LEVEL II SCOUR ANALYSIS FOR BRIDGE 10 (GROTTH00240010) on TOWN HIGHWAY 24, crossing HEATH BROOK, GROTON, VERMONT

U.S. Geological Survey
Open-File Report 98-288

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 LORA K. STRIKER AND ROBERT E. HAMMOND

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Pembroke, New Hampshire

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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 10 (GROTTH00240010) ON TOWN HIGHWAY 24, CROSSING HEATH BROOK, GROTON, VERMONT

By **Lora K. Striker and Robert E. Hammond**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure GROTTH00240010 on Town Highway 24 crossing Heath Brook, Groton, 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 east-central Vermont. The 5.6-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is predominantly pasture.

In the study area, the Heath Brook has an incised, straight channel with a slope of approximately 0.01 ft/ft, an average channel top width of 53 ft and an average bank height of 9 ft. The channel bed material ranges from gravel to boulder with a median grain size (D_{50}) of 77.5 mm (0.254 ft). The geomorphic assessment at the time of the Level I and Level II site visit on August 29, 1995, indicated that the reach was stable.

The Town Highway 24 crossing of the Heath Brook is a 30-ft-long, two-lane bridge consisting of one 27-foot concrete span (Vermont Agency of Transportation, written communication, March 17, 1995). The opening length of the structure parallel to the bridge face is 24.9 ft.The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 30 degrees to the opening while the computed opening-skew-to-roadway is 30 degrees.

A scour hole 3.0 ft deeper than the mean thalweg depth was observed in mid-channel underneath the bridge during the Level I assessment. Scour protection measures at the site were type-3 stone fill (less than 48 inches diameter) along the left bank upstream, and type-2 stone fill (less than 36 inches diameter) along the right bank upstream, the left and right bank downstream, along the entire base length of the left and right abutments and upstream and downstream wingwalls. 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 is 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 1.1 ft. The worst-case contraction scour occurred at the incipient roadway-overtopping discharge which was less than the 100-year discharge. Abutment scour ranged from 7.1 to 8.1 ft at the left abutment and 4.4 to 5.3 at the right abutment. The worst-case abutment scour occurred at the 500-year discharge at the left abutment and at the incipient roadway-overtopping 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. 47). 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.

Knox Mountain, VT. Quadrangle, 1:24,000, 1981

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 GROTTH00240010 ***Stream*** Heath Brook

County Caledonia ***Road*** TH24 ***District*** 7

Description of Bridge

Bridge length 30 ***ft*** ***Bridge width*** 25.4 ***ft*** ***Max span length*** 27 ***ft***

Alignment of bridge to road (on curve or straight) Curve, left; Straight, right

Abutment type Vertical, concrete ***Embankment type*** Sloping; near vertical

Stone fill on abutment? Yes ***Date of inspection*** 8/29/95

Description of stone fill Type-2, along the entire base length of the left and right abutment, upstream left and right wingwall, and downstream left and right wingwall.

Abutments and wingwalls are concrete. There is a 3 ft scour hole from 15 ft UB to 50 ft DS.

Yes 30

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

The reach is straight.

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	8/29/95	0	0
Level II	8/29/95	0	0

Potential for debris Moderate. There was no debris problems noted at the time of the assessment, 8/29/95. There was one log located in the USRWW area.

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

None as of 8/29/95.

Description of the Geomorphic Setting

General topography The channel is located within a moderate relief valley with a narrow flood plain.

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

Date of inspection 8/29/95

DS left: Steep channel bank to moderately sloping overbank and confluence

DS right: Steep channel bank to flood plain

US left: Steep channel bank to moderately sloping overbank

US right: Steep channel bank to flood plain

Description of the Channel

Average top width 53 ft ***Average depth*** 9 ft

Predominant bed material Boulder/ Cobbles ***Bank material*** Boulder/Sand

Straight and stable with non-alluvial channel boundaries and a narrow flood plain.

8/29/95

Vegetative co Tall and short grass with a few bushes; trees beyond 1B on immediate bank

DS left: Pasture

DS right: Tall grass and bushes: trees beyond 1B on immediate bank

US left: Pasture

US right:

Do banks appear stable? Yes

date of observation.

None observed on 8/29/95.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 5.6 ***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***: None.

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 1,550 ***ft³/s*** ***Q500*** 2,220 ***ft³/s***

The 100- and 500-year discharges are taken directly from flood frequency estimates available from the VTAOT database and are within a range of other empirical flood frequency curves. (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 Subtract 0.7 ft from USGS survey to obtain NGVD of 1929 (also VTAOT). Datum tie points: USRAB and DSLAB.

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of the downstream end of the left abutment (elev. 1271.76 ft, arbitrary survey datum). RM2 is a brass survey disk on top of the downstream end of the right abutment (elev. 1270.35 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITF	-40	3	Exit section (EXITX section with elevation adjustments)
EXITX	-7	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	18	1	Road Grade section
APTEM	65	2	Approach section as surveyed (Used as a template)
APPRO	76	1	Modelled Approach section (Templated from APTEM)

[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 modelling of the reach. Channel "n" values for the reach ranged from 0.035 to 0.045, and overbank "n" values ranged from 0.035 to 0.045.

The surveyed exit section (EXITX) was copied and placed one bridge length downstream of the site with elevation adjustments. These adjustments were made using a slope of 0.0134 ft/ft which was taken from points surveyed downstream of the site. Starting water surface elevations for the 100-year, 500-year, and incipient overtopping discharge at the adjusted exit section (EXITF) were estimated from a rating curve developed from water surface profiles generated in the Flood Insurance Study (FIS) for the Town of Groton (Federal Emergency Management Agency, 1991).

The surveyed approach section (APTEM) was moved along the approach channel slope (0.0308 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 location also provides a consistent method for determining scour variables.

For the incipient-overtopping 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 for the incipient-overtopping discharge, it was 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 a satisfactory solution.

Bridge Hydraulics Summary

Average bridge embankment elevation 1272.3 *ft*
Average low steel elevation 1270.5 *ft*

100-year discharge 1,550 *ft*^{3}*/s*
Water-surface elevation in bridge opening 1271.1 *ft*
Road overtopping? Yes *Discharge over road* 37 *ft*^{3}*/s*
Area of flow in bridge opening 172 *ft*^{2}
Average velocity in bridge opening 8.8 *ft/s*
Maximum WSPRO tube velocity at bridge 10.8 *ft/s*

Water-surface elevation at Approach section with bridge 1272.5
Water-surface elevation at Approach section without bridge 1268.8
Amount of backwater caused by bridge 3.7 *ft*

500-year discharge 2,220 *ft*^{3}*/s*
Water-surface elevation in bridge opening 1271.1 *ft*
Road overtopping? Yes *Discharge over road* 774 *ft*^{3}*/s*
Area of flow in bridge opening 172 *ft*^{2}
Average velocity in bridge opening 8.5 *ft/s*
Maximum WSPRO tube velocity at bridge 10.3 */s*

Water-surface elevation at Approach section with bridge 1273.1
Water-surface elevation at Approach section without bridge 1271.5
Amount of backwater caused by bridge 1.6 *ft*

Incipient overtopping discharge 1,400 *ft*^{3}*/s*
Water-surface elevation in bridge opening 1267.6 *ft*
Area of flow in bridge opening 109 *ft*^{2}
Average velocity in bridge opening 12.8 *ft/s*
Maximum WSPRO tube velocity at bridge 16.0 *ft/s*

Water-surface elevation at Approach section with bridge 1270.8
Water-surface elevation at Approach section without bridge 1268.3
Amount of backwater caused by bridge 2.5 *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 100- and 500-year scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

At this site, the 100-year discharge resulted in unsubmerged orifice flow while the 500-year discharge 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). Thus, contraction scour for the 100- and 500-year discharges was computed by use of the Chang equation (Richardson and Davis, 1995, p. 145-146). Contraction scour for the incipient roadway-overtopping discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). The computed streambed armoring depths suggest that armoring will not limit the depth of contraction scour.

For comparison, contraction scour for the discharges resulting in orifice flow was also computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144) and presented in appendix F. Furthermore, for the discharge resulting in unsubmerged orifice flow, 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 substitutions are provided in appendix F.

