LEVEL II SCOUR ANALYSIS FOR BRIDGE 35 (BRNATH00680035) on TOWN HIGHWAY 68, crossing LOCUST CREEK, BARNARD, VERMONT

U.S. Geological Survey
Open-File Report 96-306

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

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By MICHAEL A. IVANOFF and MATTHEW A. WEBER

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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	VT AOT	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 35 (BRNATH00680035) ON TOWN HIGHWAY 68, CROSSING LOCUST CREEK, BARNARD, VERMONT

By Michael A. Ivanoff and Matthew A. Weber

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRNATH00680035 on town highway 68 crossing Locust Creek, Barnard, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic province of central Vermont in the town of Barnard. The 24.1-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have woody vegetation coverage.

In the study area, Locust Creek has an incised sinuous channel with a slope of approximately 0.0133 ft/ft, an average channel top width of 58 ft and an average channel depth of 5 ft. The predominant channel bed material is cobble (D_{50} is 135 mm or 0.443 ft). The geomorphic assessment at the time of the Level I and Level II site visits on September 21 and 27, respectively, with a check on December 15, 1994, indicated that the reach was stable.

The town highway 68 crossing of Locust Creek is a 30-ft-long, one-lane bridge consisting of one 28-foot concrete slab type superstructure (Vermont Agency of Transportation, written commun., August 23, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is not skewed to the opening and the opening-skew-to-roadway is zero degrees.

A scour hole 0.5 ft deeper than the mean thalweg depth was observed along the right abutment and downstream right wingwall during the Level I assessment. The only scour protection measure in place at the site was type-2 stone fill (less than 36 inches diameter) at the left abutment and wingwalls except the downstream right wingwall. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). 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 3.4 ft. The worst-case contraction scour occurred at the incipient overtopping discharge, which was between the 100- and 500-year discharges. Abutment scour ranged from 11.5 to 25.7 ft. with the worst-case scenario 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 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 others, 1993, p. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, 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 BRNATH00680035 **Stream** Locust Creek
County Windsor **Road** TH 68 **District** 04

Description of Bridge

Bridge length 30 **ft** **Bridge width** 14.5 **ft** **Max span length** 28 **ft**
Alignment of bridge to road (on curve or straight) Straight
Abutment type Vertical **Embankment type** Sloping
Stone fill on abutment? Yes **Date of inspection** 9/21 & 12/15/94
Description of stone fill type-2, at the left abutment and all wingwalls except the downstream right wingwall.

Abutments and wingwalls are concrete. There is a half foot deep scour hole along the right abutment. The entire right abutment and both wingwall footings are exposed with undermining along the downstream end 0.5 ft. deep.

Is bridge skewed to flood flow according to N **' survey?** No **Angle** 0

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>09/21 & 12/15/94</u>	<u>0</u>	<u>0</u>
Level II	<u>09/27/94</u>	<u>--</u>	<u>--</u>

Potential for debris

09/21 & 12/15/94 -- A gravel, cobble, and boulder side bar from 150 ft. upstream along the left bank to the upstream bridge face.
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 incised with no floodplains and steep valley walls on both sides.

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

Date of inspection 09/21 & 12/15/94

DS left: Steep valley wall

DS right: Steep valley wall with town highway 70 parallel to the creek

US left: Steep valley wall

US right: Steep valley wall with town highway 70 parallel to the creek

Description of the Channel

Average top width	<u>58</u>		<u>5</u>		
	<u>Cobbles</u>			<u>Boulder/Cobble</u>	

Predominant bed material	Bank material
<u>semi-alluvial channel boundaries and no flood plain.</u>	<u>Sinuuous but stable with</u>

9/21 & 12/15/94

Vegetative cover Forest

DS left: Trees on bank up to town highway 70 with forest beyond

DS right: Forest

US left: Forest with town highway 70 parallel to the stream

US right: Yes

Do banks appear stable? - if not, describe location and type of instability and

date of observation.

