.90      160.8,5010.56
BP      0
*
XT      APTEM      66
GR      -90.3,5011.00      -69.7,5004.90      -55.3,5003.79      -42.8,5001.43
GR      -31.0,4998.56      -17.2,4999.02      0.0,4999.31      10.1,4992.85
GR      12.7,4992.53      16.9,4992.13      21.5,4992.23      24.8,4992.77
GR      30.5,4994.12      40.5,4999.79      50.1,5001.02      54.3,5004.69
*      The 0 on the GT record below is for the INCIPIENT OVERFLOW MODEL ONLY
AS      APPRO      41
GT      -0.87 0
N      0.045      0.060
SA      0
*
HP 1 BRIDG      4997.20 1 4997.20
HP 2 BRIDG      4997.20 * * 1470
HP 1 APPRO      4998.09 1 4998.09
HP 2 APPRO      4998.09 * * 1470

HP 1 BRIDG      4997.89 1 4997.89
HP 2 BRIDG      4997.89 * * 1510
HP 2 RDWAY      4999.60 * * 72
HP 1 APPRO      4999.60 1 4999.60

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APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid046.wsp
 CREATED ON 31-AUG-95 FOR BRIDGE BRIDTH00050046 USING FILE brid046.dca
 HYDRAULIC ANALYSIS OF BRID046 SAO

*** RUN DATE & TIME: 01-19-96 15:36

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	174.	10043.	2.	64.				10282.
4997.89		174.	10043.	2.	64.	1.00	0.	32.	10282.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
4997.89	0.0	31.7	173.9	10043.	1510.	8.68
X STA.	0.0	2.7	4.4		6.0	7.4
A(I)		13.2	9.2	8.5	8.1	8.0
V(I)		5.71	8.24	8.84	9.33	9.41
X STA.	8.8	10.2	11.5		12.8	14.0
A(I)		7.9	7.7	7.5	7.5	7.6
V(I)		9.57	9.78	10.01	10.03	9.93
X STA.	15.3	16.5	17.7		18.9	20.2
A(I)		7.5	7.6	7.5	7.7	7.8
V(I)		10.03	9.93	10.07	9.85	9.73
X STA.	21.4	22.7	24.0		26.0	28.1
A(I)		7.9	8.4	10.2	10.0	14.2
V(I)		9.62	9.02	7.43	7.55	5.33

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = RDWAY; SRD = 7.

WSEL	LEW	REW	AREA	K	Q	VEL
4999.60	-49.6	117.8	27.4	315.	72.	2.62
X STA.	-49.6	-46.4	-45.5		-44.7	-44.0
A(I)		1.2	0.8	0.8	0.7	0.8
V(I)		2.91	4.39	4.60	4.88	4.67
X STA.	-43.2	-42.4	-41.5		-40.5	-39.4
A(I)		0.8	0.8	0.9	0.9	1.0
V(I)		4.53	4.31	4.21	3.94	3.63
X STA.	-38.2	-36.9	-35.4		-33.5	-31.3
A(I)		1.0	1.1	1.2	1.4	1.6
V(I)		3.43	3.23	2.89	2.58	2.29
X STA.	-28.1	35.0	40.3		47.0	110.2
A(I)		5.1	1.5	1.7	2.5	1.4
V(I)		0.70	2.35	2.13	1.42	2.51

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 41.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	53.	2159.	39.	39.				353.
	2	240.	17101.	46.	49.				3121.
4999.60		293.	19260.	85.	89.	1.09	-39.	46.	2972.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 41.

WSEL	LEW	REW	AREA	K	Q	VEL
4999.60	-38.9	45.8	293.3	19260.	1580.	5.39
X STA.	-38.9	-21.8	-5.4		5.7	8.4
A(I)		23.6	23.0	23.6	15.0	13.2
V(I)		3.35	3.44	3.35	5.27	5.98
X STA.	10.2	11.7	13.1		14.4	15.7
A(I)		11.5	11.0	10.8	10.5	10.7
V(I)		6.87	7.19	7.28	7.51	7.40
X STA.	17.0	18.3	19.6		20.9	22.3
A(I)		10.6	10.9	10.8	11.3	11.5
V(I)		7.48	7.28	7.33	7.00	6.87
X STA.	23.7	25.3	27.1		29.3	32.1
A(I)		12.6	13.1	14.8	17.4	27.6
V(I)		6.28	6.05	5.32	4.54	2.86

WSPRO OUTPUT FILE (continued)