Abutment scour for the left abutment 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 at the right abutment was computed by use of the HIRE equation (Richardson and Davis, 1995, p. 49, equation 29) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
		(Scour depths in feet)	
Main channel			
Live-bed scour	--	--	--
Clear-water scour	0.0	0.0	1.1
Depth to armoring	9.9	1.2	N/A
Left overbank	--	--	--
Right overbank	--	--	--
Local scour:			
Abutment scour			
Left abutment	7.6	8.1	7.1
Right abutment	5.2	4.4	5.3
Pier scour			
Pier 1	--	--	--
Pier 2	--	--	--
Pier 3	--	--	--

Riprap Sizing

	100-yr discharge	*500-yr discharge*	*Incipient overtopping discharge*
		(D_{50} in feet)	
Abutments:			
Left abutment	2.4	1.6	2.1
Right abutment	2.4	1.6	2.1
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

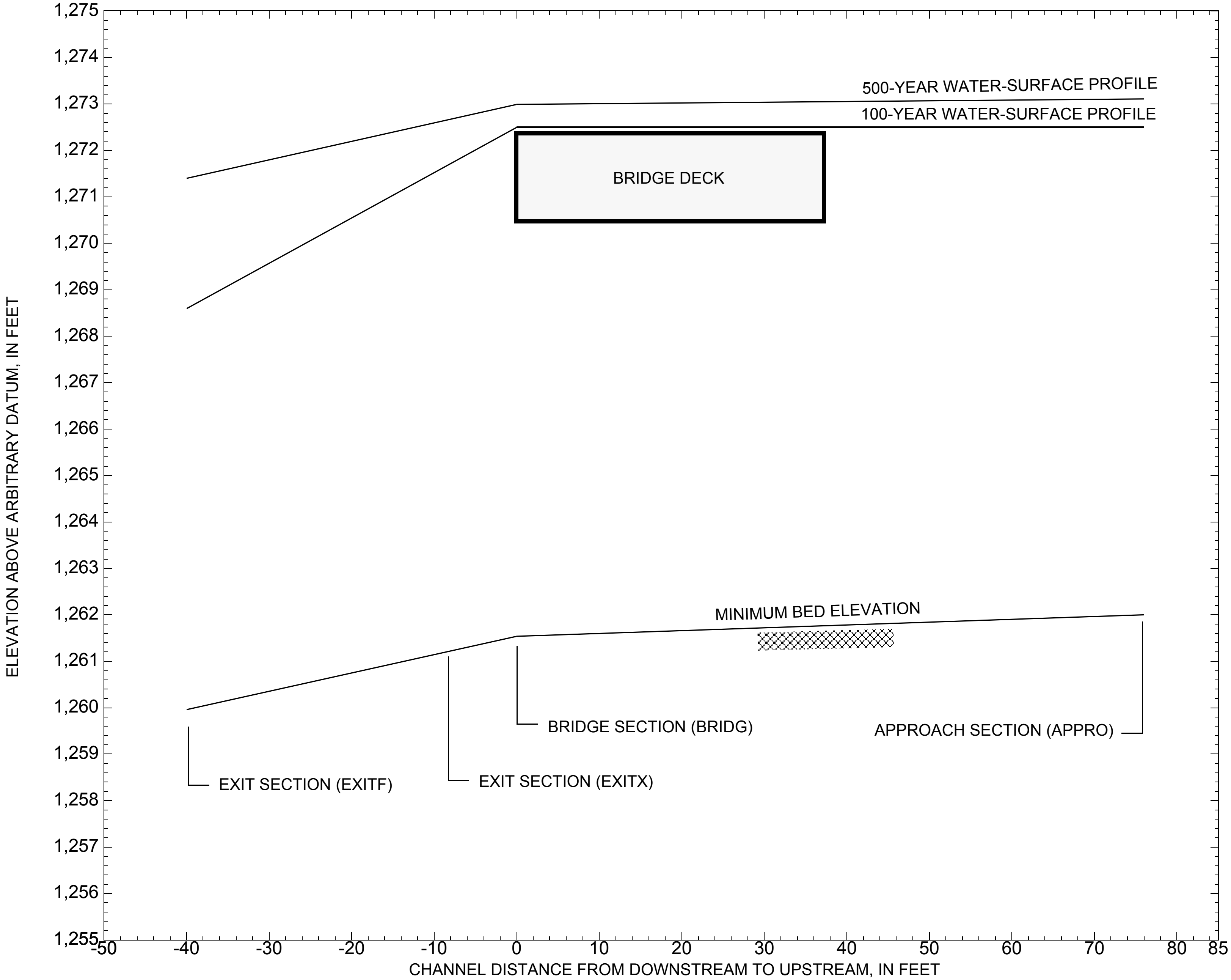

Figure 7. Water-surface profiles for the 100-year and 500-year discharges at structure GROTTH00240010 on Town Highway 24, crossing Heath Brook, Groton, Vermont.

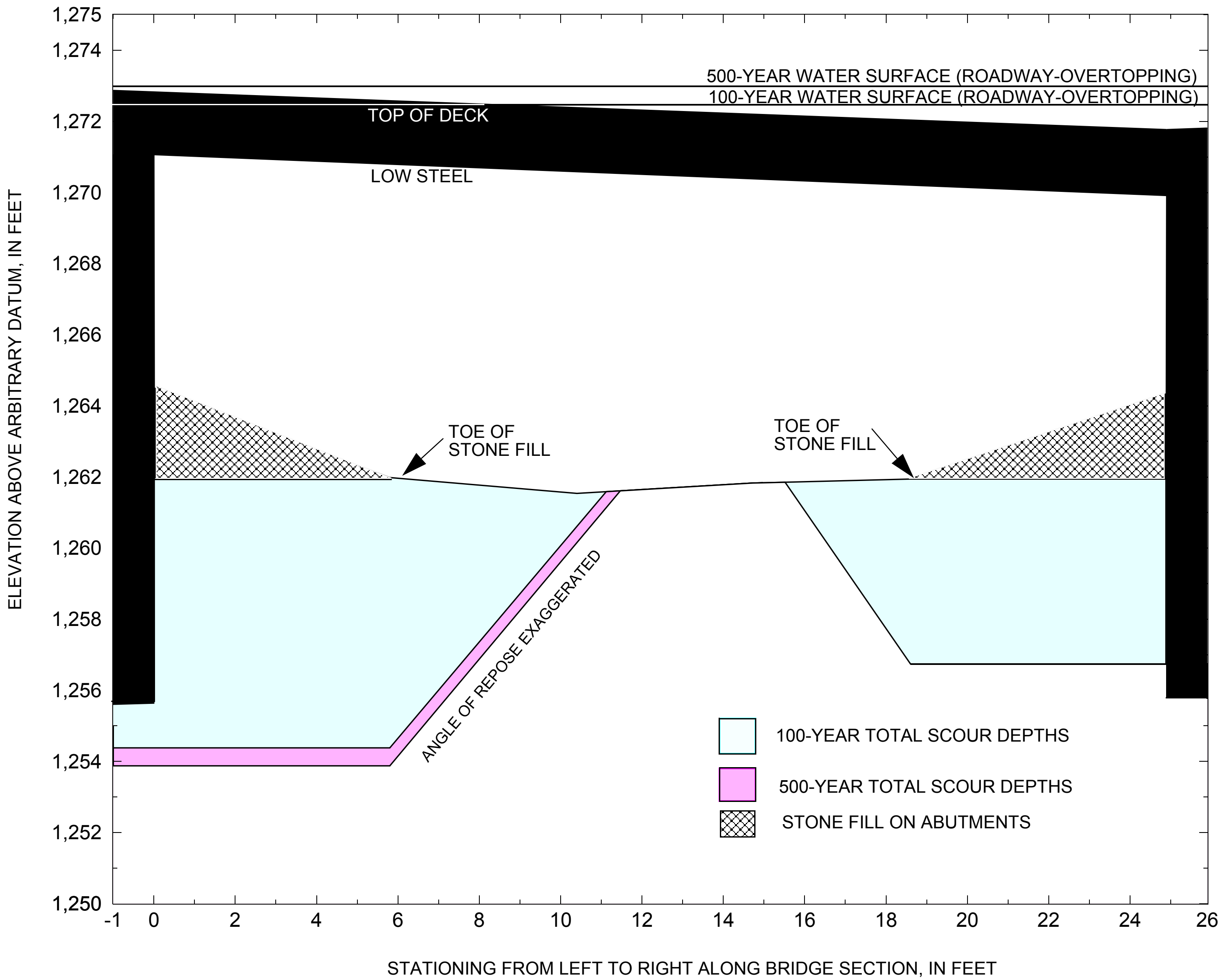

Figure 8. Scour elevations for the 100-year and 500-year discharges at structure GROTTH00240010 on Town Highway 24, crossing Heath Brook, Groton, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure GROTTH00240010 on Town Highway 24, crossing Heath Brook, Groton, 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-yr. discharge is 1,550 cubic-feet per second											
Left abutment	0.0	1271.2	1271.1	1255.7	1264.5	--	--	--	--	--	-1.3
Toe of Stone Fill	5.8	--	--	--	1262.0	0.0	7.6	--	7.6	1254.4	--
Toe of Stone Fill	18.6	--	--	--	1261.9	0.0	5.2	--	5.2	1256.7	--
Right abutment	24.9	1271.2	1270.0	1255.7	1264.3	--	--	--	--	--	1.0

