LEVEL II SCOUR ANALYSIS FOR BRIDGE 41 (NORWTH00160041) on TOWN HIGHWAY 16, crossing BLOODY BROOK, NORWICH, VERMONT

Open-File Report 98-399

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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LEVEL II SCOUR ANALYSIS FOR BRIDGE 41 (NORWTH00160041) on TOWN HIGHWAY 16, crossing BLOODY BROOK, NORWICH, VERMONT

By SCOTT A. OLSON

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Pembroke, New Hampshire

1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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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 41 (NORWTH00160041) ON TOWN HIGHWAY 16, CROSSING BLOODY BROOK, NORWICH, VERMONT

By **Scott A. Olson**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure NORWTH00160041 on Town Highway 16 crossing Bloody Brook, Norwich, 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 about the bridge 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 5.74-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is forest upstream of the bridge. Downstream of the bridge, the surface cover is grass on the left and brush on the right.

In the study area, Bloody Brook has an incised, sinuous channel with a slope of approximately 0.02 ft/ft, an average channel top width of 42 ft and an average bank height of 6 ft. The channel bed material ranges from sand to cobble with a median grain size (D_{50}) of 67.9 mm (0.223 ft). The geomorphic assessment at the time of the Level I and Level II site visit on August 3, 1994, indicated that the reach was laterally unstable. This assessment was primarily due to mass wasting of the right bank about 200 ft upstream.

The Town Highway 16 crossing of Bloody Brook is a 27-ft-long, two-lane bridge consisting of one 25-foot steel-beam span (Vermont Agency of Transportation, written communication, July 29, 1994). The opening length of the structure parallel to the bridge face is 21 ft. The bridge is supported by near vertical, concrete abutments with wingwalls. The channel is skewed approximately 50 degrees to the opening while the opening-skew-to-roadway is 30 degrees.

Local scour, approximately 0.5 ft deeper than the mean thalweg depth, was observed along the right abutment during the Level I assessment. Scour countermeasures at the site included type-1 stone fill (less than 12 inches diameter) along the left abutment and at the end of the downtream right wingwall, type-2 stone fill (less than 36 inches diameter) at the upstream wingwalls, and type-3 stone fill (less than 48 inches diameter) at the end of the downstream left wingwall. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995) for the 100- and 500-year discharges. In addition, the incipient roadway-overtopping discharge was determined and analyzed as a 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 0.1 to 1.5 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 7.9 to 9.3 ft at the left abutment with the worst-case occurring at the 500-year discharge. Abutment scour ranged from 11.6 to 11.7 ft at the right abutment with the worst-case occurring at the incipient roadway-overtopping 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 Davis, 1995, p. 46). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.

Hanover, VT-NH Quadrangle, 1:24,000, 1959

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 NORWTH00160041 ***Stream*** Bloody Brook

County Windsor ***Road*** TH 16 ***District*** 4

Description of Bridge

Bridge length 27 ***ft*** ***Bridge width*** 25.7 ***ft*** ***Max span length*** 25 ***ft***

Alignment of bridge to road (on curve or straight) Straight, but skewed.

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

Stone fill on abutment? Yes ***Date of inspection*** 11/8/94

Description of stone fill Type-1, along all but the upstream 6 ft of the left abutment. There is no stone fill on the right abutment.

Abutments and wingwalls are concrete. Extensive subfooting have been added to the abutments. There is local scour along the right abutment.

Yes

Is bridge skewed to flood flow according to There ***survey?*** 50 ***Angle*** Yes

is a mild channel bend in the upstream and downstream reaches. Local scour has developed in the location where the channel impacts the right abutment.

Debris accumulation on bridge at time of Level I or Level II site visit:

	Date of inspection	***Percent of channel blocked horizontally***	***Percent of channel blocked vertically***
Level I	8/3/94	0	0
Level II	8/4/94	0	0

Potential for debris High. The right bank is failing about 200 ft upstream. Numerous trees have already fallen into the channel.