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.
WSEL SA# AREA K TOPW WETP ALPH LEW REW QCR
1 174. 9879. 0. 66. 9426233.
4997.92 174. 9879. 0. 66. 1.00 0. 32.9426233.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRIDG; SRD = 0.
WSEL LEW REW AREA K Q VEL
4997.92 0.0 31.7 173.9 9879. 1450. 8.34
X STA. 0.0 2.8 4.6 6.2 7.7 9.1
A(I) 14.1 9.5 8.8 8.3 8.0
V(I) 5.15 7.65 8.24 8.75 9.09
X STA. 9.1 10.5 11.7 13.0 14.3 15.5
A(I) 7.8 7.7 7.4 7.4
V(I) 9.25 9.47 9.48 9.83 9.74
X STA. 15.5 16.7 17.9 19.1 20.3 21.5
A(I) 7.5 7.5 7.4 7.6 7.7
V(I) 9.73 9.64 9.78 9.58 9.47
X STA. 21.5 22.8 24.1 26.0 28.2 31.7
A(I) 7.7 8.3 9.9 9.9 14.0
V(I) 9.36 8.77 7.30 7.35 5.19

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = RDWAY; SRD = 7.
WSEL LEW REW AREA K Q VEL
5000.40 -52.9 133.3 162.0 4086. 782. 4.83
X STA. -52.9 -44.5 -41.0 -37.1 -32.9 -27.5
A(I) 8.4 6.1 6.4 6.3 7.1
V(I) 4.65 6.42 6.15 6.17 5.50
X STA. -27.5 -19.0 1.2 14.3 24.4 32.8
A(I) 8.5 13.5 10.1 9.0 8.3
V(I) 4.59 2.90 3.88 4.33 4.71
X STA. 32.8 40.0 47.7 56.4 65.2 75.2
A(I) 7.8 8.1 8.0 7.2 7.5
V(I) 5.04 4.83 4.86 5.46 5.24
X STA. 75.2 86.3 98.6 107.3 113.7 133.3
A(I) 7.8 8.1 7.2 6.7 9.9
V(I) 5.01 4.84 5.41 5.82 3.93

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 41.
WSEL SA# AREA K TOPW WETP ALPH LEW REW QCR
1 86. 4515. 42. 42. 691.
2 279. 20674. 50. 54. 3728.
5000.40 365. 25190. 93. 97. 1.05 -42. 50. 4012.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 41.
WSEL LEW REW AREA K Q VEL
5000.40 -42.1 50.4 364.6 25190. 2230. 6.12
X STA. -42.1 -26.5 -17.3 -7.0 3.8 7.3
A(I) 26.8 22.3 22.3 26.4 19.0
V(I) 4.15 5.01 4.99 4.23 5.88
X STA. 7.3 9.5 11.2 12.8 14.3 15.7
A(I) 16.2 14.3 13.5 13.3 13.1
V(I) 6.88 7.79 8.27 8.37 8.50
X STA. 15.7 17.2 18.7 20.1 21.7 23.3
A(I) 13.3 13.4 13.5 13.9 14.8
V(I) 8.36 8.34 8.28 8.03 7.55
X STA. 23.3 25.1 27.2 29.6 32.8 50.4
A(I) 15.1 16.8 18.6 21.5 36.6
V(I) 7.39 6.64 5.98 5.19 3.05

WSPRO OUTPUT FILE (continued)

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid046.wsp

CREATED ON 31-AUG-95 FOR BRIDGE BRIDTH00050046 USING FILE brid046.dca

HYDRAULIC ANALYSIS OF BRID046 SAO

*** RUN DATE & TIME: 01-19-96 15:36

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	161.	12649.	27.	38.				2219.
4997.20		161.	12649.	27.	38.	1.00	0.	32.	2219.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRIDG; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
4997.20	0.0	31.7	161.2	12649.	1470.	9.12
X STA.	0.0	3.4	5.3		6.9	8.4
A(I)	14.9		9.1	8.2	7.5	7.4
V(I)	4.93		8.07	8.95	9.80	9.98
X STA.	9.8	11.1	12.3		13.5	14.7
A(I)	6.9		6.7	6.8	6.6	6.5
V(I)	10.68		10.91	10.88	11.08	11.29
X STA.	15.8	17.0	18.1		19.2	20.3
A(I)	6.5		6.6	6.5	6.7	6.8
V(I)	11.25		11.12	11.25	11.00	10.85
X STA.	21.5	22.7	24.0		25.8	27.9
A(I)	7.1		7.4	9.5	9.2	14.3
V(I)	10.40		9.95	7.70	8.02	5.14

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPRO; SRD = 41.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	2	178.	11606.	38.	42.				2171.
4998.09		178.	11606.	38.	42.	1.00	1.	39.	2171.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 41.