09/21 & 12/15/94 --

None

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 24.1 mi^2

Percentage of drainage area in physiographic provinces: (approximate)

Physiographic province	Percent of drainage area
<u>Green Mountain</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

	Calculated Discharges	
<u>4,200</u>	<u>5,400</u>	
Q_{100}	Q_{500}	ft^3/s

The 100-year discharge is based on the value from the VTAOT database (VTAOT, written communication, May 4, 1995) and those computed by use of several empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; Benson, 1962; FHWA, 1983; Talbot, 1887; Richardson and others, 1993). The 500-year discharge is based on an extrapolation of the empirical relationship flood frequency curves and that of the VTAOT database values (VTAOT, written communication, May 4, 1995).

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

<i>Datum for WSPRO analysis (USGS survey, sea level, VTAOT plans)</i>	<u>USGS survey</u>
<i>Datum tie between USGS survey and VTAOT plans</i>	<u>Subtract 4,506 ft. from USGS survey to obtain VTAOT plans' datum.</u>
<i>Description of reference marks used to determine USGS datum.</i>	<u>RM1 is a chiseled X in a chiseled square on top of the US end of the right abutment (elev. 4999.74 ft, arbitrary survey datum). RM2 is a chiseled X in a chiseled square on top of the DS end of the left abutment (elev. 4999.92 ft, arbitrary survey datum).</u>

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>
EXIT-	-47	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RD	10	1	Road Grade section
APPR-	52	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 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 0.042 to 0.058.

Normal depth at the exit section (EXIT-) 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 0.0133 ft/ft which was determined from thalweg points downstream of the bridge.

The approach section (APPR-) was 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.

For the 100-year and incipient road-overflow discharge, WSPRO assumes critical depth at the bridge section. Supercritical models were developed for these discharges. Analyzing both the supercritical and subcritical profiles for each discharge, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satisfactory solutions.

The incipient road-overflow discharge was determined to be 5,320 cfs.

Bridge Hydraulics Summary

Average bridge embankment elevation 4999.8 ft
 Average low steel elevation 4998.2 ft

100-year discharge 4,200 ft³/s
 Water-surface elevation in bridge opening 4991.0 ft
 Road overtopping? No Discharge over road 0 ft³/s
 Area of flow in bridge opening 247 ft²
 Average velocity in bridge opening 17.0 ft/s
 Maximum WSPRO tube velocity at bridge 22.0 ft/s

Water-surface elevation at Approach section with bridge 4996.0
 Water-surface elevation at Approach section without bridge 4992.3
 Amount of backwater caused by bridge 3.7 ft

500-year discharge 5,400 ft³/s
 Water-surface elevation in bridge opening 4998.3 ft
 Road overtopping? Yes Discharge over road 346 ft³/s
 Area of flow in bridge opening 440 ft²
 Average velocity in bridge opening 11.6 ft/s
 Maximum WSPRO tube velocity at bridge 14.6 ft/s

Water-surface elevation at Approach section with bridge 5001.0
 Water-surface elevation at Approach section without bridge 4993.8
 Amount of backwater caused by bridge 7.2 ft

Incipient overtopping discharge 5,320 ft³/s
 Water-surface elevation in bridge opening 4992.6 ft
 Area of flow in bridge opening 288 ft²
 Average velocity in bridge opening 18.5 ft/s
 Maximum WSPRO tube velocity at bridge 24.2 ft/s

Water-surface elevation at Approach section with bridge 4998.4
 Water-surface elevation at Approach section without bridge 4993.7
 Amount of backwater caused by bridge 4.7 ft

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

Contraction scour was computed by use of the [clear-water contraction scour equation](#) (Richardson and others, 1993, p. 35, equation 18) for the 100-year and incipient road-overflow discharges. Contraction scour was computed by use of the [Chang pressure-flow scour equation](#) (Richardson and others, 1995, p. 145-146) for the 500-year discharge, where there was orifice flow at the bridge. 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). The results of [Laursen's clear-water contraction scour equation](#) (Richardson and others, 1993, p. 35, equation 18) was 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. In this case, the incipient road-overflow model resulted in the worst case contraction scour with a scour depth of 3.4 ft. This discharge also resulted in worst case total scour with a depth of 28.5 ft. at the left abutment. [The results of the streambed armoring computations suggest that the depth of contraction scour will not be limited by armoring.](#)

Abutment scour was computed by use of the [Froehlich equation](#) (Richardson and others, 1993, p. 49, equation 24). [For the 100-year and incipient overtopping discharge, WSPRO assumes critical depth at the bridge section. Supercritical models were developed for these discharges. Analyzing both the supercritical and subcritical profiles for each discharge, it can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satisfactory solutions.](#)