Describe any features near or at the bridge that may affect flow (include observation date) None--August 3, 1994.

Description of the Geomorphic Setting

General topography This steep upland channel reach is in a moderate-relief valley with little to no flood plains.

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

Date of inspection 8/3/94

DS left: Narrow flood plain.

DS right: Steep channel bank to a narrow terrace.

US left: Steep channel bank to a narrow terrace.

US right: Steep valley wall.

Description of the Channel

Average top width 42 *ft* ***Average depth*** 6 *ft*

Predominant bed material Cobbles ***Bank material*** Cobbles/Gravel

Sinuous, localized areas of lateral instablity with semi-alluvial to non-alluvial channel boundaries.

Vegetative co

8/3/94

DS left: Grass.

DS right: Brush.

US left: Trees and brush.

US right: Trees and brush.

Do banks appear stable? No

date of observation.

August 3, 1994. There appears to be some lateral shifting of the channel near the structure. Furthermore, approximately 200 ft upstream of the bridge, the right bank is failing. The hillside material from as high as 50 ft above the channel is sliding toward the channel. Numerous trees have been downed on this hillside.

Describe any obstructions in channel and date of observation.

The failing right bank could result in debris blocking the channel and could be a significant source of sediment. There are already some trees fallen into the channel at the right bank failure--August 3, 1994.

Hydrology

Drainage area 5.74 ***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 1,300 ***ft³/s*** ***Q500*** 1,850 ***ft³/s***

The 100-year discharge was from Vermont Agency of Transportation files (written communication, Danny Landry, March 8, 1995). Extrapolation to the 500-year discharge was done graphically based on the slopes of frequency curved developed from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887). The final calculated values were within a range defined by these empirical methods.

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

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

Datum tie between USGS survey and VTAOT plans None

Description of reference marks used to determine USGS datum. RM1 is a chiseled X on top of the upstream end of the left abutment (elev. 501.28 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]Cross-section	*Section Reference Distance (SRD) in feet*	*[2]Cross-section development*	*Comments*
EXIT1	-35	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXIT1)
BRIDG	0	1	Bridge section
RDWAY	16	1	Road Grade section
APPRO	50	3	Approach section. Channel points adjusted -1.06 ft to account for moving the section from SRD=87 to SRD= 50.

[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 0.043 to 0.057, and overbank "n" values ranged from 0.030 to 0.052.

Critical depth at the exit section (EXIT1) was utilized as the starting water surface. Normal depth at the exit section was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990) and was determined to be supercritical but within 0.3 feet of critical depth. The slope used for the computation was 0.022 ft/ft determined from the topographic map (U.S. Geological Survey, 1959).

The surveyed approach section (APPRO) was moved along the approach channel slope (0.0286 ft/ft) to establish the modelled approach section, one bridge length upstream of the upstream face as recommended by Shearman and others (1986). The channel points were adjusted for this slope.

Bridge Hydraulics Summary

Average bridge embankment elevation 501.7 ***ft***
Average low steel elevation 499.1 ***ft***

100-year discharge 1,300 ***ft³/s***
Water-surface elevation in bridge opening 499.1 ***ft***
Road overtopping? Y ***Discharge over road*** 35.0 ***ft³/s***
Area of flow in bridge opening 134 ***ft²***
Average velocity in bridge opening 9.6 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.1 ***ft/s***

Water-surface elevation at Approach section with bridge 501.8
Water-surface elevation at Approach section without bridge 497.4
Amount of backwater caused by bridge 4.4 ***ft***

500-year discharge 1,850 ***ft³/s***
Water-surface elevation in bridge opening 499.1 ***ft***
Road overtopping? Y ***Discharge over road*** 450 ***ft³/s***
Area of flow in bridge opening 134 ***ft²***
Average velocity in bridge opening 10.4 ***ft/s***
Maximum WSPRO tube velocity at bridge 13.1 ***/s***