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure GROTTH00240010 on Town Highway 24, crossing Heath Brook, Groton, 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-yr. discharge is 2,220 cubic-feet per second											
Left abutment	0.0	1271.2	1271.1	1255.7	1264.5	--	--	--	--	--	-1.8
Toe of Stone Fill	5.8	--	--	--	1262.0	0.0	8.1	--	8.1	1253.9	--
Toe of Stone Fill	18.6	--	--	--	1261.9	0.0	4.4	--	4.4	1257.5	--
Right abutment	24.9	1271.2	1270.0	1255.7	1264.3	--	--	--	--	--	1.8

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 grot010.wsp
T2        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
T3        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           2220.0   1400.0
WS          1271.4   1268.1
*
*         WS Q of the incipient was rounded to the nearest tenth
*
XS   EXITF     -40          0.
GR         -124.3,1279.29   -104.4,1275.98    -43.3,1273.59    -17.3,1271.32
GR           -9.8,1270.42      0.0,1265.38      9.7,1261.05     11.5,1260.25
GR           15.8,1260.38     20.1,1259.96     24.4,1261.07     35.7,1265.55
GR           46.5,1268.83
*           163.5,1264.00    264.4,1263.01    325.4,1263.00
*
N           0.045        0.035        0.045
SA                  -9.8         46.5
*
XS   EXITX     -7           0.
GR         -124.3,1279.73   -104.4,1276.42    -43.3,1274.03    -17.3,1271.76
GR           -9.8,1270.86      0.0,1265.82      9.7,1261.49     11.5,1260.69
GR           15.8,1260.82     20.1,1260.40     24.4,1261.51     35.7,1265.99
GR           46.5,1269.27
*           163.5,1264.44    264.4,1263.45    325.4,1263.44
*
N           0.040        0.035        0.035
SA                  -9.8         46.5
*
*
XS   FULLV      0  * * *   0.0198
*
*             SRD     LSEL    XSSKEW
BR   BRIDG     0   1270.50      30.0
GR            0.0,1271.07      0.0,1264.50      5.8,1261.98     10.4,1261.54
GR           14.7,1261.83     18.6,1261.94     24.6,1264.34     24.9,1269.92
GR            0.0,1271.07
*
*         BRTYPE  BRWDTH       WWANGL    WWWID
CD           1      44.8 * *     40.4     12.9
N           0.040
*
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     18      25.4     2
GR         -166.8,1288.94   -153.0,1283.84    -77.1,1277.72    -70.3,1274.61
GR          -64.8,1275.13      0.0,1272.83     24.9,1271.77     58.7,1272.79
GR           71.4,1272.18    336.1,1272.55
*
*
XT   APTEM     65           0.
GR          -94.2,1282.17    -85.5,1278.53    -55.5,1276.76    -12.4,1274.05
GR            0.0,1265.98      5.1,1263.05      9.6,1262.12     13.7,1261.66
GR           17.5,1262.83     22.4,1263.09     36.0,1270.02    336.1,1272.55
*
AS   APPRO     76    * * *  0.0308
GT
N           0.045        0.045        0.035
SA                 -12.4         36.0
*
*
HP 1 BRIDG   1271.07 1 1271.07
HP 2 BRIDG   1271.07 * *  1455
HP 2 RDWAY   1272.99 * *   774
HP 1 APPRO   1273.11 1 1273.11
HP 2 APPRO   1273.11 * *  2220
```

```
*
HP 1 BRIDG   1267.57 1 1267.57
HP 2 BRIDG   1267.57 * *  1400
HP 1 APPRO   1270.75 1 1270.75
HP 2 APPRO   1270.75 * *  1400
*
EX
ER



T1        U.S. Geological Survey WSPRO Input File grot010.wsp
T2        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
T3        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
*
J1          * * 0.002
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1550.0
WS          1268.6
*
*
XS   EXITF     -40          0.
GR         -124.3,1279.29   -104.4,1275.98    -43.3,1273.59    -17.3,1271.32
GR           -9.8,1270.42      0.0,1265.38      9.7,1261.05     11.5,1260.25
GR           15.8,1260.38     20.1,1259.96     24.4,1261.07     35.7,1265.55
GR           46.5,1268.83
*           163.5,1264.00    264.4,1263.01    325.4,1263.00
*
N           0.045        0.035        0.045
SA                   -9.8         46.5
*
XS   EXITX     -7           0.
GR         -124.3,1279.73   -104.4,1276.42    -43.3,1274.03    -17.3,1271.76
GR           -9.8,1270.86      0.0,1265.82      9.7,1261.49     11.5,1260.69
GR           15.8,1260.82     20.1,1260.40     24.4,1261.51     35.7,1265.99
GR           46.5,1269.27
*           163.5,1264.44    264.4,1263.45    325.4,1263.44
*
N           0.040        0.035        0.035
SA                   -9.8         46.5
*
*
XS   FULLV      0  * * *   0.0198
*
*             SRD     LSEL    XSSKEW
BR   BRIDG      0   1270.50      30.0
GR            0.0,1271.07      0.0,1264.50      5.8,1261.98     10.4,1261.54
GR           14.7,1261.83     18.6,1261.94     24.6,1264.34     24.9,1269.92
GR            0.0,1271.07
*
*         BRTYPE  BRWDTH       WWANGL    WWWID
CD            1      44.8 * *     40.4     12.9
N           0.040
*
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     18      25.4     2
GR         -166.8,1288.94   -153.0,1283.84    -77.1,1277.72    -70.3,1274.61
GR          -64.8,1275.13      0.0,1272.83     24.9,1271.77     58.7,1272.79
*   GR           71.4,1272.18    336.1,1272.55
*
*            Roadway section was truncated because water surface elevation on roadway does not get over
*            the elevation at station 58.7.
*
XT   APTEM     65           0.
GR          -94.2,1282.17    -85.5,1278.53    -55.5,1276.76    -12.4,1274.05
GR            0.0,1265.98      5.1,1263.05      9.6,1262.12     13.7,1261.66
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
        U.S. Geological Survey WSPRO Input File grot010.wsp
       Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
       TH 24 crossing Heath Brook located at junction with TH 27,    LKS
          *** RUN DATE & TIME: 09-15-97  16:09
   CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      172     13532      0     56                            0
  1271.07          172     13532      0     56  1.00      0     25        0

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
     1271.07     0.0    24.9   172.2   13532.    1516.   8.80

X STA.         0.0        2.5        4.0        5.2        6.2        7.2
  A(I)            15.3        9.9        8.7        7.9        7.8
  V(I)            4.96       7.64       8.72       9.56       9.72

X STA.         7.2        8.2        9.1       10.0       11.0       11.9
  A(I)             7.3        7.4        7.2        7.1        7.0
  V(I)           10.43      10.25      10.55      10.65      10.76

X STA.        11.9       12.8       13.8       14.7       15.7       16.8
  A(I)             7.2        7.1        7.4        7.4        7.6
  V(I)           10.48      10.61      10.26      10.26       9.98

X STA.        16.8       17.9       19.0       20.3       21.9       24.9
  A(I)             7.8        8.2        8.9       10.0       14.9
  V(I)            9.71       9.27       8.49       7.60       5.07

   CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      133     13044     22     31                         1870
  1268.66          133     13044     22     31  1.00      0     25     1870

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = RDWAY;  SRD =      18.
        WSEL     LEW     REW    AREA        K        Q    VEL
     1272.47     8.5    48.1    13.9     300.      37.   2.67

X STA.         8.5       16.1       18.3       19.9       21.2       22.2
  A(I)             1.2        0.8        0.7        0.6        0.6
  V(I)            1.49       2.20       2.59       2.85       3.10

X STA.        22.2       23.2       24.0       24.8       25.6       26.4
  A(I)             0.6        0.6        0.5        0.5        0.5
  V(I)            3.25       3.27       3.47       3.57       3.47

X STA.        26.4       27.2       28.1       29.1       30.1       31.3
  A(I)             0.5        0.5        0.6        0.6        0.6
  V(I)            3.45       3.38       3.25       3.15       3.01

X STA.        31.3       32.6       34.2       36.2       38.9       48.1
  A(I)             0.6        0.7        0.8        0.9        1.3
  V(I)            2.89       2.63       2.38       2.12       1.46

   CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      76.
    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            2      312     35006     45     50                         4640
            3      269     11964    253    253                         1578
  1272.49          581     46970    298    303  1.51     -8    289     3744

   VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      76.