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

<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>	--	--	--
<i>Clear-water scour</i>	2.4	0.0	3.4
<i>Depth to armoring</i>	55.7	2.3	87.4
<i>Left overbank</i>	--	--	--
<i>Right overbank</i>	--	--	--

Local scour:

<i>Abutment scour</i>	21.7	25.7	25.1
<i>Left abutment</i>	11.5	13.2	13.9
<i>Right abutment</i>			
<i>Pier scour</i>	--	--	--
<i>Pier 1</i>	--	--	--
<i>Pier 2</i>	--	--	--
<i>Pier 3</i>			

Rock 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>	3.8	2.6	4.5
<i>Left abutment</i>	3.8	2.6	4.5
<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 [BRNATH00680035](#) on town highway 68, crossing [Locust Creek, Barnard, Vermont](#).

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure [BRNATH00680035](#) on town highway 68, crossing [Locust Creek, Barnard, Vermont](#).

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure [BRNATH00680035](#) on [Town Highway 68](#), crossing [Locust Creek, Barnard, Vermont](#).

[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station ¹	VTAOT plans' bridge seat 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 4,200 cubic-feet per second											
Left abutment	0.0	492.1	4998.3	4980	4983.3	2.4	21.7	--	24.1	4959.2	-21
Right abutment	27.0	492.8	4998.1	4980	4980.6	2.4	11.5	--	13.9	4966.7	-13

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 [BRNATH00680035](#) on [Town Highway 68](#), crossing [Locust Creek, Barnard, Vermont](#).

[VTAOT, Vermont Agency of Transportation; --, no data]

Description	Station ¹	VTAOT plans' bridge seat 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 5,400 cubic-feet per second											
Left abutment	0.0	492.1	4998.3	4980	4983.3	0	25.7	--	25.7	4957.6	-22
Right abutment	27.0	492.8	4998.1	4980	4980.6	0	13.2	--	13.2	4967.4	-13