WSEL	LEW	REW	AREA	K	Q	VEL
4998.09	0.5	39.0	177.9	11606.	1470.	8.26
X STA.	0.5	7.6	9.7		11.2	12.4
A(I)	16.1		10.7	9.0	8.2	7.7
V(I)	4.58		6.90	8.20	8.97	9.58
X STA.	13.6	14.8	15.9		16.9	18.0
A(I)	7.5		7.4	7.2	7.2	7.2
V(I)	9.77		9.97	10.16	10.23	10.26
X STA.	19.1	20.1	21.2		22.3	23.4
A(I)	7.1		7.3	7.2	7.6	7.7
V(I)	10.35		10.07	10.20	9.73	9.52
X STA.	24.6	26.0	27.5		29.2	31.5
A(I)	8.0		8.7	9.4	10.7	16.2
V(I)	9.15		8.47	7.86	6.86	4.52

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXITX:XS	*****	-20.	225.	0.77	*****	4998.16	4996.23	1580.	4997.39
-34.	*****	41.	13115.	1.00	*****	*****	0.64	7.02	
FULLV:FV	34.	-19.	212.	0.86	0.53	4998.75	*****	1580.	4997.89
0.	34.	40.	12165.	1.00	0.05	0.02	0.69	7.44	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									
===125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.									
FNTEST,FR#,WSEL,CRWS = 0.80 0.85 4998.47 4997.06									
===110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.									
WSLIM1,WSLIM2,DELTAY = 4997.39 5010.13 0.50									
===115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.									
WSLIM1,WSLIM2,CRWS = 4997.39 5010.13 4997.06									
APPRO:AS	41.	-34.	204.	1.01	0.64	4999.47	4997.06	1580.	4998.46
41.	41.	40.	13114.	1.08	0.07	0.00	0.85	7.75	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									
===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.									
WS3N,LSEL = 4997.89 4997.70									
<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>									
XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
BRIDG:BR	34.	0.	174.	1.17	*****	4999.06	4995.86	1510.	4997.89
0.	*****	32.	10037.	1.00	*****	*****	0.65	8.68	
TYPE PPCD FLOW C P/A LSEL BLEN XLAB XRAB									
1.	****	6.	0.800	0.000	4997.70	*****	*****	*****	
XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL	
RDWAY:RG	7.	27.	0.18	0.49	4999.91	0.00	72.	4999.60	
Q WLEN LEW REW DMAX DAVG VMAX VAVG HAVG CAVG									
LT:	72.	31.	-50.	-19.	1.0	0.6	4.0	4.2	0.9 2.9
RT:	0.	25.	15.	40.	0.3	0.2	2.8	4.9	0.5 2.7
XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	28.	-39.	293.	0.49	0.37	5000.09	4997.06	1580.	4999.60
41.	30.	46.	19263.	1.09	0.00	0.00	0.53	5.39	
M(G) M(K) KQ XLKQ XRKQ OTEL									

FIRST USER DEFINED TABLE.									
XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL	
EXITX:XS	-34.	-20.	41.	1580.	13115.	225.	7.02	4997.39	
FULLV:FV	0.	-19.	40.	1580.	12165.	212.	7.44	4997.89	
BRIDG:BR	0.	0.	32.	1510.	10037.	174.	8.68	4997.89	
RDWAY:RG	7.	*****	72.	72.	*****	0.	2.00	4999.60	
APPRO:AS	41.	-39.	46.	1580.	19263.	293.	5.39	4999.60	
XSID:CODE XLKQ XRKQ KQ									
APPRO:AS *****									
SECOND USER DEFINED TABLE.									
XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXITX:XS	4996.23	0.64	4991.06	5010.56	*****	0.77	4998.16	4997.39	
FULLV:FV	*****	0.69	4991.77	5011.27	0.53 0.05	0.86	4998.75	4997.89	
BRIDG:BR	4995.86	0.65	4990.33	4997.92	*****	1.17	4999.06	4997.89	
RDWAY:RG	*****	4998.56	5011.00	0.18	*****	0.49	4999.91	4999.60	
APPRO:AS	4997.06	0.53	4991.26	5010.13	0.37 0.00	0.49	5000.09	4999.60	

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXITX:XS	*****	-24.	296.	0.88	*****	4999.33	4997.13	2230.	4998.45
-34.	*****	48.	18517.	1.00	*****	*****	0.66	7.53	
FULLV:FV	34.	-23.	279.	0.99	0.53	4999.92	*****	2230.	4998.93
0.	34.	47.	17179.	1.00	0.06	0.00	0.70	7.99	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									
APPRO:AS	41.	-39.	290.	1.00	0.62	5000.56	*****	2230.	4999.56
41.	41.	46.	19041.	1.09	0.00	0.02	0.76	7.68	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.