Water-surface elevation at Approach section with bridge 502.6
Water-surface elevation at Approach section without bridge 498.0
Amount of backwater caused by bridge 4.6 ***ft***

Incipient overtopping discharge 1,170 ***ft³/s***
Water-surface elevation in bridge opening 499.1 ***ft***
Area of flow in bridge opening 134 ***ft²***
Average velocity in bridge opening 8.7 ***ft/s***
Maximum WSPRO tube velocity at bridge 11.0 ***ft/s***

Water-surface elevation at Approach section with bridge 501.0
Water-surface elevation at Approach section without bridge 497.2
Amount of backwater caused by bridge 3.8 ***ft***

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the scour depths are shown graphically in figure 8.

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

For comparison, contraction scour also was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20) and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Results from these computations are presented in appendix F. Furthermore, since the modelled discharge resulted 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 also are provided in appendix F.

Abutment scour was computed by use of the Froehlich equation (Richardson and Davis, 1995, p. 48, equation 28). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

Scour Results

Contraction scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
	(Scour depths in feet)		
Main channel			
Live-bed scour	--	--	--
Clear-water scour	1.0	1.5	0.1
Depth to armoring	19.6	12.0	15.6
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:			
Abutment scour			
Left abutment	8.7	9.3	7.9
Right abutment	11.7	11.6	11.7
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	2.3	2.5	2.2
Right abutment	2.3	2.5	2.2
Piers:	--	--	--
Pier 1	--	--	--
Pier 2	--	--	--