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 brna035.wsp
T2      CREATED ON 06-NOV-95 FOR BRIDGE brnath00680035 USING FILE brna035.dca
T3      Hydraulic analysis of barnard035  ts
*
J3      6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q      4200.0,      5400.0,      5320.0
SK      0.0133      0.0133      0.0133
*
XS      EXIT-      -47
GR      -41.7,5006.22      -17.6,4988.91      -12.3,4984.85      -5.3,4982.56
GR      -3.3,4981.87      0.0,4982.59      4.7,4982.06      16.3,4981.33
GR      22.4,4981.21      27.2,4982.87      27.2,4982.88      32.5,4987.02
GR      43.2,4995.67      59.1,4997.02      70.1,4996.23      78.5,5006.05
N      0.058
*
XS      FULLV      0 * * * 0.0062
*
BR      BRDG-      0      4998.2      0.0
GR      0.0,4998.33      0.1,4983.27      1.9,4983.13      4.0,4981.58
GR      8.9,4981.32      14.2,4981.66      20.9,4981.10      24.4,4980.59
GR      24.7,4983.00      24.9,4985.13      26.8,4985.13      27.0,4998.14
GR      0.0,4998.33
N      0.042
CD      1      31.3 * *      50      9.5
*
XR      RD      10      14.5      2
GR      -35.4,5001.74      -17.7,5000.41      0.0,4999.95      13.6,4999.72
GR      28.0,4999.81      52.6,5000.32      63.5,5000.97      73.8,5000.09
GR      85.9,5009.16
BP      0
*
AS      APPR-      52
GR      -70.9,5009.47      -43.9,4995.04      -32.6,4992.66      -20.6,4987.38
GR      0.0,4983.79      9.4,4982.74      16.1,4982.06      21.6,4982.12
GR      24.6,4983.80      24.6,4983.79      27.1,4986.94      32.9,4990.34
GR      36.5,4993.11      42.4,4997.70      53.1,5003.67      57.9,5004.37
N      0.058
*
HP 1 BRDG-      4991.05 1 4991.05
HP 2 BRDG-      4991.05 * * 4200
HP 1 APPR-      4996.00 1 4996.00
HP 2 APPR-      4996.00 * * 4200
*
HP 1 BRDG-      4998.33 1 4998.33
HP 2 BRDG-      4998.33 * * 5097
HP 2 RD      5001.02 * * 346
HP 1 APPR-      5001.02 1 5001.02
HP 2 APPR-      5001.02 * * 5400
*
HP 1 BRDG-      4992.59 1 4992.59
HP 2 BRDG-      4992.59 * * 5320
HP 1 APPR-      4998.37 1 4998.37

```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brna035.wsp
 CREATED ON 06-NOV-95 FOR BRIDGE brnath00680035 USING FILE brna035.dca
 Hydraulic analysis of barnard035 ts

*** RUN DATE & TIME: 11-07-95 15:34

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

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	246.	27147.	27.	45.				4239.
4991.05		246.	27147.	27.	45.	1.00	0.	27.	4239.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRDG-; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
4991.05	0.0	26.9	246.5	27147.	4200.	17.04

X STA.	0.0	3.1	4.6	5.9	7.0	8.1
A(I)	24.1	14.3	12.1	10.9	10.5	
V(I)	8.70	14.71	17.32	19.19	20.09	

X STA.	8.1	9.1	10.1	11.2	12.2	13.2
A(I)	10.0	9.8	9.8	9.6	9.6	
V(I)	20.98	21.46	21.44	21.84	21.99	

X STA.	13.2	14.2	15.2	16.3	17.3	18.4
A(I)	9.7	9.7	9.9	10.0	10.2	
V(I)	21.59	21.56	21.12	21.09	20.50	

X STA.	18.4	19.5	20.7	21.9	23.4	26.9
A(I)	10.9	11.5	12.2	15.0	26.5	
V(I)	19.34	18.18	17.15	14.00	7.92	

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	728.	73862.	86.	93.				12024.
4996.00		728.	73862.	86.	93.	1.00	-46.	40.	12024.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	LEW	REW	AREA	K	Q	VEL
4996.00	-45.7	40.2	728.0	73862.	4200.	5.77

X STA.	-45.7	-23.7	-18.1	-13.8	-10.1	-6.8