        WSEL     LEW     REW    AREA        K        Q    VEL
     1272.49    -9.5   288.8   581.5   46970.    1550.   2.67

X STA.        -9.5        1.2        4.3        6.6        8.5       10.3
  A(I)            36.8       24.1       20.8       18.5       18.2
  V(I)            2.11       3.22       3.73       4.19       4.25

X STA.        10.3       12.0       13.6       15.3       17.0       18.9
  A(I)            17.1       16.8       16.9       17.1       17.4
  V(I)            4.54       4.61       4.57       4.52       4.44

X STA.        18.9       20.8       22.8       25.2       28.6       37.7
  A(I)            17.3       18.2       19.9       23.1       33.4
  V(I)            4.49       4.27       3.90       3.35       2.32

X STA.        37.7       57.1       80.0      108.8      149.6      288.8
  A(I)            39.5       42.5       47.2       55.0       81.6
  V(I)            1.96       1.82       1.64       1.41       0.95
```

```
        U.S. Geological Survey WSPRO Input File grot010.wsp
        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
           *** RUN DATE & TIME: 09-17-97  10:45
    CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      172     13532      0     56                            0
  1271.07           172     13532      0     56  1.00      0     25        0

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1271.07     0.0    24.9   172.2   13532.    1455.   8.45

X STA.         0.0        2.5        4.0        5.2        6.2        7.2
  A(I)            15.3        9.9        8.7        7.9        7.8
  V(I)            4.76       7.34       8.37       9.17       9.33

X STA.         7.2        8.2        9.1       10.0       11.0       11.9
  A(I)             7.3        7.4        7.2        7.1        7.0
  V(I)           10.01       9.84      10.12      10.22      10.33

X STA.        11.9       12.8       13.8       14.7       15.7       16.8
  A(I)             7.2        7.1        7.4        7.4        7.6
  V(I)           10.06      10.18       9.85       9.85       9.58

X STA.        16.8       17.9       19.0       20.3       21.9       24.9
  A(I)             7.8        8.2        8.9       10.0       14.9
  V(I)            9.31       8.89       8.15       7.29       4.87

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = RDWAY;  SRD =      18.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1272.99    -4.5   336.1   213.4    6660.     774.   3.63

X STA.        -4.5       20.3       27.8       36.1       52.3       76.2
  A(I)            12.4        8.5        8.4       10.3       12.2
  V(I)            3.12       4.53       4.62       3.74       3.17

X STA.        76.2       88.2      100.7      113.2      126.1      139.9
  A(I)             9.5        9.7        9.5        9.6        9.9
  V(I)            4.08       3.98       4.06       4.04       3.90

X STA.       139.9      153.9      168.9      184.6      201.5      219.1
  A(I)             9.9       10.2       10.4       10.8       10.9
  V(I)            3.91       3.78       3.71       3.59       3.56

X STA.       219.1      238.4      259.4      282.2      307.0      336.1
  A(I)            11.4       11.8       12.1       12.4       13.4
  V(I)            3.41       3.28       3.20       3.13       2.89

    CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      76.
     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             2      341     39892     46     51                         5235
             3      446     24715    300    300                         3085
  1273.11           787     64607    347    352  1.43     -9    336     5624

    VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      76.
         WSEL     LEW     REW    AREA        K        Q    VEL
      1273.11   -10.4   336.1   786.6   64607.    2220.   2.82

X STA.       -10.4        1.4        5.0        7.6        9.9       12.1
  A(I)            45.5       30.9       26.3       24.3       23.0
  V(I)            2.44       3.59       4.22       4.57       4.82

X STA.        12.1       14.1       16.2       18.5       20.8       23.2
  A(I)            22.1       22.9       22.6       22.7       23.7
  V(I)            5.02       4.85       4.92       4.89       4.69

X STA.        23.2       26.3       31.5       46.2       63.6       82.6
  A(I)            26.2       32.9       45.3       44.9       46.4
  V(I)            4.23       3.38       2.45       2.47       2.39

X STA.        82.6      104.9      131.0      164.0      209.0      336.1
  A(I)            50.6       53.8       59.8       66.7       96.2
  V(I)            2.19       2.06       1.86       1.66       1.15
```

```
          U.S. Geological Survey WSPRO Input File grot010.wsp
        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
           *** RUN DATE & TIME: 09-17-97  10:45
      CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

       WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
               1      109      9909     21     29                          1399
    1267.57           109      9909     21     29  1.00      0     25      1399

      VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
           WSEL     LEW     REW    AREA        K        Q    VEL
        1267.57     0.0    24.8   109.3    9909.    1400.  12.81

  X STA.        0.0        3.1        4.6        5.9        6.9        7.9
    A(I)             9.9        6.5        5.7        5.1        4.8
    V(I)            7.06      10.77      12.37      13.64      14.65

  X STA.        7.9        8.8        9.7       10.6       11.4       12.3
    A(I)             4.7        4.6        4.5        4.4        4.4
    V(I)           14.97      15.30      15.60      15.82      15.97

  X STA.       12.3       13.1       14.0       14.9       15.8       16.8
    A(I)             4.4        4.5        4.4        4.6        4.7
    V(I)           15.84      15.51      15.73      15.31      14.83

  X STA.       16.8       17.8       18.9       20.1       21.6       24.8
    A(I)             4.9        5.1        5.6        6.4       10.0
    V(I)           14.35      13.62      12.54      10.85       6.99

      CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      76.
       WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
               2      235     22842     43     47                          3130
               3        9       130     46     46                            23
    1270.75           244     22972     89     93  1.06     -6     82      2229

      VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      76.
           WSEL     LEW     REW    AREA        K        Q    VEL
        1270.75    -6.8    82.4   244.4   22972.    1400.   5.73

  X STA.       -6.8        1.3        3.7        5.5        6.9        8.2
    A(I)            21.2       14.5       12.3       11.0       10.3
    V(I)            3.30       4.83       5.67       6.38       6.80

  X STA.        8.2        9.5       10.6       11.8       12.8       13.9
    A(I)            10.1        9.5        9.6        9.3        9.4
    V(I)            6.95       7.36       7.33       7.57       7.47

  X STA.       13.9       15.0       16.2       17.4       18.8       20.1
    A(I)             9.4        9.6        9.9       10.1       10.2
    V(I)            7.48       7.33       7.06       6.96       6.86

  X STA.       20.1       21.6       23.2       25.2       28.1       82.4
    A(I)            10.7       11.5       12.7       15.2       28.1
    V(I)            6.57       6.07       5.51       4.61       2.49
```

```
        U.S. Geological Survey WSPRO Input File grot010.wsp
        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
           *** RUN DATE & TIME: 09-15-97  16:09

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

EXITF:XS   ******     -5      258  0.56 ***** 1269.16 1266.05    1550 1268.60
       -39 ******     46    30720  1.00 ***** *******    0.47    6.00

EXITX:XS       33     -4      238  0.66  0.09 1269.30 *******    1550 1268.64
        -6     33     44    27534  1.00  0.05    0.00    0.53    6.51