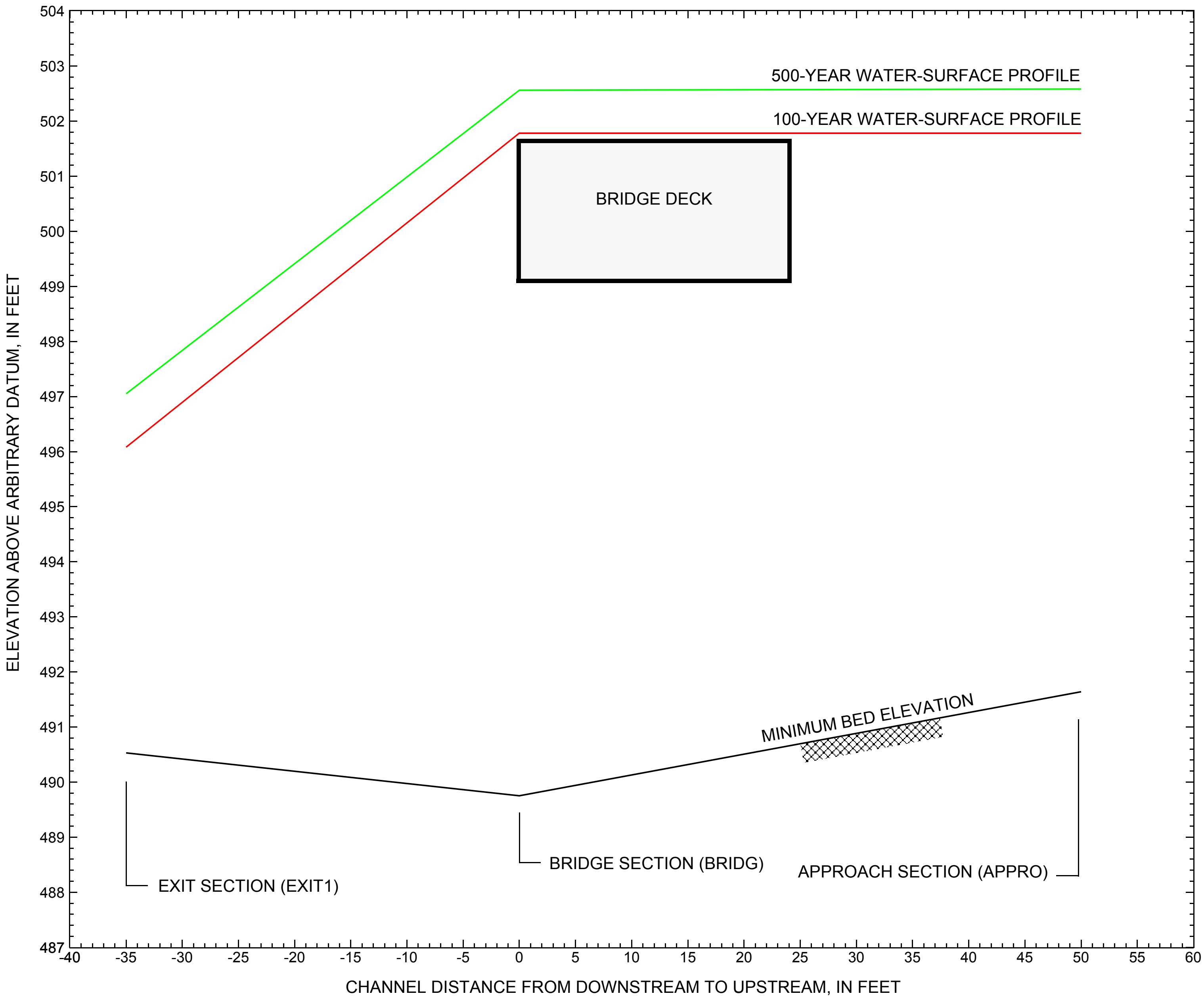

Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure NORWTH00160041 on Town Highway 16, crossing Bloody Brook, Norwich, Vermont.