A(I)	72.5	46.5	40.9	37.6	35.1	
V(I)	2.90	4.52	5.13	5.58	5.98	

X STA.	-6.8	-3.9	-1.2	1.4	3.7	6.0
A(I)	32.8	31.9	30.9	29.6	29.3	
V(I)	6.41	6.58	6.80	7.09	7.16	

X STA.	6.0	8.2	10.4	12.5	14.6	16.7
A(I)	28.7	28.4	28.6	28.9	28.9	
V(I)	7.31	7.40	7.34	7.26	7.25	

X STA.	16.7	18.8	21.0	23.6	27.4	40.2
A(I)	29.2	30.9	34.1	42.3	60.8	
V(I)	7.20	6.79	6.16	4.97	3.45	

WSPRO OUTPUT FILE (continued)

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

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	440.	46181.	0.	86.				0.
4998.33		440.	46181.	0.	86.	1.00	0.	27.	0.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRDG-; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
4998.33	0.0	27.0	439.9	46181.	5097.	11.59

X STA.	0.0	2.9	4.4	5.7	6.9	8.0
A(I)	42.8	25.4	21.5	20.0	19.0	
V(I)	5.95	10.02	11.83	12.75	13.39	
X STA.	8.0	9.1	10.1	11.2	12.2	13.3
A(I)	18.2	18.1	17.8	17.5	17.4	
V(I)	14.02	14.10	14.35	14.58	14.65	
X STA.	13.3	14.3	15.4	16.5	17.5	18.7
A(I)	17.6	17.6	17.9	17.9	18.7	
V(I)	14.49	14.47	14.23	14.28	13.60	
X STA.	18.7	19.8	21.0	22.3	23.7	27.0
A(I)	18.9	20.4	22.3	25.5	45.5	
V(I)	13.50	12.47	11.43	9.99	5.61	

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = RD ; SRD = 10.

WSEL	LEW	REW	AREA	K	Q	VEL
5001.02	-25.8	75.0	84.7	1933.	346.	4.08

X STA.	-25.8	-12.0	-6.3	-1.9	1.8	5.1
A(I)	6.4	4.7	4.2	3.9	3.7	
V(I)	2.70	3.65	4.13	4.41	4.64	
X STA.	5.1	8.1	11.0	13.7	16.3	19.0
A(I)	3.6	3.5	3.5	3.4	3.5	
V(I)	4.79	4.91	5.00	5.09	5.00	
X STA.	19.0	21.8	24.7	27.6	30.8	34.2
A(I)	3.5	3.5	3.6	3.7	3.8	
V(I)	4.97	4.89	4.81	4.62	4.51	
X STA.	34.2	38.1	42.7	48.4	56.7	75.0
A(I)	4.0	4.4	4.9	5.4	7.4	
V(I)	4.30	3.93	3.56	3.18	2.35	

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	1202.	149334.	103.	113.				23245.
5001.02		1202.	149334.	103.	113.	1.00	-55.	48.	23245.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	LEW	REW	AREA	K	Q	VEL
5001.02	-55.1	48.4	1201.8	149334.	5400.	4.49

X STA.	-55.1	-33.2	-25.2	-20.1	-15.8	-12.0
A(I)	109.7	78.9	65.3	60.6	55.3	
V(I)	2.46	3.42	4.13	4.45	4.89	
X STA.	-12.0	-8.5	-5.3	-2.3	0.6	3.3
A(I)	53.8	52.1	50.3	49.4	47.4	
V(I)	5.02	5.18	5.36	5.47	5.70	
X STA.	3.3	6.0	8.7	11.3	13.8	16.4
A(I)	47.1	47.9	47.5	47.0	48.9	
V(I)	5.73	5.63	5.68	5.75	5.52	
X STA.	16.4	19.0	21.8	25.1	30.4	48.4
A(I)	49.8	53.2	59.1	73.7	104.8	
V(I)	5.42	5.08	4.56	3.67	2.58	

WSPRO OUTPUT FILE (continued)

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

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	288.	33641.	27.	48.				5346.
4992.59		288.	33641.	27.	48.	1.00	0.	27.	5346.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRDG-; SRD = 0.

WSEL	LEW	REW	AREA	K	Q	VEL
4992.59	0.0	26.9	287.9	33641.	5320.	18.48

X STA.	0.0	3.1	4.7	5.9	7.1	8.2
A(I)	29.3	16.6	14.1	13.0	12.0	
V(I)	9.06	15.98	18.92	20.47	22.09	

X STA.	8.2	9.2	10.2	11.2	12.2	13.2
A(I)	11.5	11.4	11.2	11.0	11.0	
V(I)	23.09	23.25	23.69	24.11	24.25	

X STA.	13.2	14.2	15.2	16.3	17.3	18.4
A(I)	11.1	11.2	11.4	11.4	12.0	
V(I)	23.86	23.83	23.37	23.37	22.20	

X STA.	18.4	19.5	20.6	21.9	23.4	26.9
A(I)	12.4	13.2	14.4	17.7	31.7	
V(I)	21.38	20.13	18.41	15.01	8.40	

CROSS-SECTION PROPERTIES: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	SA#	AREA	K	TOPW	WETP	ALPH	LEW	REW	QCR
	1	941.	106311.	94.	102.				16907.
4998.37		941.	106311.	94.	102.	1.00	-50.	44.	16907.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPR-; SRD = 52.