FULLV:FV        7     -4      232  0.69  0.02 1269.35 *******    1550 1268.66
         0      7     44    26634  1.00  0.02    0.01    0.54    6.68
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80     0.85    1268.75    1268.25
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =  1268.16    1282.51    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =  1268.16    1282.51    1268.25
 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.48

APPRO:AS       76     -3      155  1.55  0.54 1270.30 1268.25    1550 1268.75
        76     76     33    12786  1.00  0.43   -0.02    0.85    9.97
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =  1267.94    1271.08    1271.33    1270.50
 ===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        7      0      172  1.21 ***** 1272.28 1267.85    1516 1271.07
         0 ******     25    13532  1.00 ***** *******    0.59    8.80

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.468  0.000 1270.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD      EGL     ERR       Q    WSEL
   RDWAY:RG      18.    51.  0.05  0.17 1272.61    0.00     37. 1272.47

            Q    WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      1.     4.     9.    12.   0.2   0.1   1.8   3.3   0.2   2.6
   RT:     36.    36.    12.    48.   0.7   0.4   2.9   2.6   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       31     -8      583  0.17  0.12 1272.66 1268.25    1550 1272.49
        76     32    289    47053  1.51  0.90    0.00    0.41    2.66

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q         K     AREA     VEL    WSEL
   EXITF:XS     -40.    -6.    46.   1550.   30720.     258.    6.00 1268.60
   EXITX:XS      -7.    -5.    44.   1550.   27534.     238.    6.51 1268.64
   FULLV:FV       0.    -5.    44.   1550.   26634.     232.    6.68 1268.66
   BRIDG:BR       0.     0.    25.   1516.   13532.     172.    8.80 1271.07
   RDWAY:RG      18.*******     1.     37.        0.*********    2.00 1272.47
   APPRO:AS      76.    -9.   289.   1550.   47053.     583.    2.66 1272.49

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITF:XS   1266.05    0.47 1259.96 1279.29************  0.56 1269.16 1268.60
   EXITX:XS  ********    0.53 1260.40 1279.73  0.09  0.05  0.66 1269.30 1268.64
   FULLV:FV  ********    0.54 1260.54 1279.87  0.02  0.02  0.69 1269.35 1268.66
   BRIDG:BR   1267.85    0.59 1261.54 1271.07************  1.21 1272.28 1271.07
   RDWAY:RG  *************** 1271.77 1288.94  0.05******  0.17 1272.61 1272.47
   APPRO:AS   1268.25    0.41 1262.00 1282.51  0.12  0.90  0.17 1272.66 1272.49
```

WSPRO OUTPUT FILE (continued)

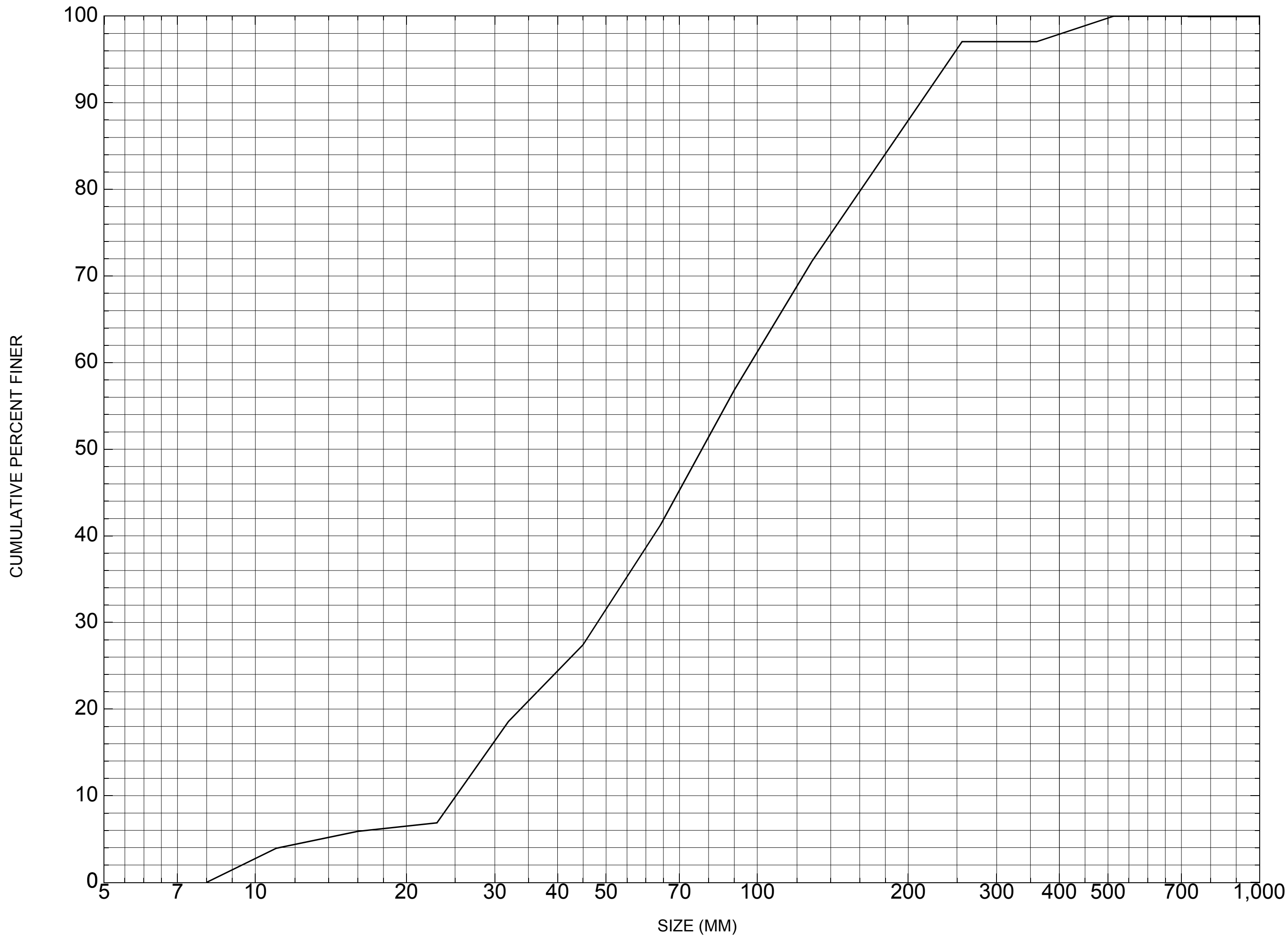
```
        U.S. Geological Survey WSPRO Input File grot010.wsp
        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
           *** RUN DATE & TIME: 09-17-97  10:45

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL
EXITF:XS   ******    -17      417  0.45 ***** 1271.85 1267.20    2220 1271.40
       -39 ******     47    61792  1.02 ***** *******    0.37    5.33

 ===140 AT SECID "EXITX":  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =  1271.42    1279.73    1269.27

EXITX:XS       33    -13      390  0.51  0.05 1271.92 *******    2220 1271.42
        -6     33     47    56158  1.01  0.03    0.00    0.40    5.69

 ===140 AT SECID "FULLV":  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =  1271.43    1279.87    1269.41

FULLV:FV        7    -12      382  0.53  0.01 1271.95 *******    2220 1271.43
         0      7     47    54497  1.00  0.01    0.01    0.41    5.81
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.95    1271.48    1269.45
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =  1270.93    1282.51    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =  1270.93    1282.51    1269.45
 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                            "APPRO"     KRATIO =  0.55

APPRO:AS       76     -7      343  0.86  0.23 1272.35 1269.45    2220 1271.49
        76     76    170    29942  1.32  0.17    0.00    0.94    6.47
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===255 ATTEMPTING FLOW CLASS 3 (6) SOLUTION.
                       WS3N,LSEL =  1271.43    1270.50

            <<<<<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        7      0      172  1.11 ***** 1272.18 1267.73    1455 1271.07
         0 ******     25    13532  1.00 ***** *******    0.57    8.45

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   6.  0.800  0.000 1270.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.    51.  0.06  0.18 1273.23    0.00    774. 1272.99

            Q    WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:     19.    16.    -4.    12.   0.7   0.3   3.1   3.7   0.6   2.8
   RT:    755.   324.    12.   336.   1.2   0.6   4.0   3.6   0.9   2.8

===140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
                            WSEL,YLT,YRT =  1273.11     1282.5     1272.9

 XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
       SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL
APPRO:AS       31     -9      788  0.18  0.13 1273.29 1269.45    2220 1273.11
        76     35    336    64786  1.43  0.00    0.00    0.39    2.82

  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITF:XS     -40.   -18.    47.   2220.   61792.     417.    5.33 1271.40
   EXITX:XS      -7.   -14.    47.   2220.   56158.     390.    5.69 1271.42
   FULLV:FV       0.   -13.    47.   2220.   54497.     382.    5.81 1271.43
   BRIDG:BR       0.     0.    25.   1455.   13532.     172.    8.45 1271.07
   RDWAY:RG      18.*******    19.    774.******************    2.00 1272.99
   APPRO:AS      76.   -10.   336.   2220.   64786.     788.    2.82 1273.11

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

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXITF:XS   1267.20    0.37 1259.96 1279.29************  0.45 1271.85 1271.40
   EXITX:XS  ********    0.40 1260.40 1279.73  0.05  0.03  0.51 1271.92 1271.42
   FULLV:FV  ********    0.41 1260.54 1279.87  0.01  0.01  0.53 1271.95 1271.43
   BRIDG:BR   1267.73    0.57 1261.54 1271.07************  1.11 1272.18 1271.07
   RDWAY:RG  *************** 1271.77 1288.94  0.06******  0.18 1273.23 1272.99
   APPRO:AS   1269.45    0.39 1262.00 1282.51  0.13  0.00  0.18 1273.29 1273.11
```

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File grot010.wsp
        Hydraulic analysis for structure GROTTH00240010   Date: 08-AUG-97
        TH 24 crossing Heath Brook located at junction with TH 27,    LKS
           *** RUN DATE & TIME: 09-17-97  10:45

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

EXITF:XS   ******     -4      233  0.56 ***** 1268.66 1265.75    1400 1268.10
       -39 ******     44    26778  1.00 ***** *******    0.49    6.01

EXITX:XS       33     -4      214  0.67  0.10 1268.81 *******    1400 1268.14
        -6     33     43    23889  1.00  0.05   -0.01    0.54    6.55

FULLV:FV        7     -3      208  0.70  0.02 1268.87 *******    1400 1268.16
         0      7     42    23076  1.00  0.02    0.01    0.56    6.72
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80     0.88    1268.32    1267.97
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =  1267.66    1282.51    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =  1267.66    1282.51    1267.97
 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                             "APPRO"     KRATIO =  0.48

APPRO:AS       76     -2      140  1.56  0.58 1269.88 1267.97    1400 1268.32
        76     76     32    11042  1.00  0.43    0.00    0.88   10.02
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID "BRIDG"     Q,CRWS =    1400.    1267.57

            <<<<<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        7      0      109  2.55 ***** 1270.12 1267.57    1400 1267.57
         0      7     25     9914  1.00 ***** *******    1.00   12.81

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ****** 1270.50 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      18.        <<<<<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       31     -6      245  0.54  0.28 1271.29 1267.97    1400 1270.75
        76     32     83    22990  1.06  0.89    0.00    0.63    5.72

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.292  0.017   22578.     1.    26.  1270.56

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITF:XS     -40.    -5.    44.   1400.   26778.     233.    6.01 1268.10
   EXITX:XS      -7.    -5.    43.   1400.   23889.     214.    6.55 1268.14
   FULLV:FV       0.    -4.    42.   1400.   23076.     208.    6.72 1268.16
   BRIDG:BR       0.     0.    25.   1400.    9914.     109.   12.81 1267.57
   RDWAY:RG      18.**************      0.*****************    2.00********
   APPRO:AS      76.    -7.    83.   1400.   22990.     245.    5.72 1270.75

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       1.    26.   22578.
1
  SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITF:XS   1265.75    0.49 1259.96 1279.29************  0.56 1268.66 1268.10
   EXITX:XS   ********   0.54 1260.40 1279.73  0.10  0.05  0.67 1268.81 1268.14
   FULLV:FV   ********   0.56 1260.54 1279.87  0.02  0.02  0.70 1268.87 1268.16
   BRIDG:BR    1267.57   1.00 1261.54 1271.07************  2.55 1270.12 1267.57
   RDWAY:RG   **************** 1271.77 1288.94**********************************
   APPRO:AS    1267.97   0.63 1262.00 1282.51  0.28  0.89  0.54 1271.29 1270.75
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure GROTTH00240010, in Groton, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number GROTTH00240010

General Location Descriptive

Data collected by *(First Initial, Full last name)* E. BOEHMLER

Date *(MM/DD/YY)* 03 / 17 / 95

Highway District Number *(I - 2; nn)* 07

County *(FIPS county code; I - 3; nnn)* 005

Town *(FIPS place code; I - 4; nnnnn)* 30550

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

Waterway *(I - 6)* HEATH BROOK

Road Name *(I - 7)*: SEYON POND ROAD

Route Number TH024

Vicinity *(I - 9)* @ JCT W CL3 TH27

Topographic Map Knox Mountain

Hydrologic Unit Code: 01080102

Latitude *(I - 16; nnnn.n)* 44133

Longitude *(i - 17; nnnnn.n)* 72163

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10030400100304

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

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

Year built *(I - 27; YYYY)* 1988

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

Average daily traffic, ADT *(I - 29; nnnnnn)* 000080

Deck Width *(I - 52; nn.n)* 254

Year of ADT *(I - 30; YY)* 93

Channel & Protection *(I - 61; n)* 8

Opening skew to Roadway *(I - 34; nn)* 28

Waterway adequacy *(I - 71; n)* 7

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

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

Structure type *(I - 43; nnn)* 101

Year Reconstructed *(I - 106)* 0000

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

Clear span (*nnn.n ft*) 022.4

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

Vertical clearance from streambed (*nnn.n ft*) 007.0

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

Waterway of full opening (*nnn.n* ft^2) 180.0

Comments:

The structural inspection report of 6/29/93 indicates the structure is a concrete slab type bridge. The deck is slightly curved. The abutment walls and wingwalls are concrete. Overall, the abutment concrete has fine cracks and small leaks reported at the top corners of each wall. There is stone and boulder fill protection noted as placed in front of the abutment walls and wingwalls. The stone fill is further noted as extending along the banks upstream and downstream. The bridge is fairly new. The channel bed is reported as composed of mainly boulders. The footings are not in view at the surface with no undermining or settling apparent.

Bridge Hydrologic Data

Is there hydrologic data available? **Y** *if No, type ctrl-n h* VTAOT Drainage area (*mi²*): **5.6**

Terrain character: **Hilly to mountainous**

Stream character & type: **Straight**

Streambed material: **Gravel and small boulders**

Discharge Data (*cfs*): $Q_{2.33}$ **375** Q_{10} **750** Q_{25} **1050**

Q_{50} **1300** Q_{100} **1550** Q_{500} **-**

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

Estimated Discharge (*cfs*): **-** Velocity at Q **25** (*ft/s*): **10.9**

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

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

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

Describe any significant site conditions upstream or downstream that may influence the stream's stage: **Downstream Heath brook joins the South Branch Wells River, which may backwater up through the bridge.**

Watershed storage area (*in percent*): **1** %

The watershed storage area is: **2** (*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*)	**1264.5**	**1266.4**	**1267.6**	**1268.5**	**1269.2**