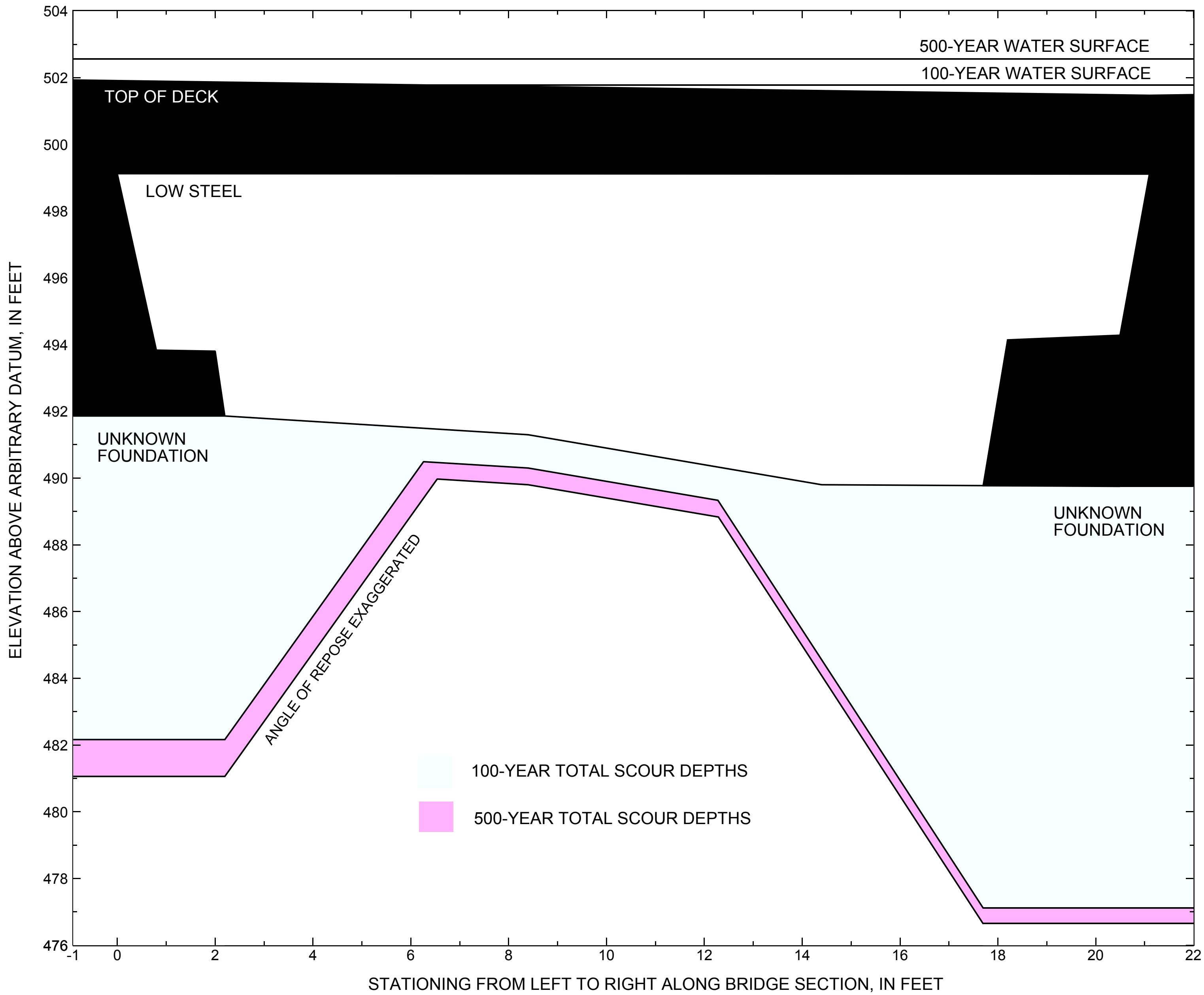

Figure 8. Scour elevations for the 100- and 500-year discharges at structure NORWTH00160041 on Town Highway 16, crossing Bloody Brook, Norwich, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure NORWTH00160041 on Town Highway 16, crossing Bloody Brook, Norwich, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing/pile elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-year discharge is 1,300 cubic-feet per second											
Left abutment	0.0	--	499.1	--	491.9	1.0	8.7	--	9.7	482.2	--
Right abutment	21.1	--	499.1	--	489.8	1.0	11.7	--	12.7	477.1	--

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 NORWTH00160041 on Town Highway 16, crossing Bloody Brook, Norwich, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing/pile elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-year discharge is 1,850 cubic-feet per second											
Left abutment	0.0	--	499.1	--	491.9	1.5	9.3	--	10.8	481.1	--
Right abutment	21.1	--	499.1	--	489.8	1.5	11.6	--	13.1	476.7	--

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

SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M. A., 1962, Factors Influencing the Occurrence of Floods in a Humid Region of Diverse Terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Brown, S.A. and Clyde, E.S., 1989, Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11, Publication FHWA-IP-89-016, 156 p.

Federal Emergency Management Agency, 1988, Flood Insurance Study, Town of Norwich, Windsor County, Vermont: Washington, D.C., June 15, 1988.

Federal Highway Administration, 1983, Runoff estimates for small watersheds and development of sound design: Federal Highway Administration Report FHWA-RD-77-158.

Federal Highway Administration, 1993, Stream Stability and Scour at Highway Bridges: Participant Workbook: Federal Highway Administration Report FHWA-HI-91-011.

Froehlich, D.C., 1989, Local scour at bridge abutments *in* Ports, M.A., ed., Hydraulic Engineering--Proceedings of the 1989 National Conference on Hydraulic Engineering: New York, American Society of Civil Engineers, p. 13-18.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Bulletin 17B of the Hydrology Subcommittee, 190 p.

Johnson, C.G. and Tasker, G.D.,1974, Progress report on flood magnitude and frequency of Vermont streams: U.S. Geological Survey Open-File Report 74-130, 37 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream Stability at Highway Structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Laursen, E.M., 1960, Scour at bridge crossings: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 86, no. HY2, p. 39-53.

Potter, W. D., 1957a, Peak rates of runoff in the Adirondack, White Mountains, and Maine woods area, Bureau of Public Roads

Potter, W. D., 1957b, Peak rates of runoff in the New England Hill and Lowland area, Bureau of Public Roads

Richardson, E.V. and Davis, S.R., 1995, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process Geomorphology: W.C. Brown Co., Debuque, Iowa, 603 p.

Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

Talbot, A.N., 1887, The determination of water-way for bridges and culverts.

U.S. Geological Survey, 1959, Hanover, Vermont-New Hampshire 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File norw041.wsp
T2        Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
T3        Hydraulic analysis of bridge 41 over Bloody Brook
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           1300 1850 1170
SK          0.022 0.022 0.022
*
XS   EXIT1    -35
GR         -120.4, 500.60    -86.8, 497.70     -5.9, 495.00      0.0, 494.19
GR            3.3, 490.66     11.6, 490.53     18.4, 491.18     24.1, 492.49
GR           35.7, 499.30     42.1, 499.55
N           0.051        0.057        0.052
SA                   0.0          35.7
*
XS   FULLV      0
*
BR   BRIDG     0 499.11 30
GR            0.0, 499.11      0.8, 493.83      2.0, 493.80      2.2, 491.86
GR            8.4, 491.30     14.4, 489.80     17.7, 489.75     18.2, 494.14
GR           20.5, 494.28     21.1, 499.11      0.0, 499.11
N             0.043
CD            1 35 * * 28 12
*
XR   RDWAY     16  26
GR         -190.7, 506.95   -120.5, 503.06    -78.6, 501.88      0.0, 501.91
GR           13.1, 501.72     24.5, 501.47     38.9, 501.10     53.9, 507.84
*
AS   APPRO     50
GR         -190.7, 506.95   -120.5, 503.06    -78.6, 501.88    -19.8, 501.88
GR           -4.7, 498.10     -2.2, 495.44      0.0, 493.10      6.6, 492.08
GR           12.9, 491.64     21.1, 492.11     24.3, 493.35     27.6, 497.35
GR           36.1, 502.92     46.6, 507.64
N           0.030        0.051
SA                  -19.8
*
HP 1 BRIDG    499.11 1 499.11
HP 2 BRIDG    499.11 * * 1290
HP 1 BRIDG    497.33 1 497.33
HP 2 RDWAY    501.78 * * 35
HP 1 APPRO    501.78 1 501.78
HP 2 APPRO    501.78 * * 1300
*
HP 1 BRIDG    499.11 1 499.11
HP 2 BRIDG    499.11 * * 1395
HP 1 BRIDG    498.15 1 498.15
HP 2 RDWAY    502.56 * * 450
HP 1 APPRO    502.58 1 502.58
HP 2 APPRO    502.58 * * 1850
*
HP 1 BRIDG    499.11 1 499.11
HP 2 BRIDG    499.11 * * 1170
HP 1 BRIDG    497.06 1 497.06
HP 1 APPRO    500.98 1 500.98
HP 2 APPRO    500.98 * * 1170
*
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

```
     U.S. Geological Survey WSPRO Input File norw041.wsp
     Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
     Hydraulic analysis of bridge 41 over Bloody Brook

 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW      QCR
          1      134     8488     -2     54                            0
 499.11          134     8488     -2     54  1.00      0     21        0

 VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
      WSEL     LEW     REW    AREA        K        Q    VEL
    499.11     0.0    21.1   134.1    8488.    1290.   9.62
X STA.       0.0        2.8         4.0        5.0         6.0        6.9
 A(I)            12.4        7.5         6.7        6.4         5.9
 V(I)            5.22       8.61        9.66      10.14       10.96

X STA.       6.9        7.8         8.6        9.4        10.2       11.0
 A(I)             5.9        5.6         5.6        5.5         5.5
 V(I)           10.86      11.50       11.60      11.68       11.77

X STA.      11.0       11.7        12.4       13.1        13.8       14.5
 A(I)             5.3        5.4         5.4        5.5         5.5
 V(I)           12.12      11.87       11.91      11.74       11.68

X STA.      14.5       15.2        16.0       16.8        17.8       21.1
 A(I)             5.8        6.2         6.6        8.0        13.5
 V(I)           11.21      10.47        9.73       8.11        4.76

 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW      QCR
          1      102     8050     18     30                         1383
 497.33          102     8050     18     30  1.00      0     21     1383

 VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      16.
      WSEL     LEW     REW    AREA        K        Q    VEL
    501.78     9.0    40.4     9.9     128.      35.   3.54
X STA.       9.0       20.8        23.9       26.1        27.7       29.2