WSEL	LEW	REW	AREA	K	Q	VEL
4998.37	-50.1	43.6	940.5	106311.	5320.	5.66

X STA.	-50.1	-28.3	-21.6	-17.0	-13.0	-9.5
A(I)	90.0	60.7	51.6	47.5	44.4	
V(I)	2.95	4.38	5.15	5.59	5.99	

X STA.	-9.5	-6.3	-3.3	-0.5	2.1	4.7
A(I)	42.3	41.1	39.8	38.4	38.0	
V(I)	6.28	6.47	6.68	6.93	7.01	

X STA.	4.7	7.1	9.5	11.8	14.1	16.5
A(I)	36.8	37.4	37.1	36.7	38.3	
V(I)	7.23	7.11	7.16	7.24	6.95	

X STA.	16.5	18.8	21.4	24.2	28.7	43.6
A(I)	37.9	41.4	44.0	56.1	80.8	
V(I)	7.03	6.42	6.05	4.74	3.29	

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT-:XS	*****	-20.	409.	1.64	*****	4992.53	4989.07	4200.	4990.89
-47.	*****	37.	36402.	1.00	*****	*****	0.68	10.27	

FULLV:FV	47.	-21.	436.	1.44	0.57	4993.09	*****	4200.	4991.65
0.	47.	38.	39894.	1.00	0.00	-0.01	0.62	9.63	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

APPR-:AS	52.	-32.	442.	1.40	0.61	4993.70	*****	4200.	4992.29
52.	52.	35.	37988.	1.00	0.00	0.00	0.65	9.50	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

===285 CRITICAL WATER-SURFACE ELEVATION A _ S _ S _ U _ M _ E _ D !!!!!
 SECID "BRDG-" Q,CRWS = 4200. 4991.05

<<<<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	
BRDG-:BR	47.	0.	247.	4.51	*****	4995.56	4991.05	4200.	4991.05
0.	47.	27.	27161.	1.00	*****	*****	0.99	17.03	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	****	1.	1.000	*****	4998.20	*****	*****	*****

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RD	: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	
APPR-:AS	21.	-46.	728.	0.52	0.20	4996.52	4990.39	4200.	4996.00
52.	23.	40.	73843.	1.00	0.75	0.02	0.35	5.77	

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
0.600	0.335	48947.	-6.	21.	4995.88

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT-:XS	-47.	-20.	37.	4200.	36402.	409.	10.27	4990.89
FULLV:FV	0.	-21.	38.	4200.	39894.	436.	9.63	4991.65
BRDG-:BR	0.	0.	27.	4200.	27161.	247.	17.03	4991.05
RD :RG	10.	*****		0.	*****		2.00	*****
APPR-:AS	52.	-46.	40.	4200.	73843.	728.	5.77	4996.00

XSID:CODE	XLKQ	XRKQ	KQ
APPR-:AS	-6.	21.	48947.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT-:XS	4989.07	0.68	4981.21	5006.22	*****			1.64	4992.53 4990.89
FULLV:FV	*****	0.62	4981.50	5006.51	0.57	0.00	1.44	4993.09	4991.65
BRDG-:BR	4991.05	0.99	4980.59	4998.33	*****			4.51	4995.56 4991.05
RD :RG	*****	4999.72	5009.16	*****					
APPR-:AS	4990.39	0.35	4982.06	5009.47	0.20	0.75	0.52	4996.52	4996.00

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT-:XS	*****	-22.	488.	1.90	*****	4994.13	4990.20	5400.	4992.23
-47.	*****	39.	46819.	1.00	*****	*****	0.69	11.06	
FULLV:FV	47.	-23.	519.	1.69	0.57	4994.69	*****	5400.	4993.01
0.	47.	40.	50934.	1.00	0.00	-0.01	0.64	10.41	
<<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>									
APPR-:AS	52.	-38.	545.	1.53	0.60	4995.28	*****	5400.	4993.75
52.	52.	37.	50013.	1.00	0.00	-0.01	0.65	9.90	
<<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>									

===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
 WS3,WSIU,WS1,LSEL = 4992.70 4998.35 4998.53 4998.20

===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	
BRDG-:BR	47.	0.	440.	2.09	*****	5000.42	4992.30	5097.	4998.33
0.	*****	27.	46181.	1.00	*****	*****	0.51	11.59	
TYPE PPCD FLOW C P/A LSEL BLEN XLAB XRAB									