Velocity (*ft / sec*)	**9.4**	**12.7**	**14.7**	**16.0**	**16.6**

Long term stream bed changes: **Scour expected is between 2 and 4 feet**

Is the roadway overtopped below the Q_{100}? (*Yes, No, Unknown*): **Y** Frequency: **Q35**

Relief Elevation (*ft*): **1268.0** Discharge over roadway at Q_{100} (*ft³/ 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 (*ft²*): **-**

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

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

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

Comments:

Hydraulics section report of hydrology indicates the channel needs to be protected by type IV stone. There are no structures downstream of this bridge over Heath Brook as it drains into the South Branch Wells River immediately downstream. It is unknown if there are additional structures upstream of this bridge.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **5.63** mi^2

Lake/pond/swamp area **0** mi^2

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

Bridge site elevation **1270** ft

Headwater elevation **3352** ft

Main channel length **3.90** mi

10% channel length elevation **1340** ft

85% channel length elevation **2440** ft

Main channel slope *(S)* **376.07** 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? Y *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY)*: 05 / 1987

Project Number TH 3516 Minimum channel bed elevation: 1259.5

Low superstructure elevation: USLAB 1270.03 DSLAB 1268.93 USRAB 1268.88 DSRAB 1267.53

Benchmark location description:

No specific benchmarks were shown on the plans. The plans provided some points with elevations: 1) The point on the top of the upstream right wingwall concrete at the streamward edge where the concrete slope changes from horizontal to downward, elevation 1271.17, and 2) The point at the same location as (1) but on the downstream left wingwall, elevation 1271.76.

Reference Point (*MSL, Arbitrary, Other*): MSL Datum (*NAD27, NAD83, Other*): NGVD1929

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

If 1: Footing Thickness 2.5 Footing bottom elevation: 1255.0

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:

-

Comments:

This bridge crosses Heath Brook just upstream of the Heath Brook confluence with the South Branch Wells River.

Cross-sectional Data

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

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

Comments: **There are several channel cross sections printed and kept with the plans and may be retrieved if needed. However, there are no reproducible bridge cross sections due to differences in VTAOT and USGS survey methods.**

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

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

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

Comments: -

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

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

APPENDIX E:

LEVEL I DATA FORM

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

Qa/Qc Check by: **EW** Date: **02/28/96**
Computerized by: **EW** Date: **02/28/96**
Reviewd by: **LKS** Date: **09/17/97**

Structure Number **GROTTH00240010**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **R**. **HAMMOND** Date *(MM/DD/YY)* **08** / **29** / 19**95**

2. Highway District Number **07** Mile marker **0**

County **Caledonia (005)** Town **Groton (30550)**

Waterway *(I - 6)* **Heath Brook** Road Name **Seyon Pond Road**

Route Number **TH24** Hydrologic Unit Code: **01080102**

3. Descriptive comments:

The bridge is located at the junction with Town Highway 27 and 1.5 miles from US Route 302.

B. Bridge Deck Observations

4. Surface cover... LBUS **4** RBUS **4** LBDS **4** RBDS **4** Overall **4**
*(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 **1** *(**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 **30.0** *(feet)* Span length **27.0** *(feet)* Bridge width **25.4** *(feet)*

Road approach to bridge:

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

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

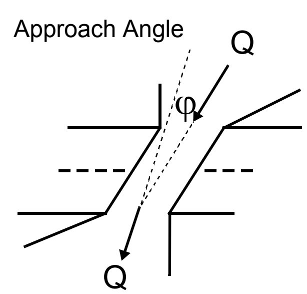
10. Embankment slope (*run / rise in feet / foot*):
US left **--** US right **--**

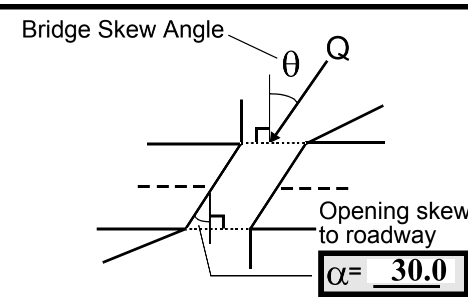
	Protection		13.Erosion	14.Severity
	11.Type	12.Cond.		
LBUS	2	1	0	-
RBUS	0	-	0	-
RBDS	2	1	0	-
LBDS	0	-	2	2

*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: **0** 16. Bridge skew: **30**





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

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

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

18. Bridge Type: **1a**

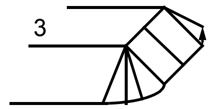
1a- Vertical abutments with wingwalls

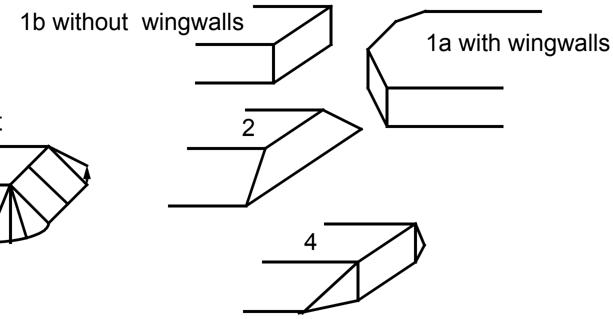
1b- Vertical abutments without wingwalls

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.)

#7: The values are from VTAOT form. The measured values include: the US bridge span length= 25.0 ft; the DS bridge span length= 26.0 ft; the bridge length= 30 ft; and the bridge width 25.4 ft.

#18: The slope of USRWW terminates just below low chord elevation.

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
76.0	**11.0**			**7.0**	**1**	**1**	**2**	**2**	**0**	**0**

23. Bank width **30.0** 24. Channel width **25.0** 25. Thalweg depth **48.5** 29. Bed Material **54**

30 .Bank protection type: LB **3** RB **2** 31. Bank protection condition: LB **1** RB **1**

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.):

Protection extent: Protection extends along the right bank from 0 ft to 80 ft upstream. Protection along the left bank extends from 0 ft to 90 ft upstream.

33. <u>Point/Side bar present?</u> **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.):

There are no point bars upstream at this site.

39. <u>Is a cut-bank present?</u> **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.):

There are no cut-banks upstream at this site.

45. <u>Is channel scour present?</u> **N** (*Y or if N type ctrl-n cs*) 46. Mid-scour distance: -

47. Scour dimensions: Length - Width - Depth : - Position - %LB to - %RB

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

There is no channel scour upstream at this site.

49. <u>Are there major confluences?</u> **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):

There are no major confluences upstream at this site.

D. Under Bridge Channel Assessment

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

56. Height (BF) LB	56. Height (BF) RB	57 Angle (BF) LB	57 Angle (BF) RB	61. Material (BF) LB	61. Material (BF) RB	62. Erosion (BF) LB	62. Erosion (BF) RB
17.0		**1.5**		**2**	**7**	**7**	**0**

58. Bank width (BF) - 59. Channel width - 60. Thalweg depth **90.0** 63. Bed Material **0**

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.):

54

Channel scour exists under the bridge- refer to notes in downstream assessment.

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

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

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

70. Debris and Ice Comments:

1

-

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		0	90	2	0	-	-	90.0
RABUT	1	0	90			2	0	21.5

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.):

-

-

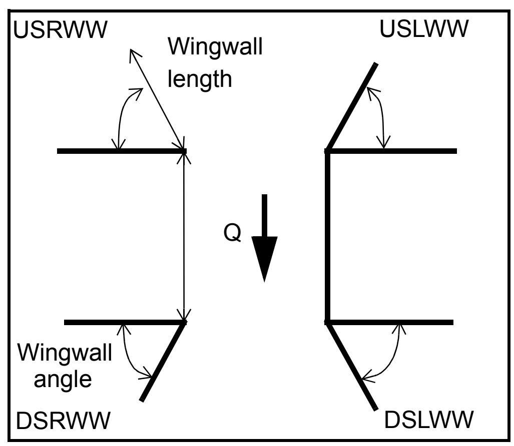
1

-

80. Wingwalls:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						21.5	
USRWW:	Y		1		0	0.5	
DSLWW:	-		-		Y	36.0	
DSRWW:	1		0		-	37.5	

*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	-	0	Y	-	1	1	1	1
Condition	Y	-	1	-	1	1	1	1
Extent	1	-	0	2	2	2	2	-

*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*

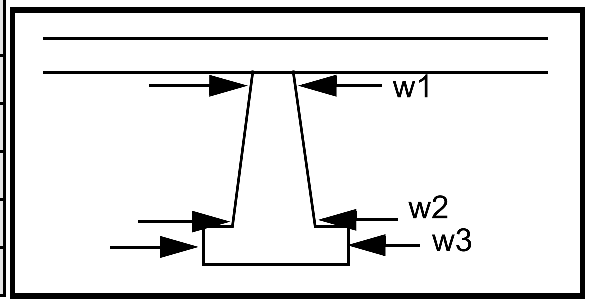
83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):

-
-
-
-
-
2
1
1
2
1
1

Piers:

84. Are there piers? _-____ *(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				**20.0**	**23.0**	**60.0**