WS3N,LSEL = 4998.93 4997.70

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

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
BRIDG:BR	34.	0.	174.	1.08	*****	4999.00	4995.73	1450.	4997.92
0.	*****	32.	9879.	1.00	*****	*****	0.63	8.34	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	****	6.	0.800	0.000	4997.70	*****	*****	*****

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RDWAY:RG	7.	27.	0.21	0.61	5000.80	0.00	782.	5000.40

	Q	WLEN	LEW	REW	DMAX	DAVG	VMAX	VAVG	HAVG	CAVG
LT:	332.	68.	-53.	15.	1.8	1.0	5.3	4.9	1.4	3.0
RT:	450.	118.	15.	133.	1.1	0.8	4.8	4.7	1.2	2.9

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	28.	-42.	365.	0.61	0.40	5001.01	4998.83	2230.	5000.40
41.	29.	50.	25221.	1.05	0.00	0.00	0.56	6.11	

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXITX:XS	-34.	-24.	48.	2230.	18517.	296.	7.53	4998.45
FULLV:FV	0.	-23.	47.	2230.	17179.	279.	7.99	4998.93
BRIDG:BR	0.	0.	32.	1450.	9879.	174.	8.34	4997.92
RDWAY:RG	7.	*****	332.	782.	*****	*****	2.00	5000.40
APPRO:AS	41.	-42.	50.	2230.	25221.	365.	6.11	5000.40

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXITX:XS	4997.13	0.66	4991.06	5010.56	*****	0.88	4999.33	4998.45	
FULLV:FV	*****	0.70	4991.77	5011.27	0.53	0.06	0.99	4999.92	
BRIDG:BR	4995.73	0.63	4990.33	4997.92	*****	1.08	4999.00	4997.92	
RDWAY:RG	*****	*****	4998.56	5011.00	0.21	*****	0.61	5000.80	
APPRO:AS	4998.83	0.56	4991.26	5010.13	0.40	0.00	0.61	5001.01	

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXITX:XS	*****	-19.	213.	0.74	*****	4997.93	4996.04	1470.	4997.18
-34.	*****	40.	12198.	1.00	*****	*****	0.64	6.91	

FULLV:FV	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
0.	34.	39.	11250.	1.00	0.05	0.01	0.69	7.34	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

APPRO:AS	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
41.	41.	39.	12205.	1.00	0.07	0.01	0.65	7.97	
<<<<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	34.	0.	161.	1.29	0.49	4998.50	4995.80	1470.	4997.20
0.	34.	32.	12660.	1.00	0.07	-0.01	0.66	9.11	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	****	1.	1.000	*****	4997.70	*****	*****	*****

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

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPRO:AS	28.	1.	178.	1.06	0.48	4999.15	4996.83	1470.	4998.09
41.	32.	39.	11613.	1.00	0.18	0.00	0.68	8.26	

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
0.189	0.000	12297.	5.	37.	4997.66

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXITX:XS	-34.	-19.	40.	1470.	12198.	213.	6.91	4997.18
FULLV:FV	0.	-18.	39.	1470.	11250.	200.	7.34	4997.68
BRIDG:BR	0.	0.	32.	1470.	12660.	161.	9.11	4997.20
RDWAY:RG	7.	*****			0.	*****		
APPRO:AS	41.	1.	39.	1470.	11613.	178.	8.26	4998.09

XSID:CODE	XLKQ	XRKQ	KQ
APPRO:AS	5.	37.	12297.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXITX:XS	4996.04	0.64	4991.06	5010.56	*****			0.74	4997.93 4997.18
FULLV:FV	*****	0.69	4991.77	5011.27	0.54	0.05	0.84	4998.52	4997.68
BRIDG:BR	4995.80	0.66	4990.33	4997.92	0.49	0.07	1.29	4998.50	4997.20
RDWAY:RG	***** 4998.56 5011.00*****								
APPRO:AS	4996.83	0.68	4991.26	5010.13	0.48	0.18	1.06	4999.15	4998.09

APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION

Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure [BRIDTH00050046](#), in Bridgewater, Vermont.

APPENDIX D:
HISTORICAL DATA FORM