1. **** 5. 0.432 ***** 4998.20 ***** ***** *****									

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RD	:RG	10.	38.	0.05	0.31	5001.28	0.01	346. 5001.02
Q WLEN LEW REW DMAX DAVG VMAX VAVG HAVG CAVG								
LT:	134.	39.	-26.	13.	1.3	0.8	4.7	4.1 1.1 3.0
RT:	211.	62.	13.	75.	1.3	0.8	4.7	4.1 1.1 3.0

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
APPR-:AS	21.	-55.	1202.	0.31	0.09	5001.33	4991.48	5400.	5001.02
52.	23.	48.	149290.	1.00	0.78	0.01	0.23	4.49	

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT-:XS	-47.	-22.	39.	5400.	46819.	488.	11.06	4992.23
FULLV:FV	0.	-23.	40.	5400.	50934.	519.	10.41	4993.01
BRDG-:BR	0.	0.	27.	5097.	46181.	440.	11.59	4998.33
RD :RG	10.	*****	134.	346.	*****	*****	2.00	5001.02
APPR-:AS	52.	-55.	48.	5400.	149290.	1202.	4.49	5001.02

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT-:XS	4990.20	0.69	4981.21	5006.22	*****	*****	1.90	4994.13	4992.23
FULLV:FV	*****	0.64	4981.50	5006.51	0.57	0.00	1.69	4994.69	4993.01
BRDG-:BR	4992.30	0.51	4980.59	4998.33	*****	*****	2.09	5000.42	4998.33
RD :RG	*****	*****	4999.72	5009.16	0.05	*****	0.31	5001.28	5001.02
APPR-:AS	4991.48	0.23	4982.06	5009.47	0.09	0.78	0.31	5001.33	5001.02

WSPRO OUTPUT FILE (continued)

XSID:CODE	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
SRD	FLEN	REW	K	ALPH	HO	ERR	FR#	VEL	
EXIT-:XS	*****	-22.	483.	1.88	*****	4994.03	4990.17	5320.	4992.14
-47.	*****	39.	46125.	1.00	*****	*****	0.69	11.01	

FULLV:FV	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
0.	47.	39.	50194.	1.00	0.00	-0.01	0.64	10.37	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

APPR-:AS	SRDL	LEW	AREA	VHD	HF	EGL	CRWS	Q	WSEL
52.	52.	37.	49188.	1.00	0.00	-0.01	0.65	9.89	
<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>									

===285 CRITICAL WATER-SURFACE ELEVATION A _ S _ S _ U _ M _ E _ D !!!!!
 SECID "BRDG-" Q,CRWS = 5320. 4992.59

<<<<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	
BRDG-:BR	47.	0.	288.	5.31	*****	4997.90	4992.59	5320.	4992.59
0.	47.	27.	33648.	1.00	*****	*****	1.00	18.48	

TYPE	PPCD	FLOW	C	P/A	LSEL	BLEN	XLAB	XRAB
1.	****	1.	1.000	*****	4998.20	*****	*****	*****

XSID:CODE	SRD	FLEN	HF	VHD	EGL	ERR	Q	WSEL
RD	: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	
APPR-:AS	21.	-50.	940.	0.50	0.18	4998.87	4991.44	5320.	4998.37
52.	23.	44.	106296.	1.00	0.78	0.01	0.31	5.66	

M(G)	M(K)	KQ	XLKQ	XRKQ	OTEL
0.639	0.391	64631.	-6.	21.	4998.27

FIRST USER DEFINED TABLE.

XSID:CODE	SRD	LEW	REW	Q	K	AREA	VEL	WSEL
EXIT-:XS	-47.	-22.	39.	5320.	46125.	483.	11.01	4992.14
FULLV:FV	0.	-23.	39.	5320.	50194.	513.	10.37	4992.92
BRDG-:BR	0.	0.	27.	5320.	33648.	288.	18.48	4992.59
RD :RG	10.	*****	*****	0.	*****	*****	2.00	*****
APPR-:AS	52.	-50.	44.	5320.	106296.	940.	5.66	4998.37

XSID:CODE	XLKQ	XRKQ	KQ
APPR-:AS	-6.	21.	64631.

SECOND USER DEFINED TABLE.

XSID:CODE	CRWS	FR#	YMIN	YMAX	HF	HO	VHD	EGL	WSEL
EXIT-:XS	4990.17	0.69	4981.21	5006.22	*****	1.88	4994.03	4992.14	
FULLV:FV	*****	0.64	4981.50	5006.51	0.57	0.00	1.67	4994.59	
BRDG-:BR	4992.59	1.00	4980.59	4998.33	*****	5.31	4997.90	4992.59	
RD :RG	*****	4999.72	5009.16	*****	*****	*****	*****	*****	
APPR-:AS	4991.44	0.31	4982.06	5009.47	0.18	0.78	0.50	4998.87	

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 [BRNATH00680035](#), in Barnard, Vermont.

APPENDIX D:
HISTORICAL DATA FORM