Pier 2	**9.0**		**5.0**	**10.0**	**16.5**	**14.0**
Pier 3	-	-	-	-	-	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)		-	-	-	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type		-	-	-	***1**- Solid pier, **2**- column, **3**- bent*
88. Material		-	-	-	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape		-	-	-	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?		-	-	-	*Y- yes; N- no*
91. Attack ∠ (BF)		-	-	-	
92. Pushed		-	-	-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles		-	-	-	
95. Cross-members		-	-	-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition		-	-	-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	**N**	-	-	-	
98. Exposure depth	-	-	-	-	

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
-	-			-	-	The	re	are	no	pier

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

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.):

2
2
5
7
0
0
543
2
2
1

101. Is a drop structure present? **1** *(Y or N, if N type ctrl-n ds)* 102. Distance: - feet

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

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

ath Brook enters the right bank of the South Branch of the Wells River at the downstream bridge face.

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

Point bar extent: ______ feet ____ *(US, UB, DS)* to ______ feet ____ *(US, UB, DS)* positioned ____ %LB to _____ %RB

Material: N

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

-

There is no drop structure at this site.

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

Cut bank extent: N feet - *(US, UB, DS)* to - feet - *(US, UB, DS)*

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

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

-

-

-

-

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

Scour dimensions: Length e are Width no Depth: poin Positioned t %LB to bar %RB

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

s downstream at this site.

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

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

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

Confluence comments (eg. confluence name):

There are no cut-banks downstream at this site.

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)*:

Y
25
65
20
3
0
80
Scour hole exists from 15 feet UB to 50 feet DS.

Y

109. G. Plan View Sketch

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

APPENDIX F:

SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number:	GROTTH00240010	Town:	GROTON
Road Number:	TH 24	County:	CALEDONIA
Stream:	HEATH BROOK		

Initials LKS Date: 09/15/97 Checked: MAI

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	1550	2220	1400
Main Channel Area, ft2	312	341	235
Left overbank area, ft2	0	0	0
Right overbank area, ft2	269	446	9
Top width main channel, ft	45	46	43
Top width L overbank, ft	0	0	0
Top width R overbank, ft	253	300	46
D50 of channel, ft	0.2544	0.2544	0.2544
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	6.9	7.4	5.5
y1, average depth, LOB, ft	ERR	ERR	ERR
y1, average depth, ROB, ft	1.1	1.5	0.2
Total conveyance, approach	46970	64607	22972
Conveyance, main channel	35006	39892	22842
Conveyance, LOB	0	0	0
Conveyance, ROB	11964	24715	130
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	1155.2	1370.8	1392.1
Ql, discharge, LOB, cfs	0.0	0.0	0.0
Qr, discharge, ROB, cfs	394.8	849.2	7.9
Vm, mean velocity MC, ft/s	3.7	4.0	5.9
Vl, mean velocity, LOB, ft/s	ERR	ERR	ERR
Vr, mean velocity, ROB, ft/s	1.5	1.9	0.9
Vc-m, crit. velocity, MC, ft/s	9.8	9.9	9.4
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
Left Overbank	N/A	N/A	N/A
Right Overbank	N/A	N/A	N/A

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	1550	2220	1400
(Q) discharge thru bridge, cfs	1516	1455	1400
Main channel conveyance	13532	13532	9909
Total conveyance	13532	13532	9909
Q2, bridge MC discharge,cfs	1516	1455	1400
Main channel area, ft2	172	172	109
Main channel width (normal), ft	21.6	21.6	21.5
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	21.6	21.6	21.5
y_bridge (avg. depth at br.), ft	7.97	7.97	5.08
Dm, median (1.25*D50), ft	0.318	0.318	0.318
y2, depth in contraction,ft	6.57	6.34	6.16
ys, scour depth (y2-ybridge), ft	-1.41	-1.63	**1.07**

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	1516	1455	1400
Main channel area (DS), ft2	133	172.2	109.3
Main channel width (normal), ft	21.6	21.6	21.5
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	21.6	21.6	21.5
D90, ft	0.6910	0.6910	0.6910
D95, ft	0.7934	0.7934	0.7934
Dc, critical grain size, ft	0.5959	0.2942	0.8179
Pc, Decimal percent coarser than Dc	0.154	0.433	0.039
Depth to armoring, ft	**9.85**	**1.16**	**N/A**

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 other, 1995, p. 144-146)

	Q100	Q500	OtherQ
Q, total, cfs	1550	2220	1400
Q, thru bridge MC, cfs	1516	1455	1400
Vc, critical velocity, ft/s	9.81	9.92	9.43
Va, velocity MC approach, ft/s	3.70	4.02	5.92
Main channel width (normal), ft	21.6	21.6	21.5
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	21.6	21.6	21.5
qbr, unit discharge, ft2/s	70.2	67.4	65.1
Area of full opening, ft2	172.2	172.2	109.3
Hb, depth of full opening, ft	7.97	7.97	5.08
Fr, Froude number, bridge MC	0.59	0.57	0
Cf, Fr correction factor (<=1.0)	1.00	1.00	0.00
**Area at downstream face, ft2	133	N/A	N/A
**Hb, depth at downstream face, ft	6.16	N/A	N/A
**Fr, Froude number at DS face	0.81	ERR	ERR
**Cf, for downstream face (<=1.0)	1.00	N/A	N/A
Elevation of Low Steel, ft	1270.5	1270.5	0
Elevation of Bed, ft	1262.53	1262.53	-5.08
Elevation of Approach, ft	1272.49	1273.11	0
Friction loss, approach, ft	0.12	0.13	0
Elevation of WS immediately US, ft	1272.37	1272.98	0.00
ya, depth immediately US, ft	9.84	10.45	5.08
Mean elevation of deck, ft	1272.3	1272.3	0
w, depth of overflow, ft (>=0)	0.07	0.68	0.00
Cc, vert contrac correction (<=1.0)	0.95	0.95	1.00
**Cc, for downstream face (<=1.0)	0.873721	ERR	ERR
Ys, scour w/Chang equation, ft	**-0.44**	**-0.82**	N/A
Ys, scour w/Umbrell equation, ft	-1.97	-1.56	N/A

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

**Ys, scour w/Chang equation, ft	2.03	N/A	N/A

**Ys, scour w/Umbrell equation, ft	-0.16	N/A	ERR

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	6.57	6.34	6.16
WSEL at downstream face, ft	1268.66	--	--
Depth at downstream face, ft	6.16	N/A	N/A
Ys, depth of scour (Laursen), ft	0.41	N/A	N/A

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)

	Left Abutment			Right Abutment		
Characteristic	100 yr Q	500 yr Q	Other Q	100 yr Q	500 yr Q	Other Q
(Qt), total discharge, cfs	1550	2220	1400	1550	2220	1400
a', abut.length blocking flow, ft	11.2	12.1	8.5	265.5	312.8	59.2
Ae, area of blocked flow ft2	40.69	44.98	23.62	328.92	324.45	56
Qe, discharge blocked abut.,cfs	90	--	81.67	--	--	210
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr man						
Ve, (Qe/Ae), ft/s	2.21	2.50	3.46	1.79	2.12	3.75
ya, depth of f/p flow, ft	3.63	3.72	2.78	1.24	1.04	0.95
--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	60	60	60	120	120	120
K2	0.95	0.95	0.95	1.04	1.04	1.04
Fr, froude number f/p flow	0.204	0.221	0.366	0.279	0.289	0.679
ys, scour depth, ft	**7.59**	**8.06**	**7.07**	12.29	11.98	9.50

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)	11.2	12.1	8.5	265.5	312.8	59.2
y1 (depth f/p flow, ft)	3.63	3.72	2.78	1.24	1.04	0.95
a'/y1	3.08	3.26	3.06	214.31	301.57	62.58
Skew correction (p. 49, fig. 16)	0.90	0.90	0.90	1.07	1.07	1.07
Froude no. f/p flow	0.20	0.22	0.37	0.28	0.29	0.68
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	6.31	5.34	6.46
vertical w/ ww's	ERR	ERR	ERR	**5.17**	**4.38**	**5.30**
spill-through	ERR	ERR	ERR	3.47	2.94	3.55

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	0.81	0.57	1	0.81	0.57	1
y, depth of flow in bridge, ft	6.16	7.97	5.08	6.16	7.97	5.08
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	**1.60**	ERR	ERR	**1.60**	ERR
Fr>0.8 (vertical abut.)	**2.43**	ERR	**2.12**	**2.43**	ERR	**2.12**