 A(I)             1.2        0.8         0.7        0.6         0.6
 V(I)            1.42       2.16        2.46       2.83        3.02

X STA.      29.2       30.3        31.4       32.3        33.2       34.0
 A(I)             0.5        0.5         0.5        0.4         0.4
 V(I)            3.38       3.51        3.69       3.96        4.06

X STA.      34.0       34.7        35.3       35.9        36.4       37.0
 A(I)             0.4        0.4         0.3        0.3         0.3
 V(I)            4.36       4.50        5.02       5.57        5.60

X STA.      37.0       37.4        37.9       38.4        38.9       40.4
 A(I)             0.3        0.3         0.3        0.4         0.5
 V(I)            5.63       5.63        5.45       4.96        3.53

 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW      QCR
          2      326    29404     54     60                         4547
 501.78          326    29404     54     60  1.00    -18     34     4547

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
      WSEL     LEW     REW    AREA        K        Q    VEL
    501.78   -19.4    34.4   325.6   29404.    1300.   3.99
X STA.     -19.4       -3.0         0.2        2.2         3.9        5.6
 A(I)            35.0       23.1        17.4       15.8        15.3
 V(I)            1.86       2.81        3.73       4.12        4.26

X STA.       5.6        7.0         8.4        9.7        11.0       12.2
 A(I)            13.8       13.6        12.8       12.9        12.7
 V(I)            4.70       4.77        5.09       5.02        5.14

X STA.      12.2       13.5        14.7       15.9        17.2       18.5
 A(I)            12.4       12.3        12.4       12.7        12.8
 V(I)            5.24       5.27        5.24       5.11        5.08

X STA.      18.5       19.9        21.3       23.0        25.2       34.4
 A(I)            13.4       14.1        15.6       18.2        29.1
 V(I)            4.84       4.60        4.17       3.57        2.23
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       U.S. Geological Survey WSPRO Input File norw041.wsp
       Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
       Hydraulic analysis of bridge 41 over Bloody Brook

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      134      8488     -2     54                            0
  499.11           134      8488     -2     54  1.00      0     21        0

   VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
        WSEL     LEW     REW    AREA        K        Q    VEL
      499.11     0.0    21.1   134.1    8488.    1395.  10.40
 X STA.        0.0         2.8         4.0         5.0         6.0         6.9
   A(I)            12.4         7.5         6.7         6.4         5.9
   V(I)            5.64        9.31       10.45       10.97       11.85

 X STA.        6.9         7.8         8.6         9.4        10.2        11.0
   A(I)             5.9         5.6         5.6         5.5         5.5
   V(I)           11.74       12.43       12.55       12.63       12.73

 X STA.       11.0        11.7        12.4        13.1        13.8        14.5
   A(I)             5.3         5.4         5.4         5.5         5.5
   V(I)           13.10       12.83       12.87       12.69       12.63

 X STA.       14.5        15.2        16.0        16.8        17.8        21.1
   A(I)             5.8         6.2         6.6         8.0        13.5
   V(I)           12.12       11.32       10.52        8.77        5.15

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1      117      9720     18     31                         1684
  498.15           117      9720     18     31  1.00      0     21     1684

   VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      16.
        WSEL     LEW     REW    AREA        K        Q    VEL
      502.56  -102.7    42.1   102.0    2327.     450.   4.41
 X STA.     -102.7       -78.4       -69.9       -61.8       -53.6       -45.7
   A(I)             8.3         5.8         5.4         5.5         5.3
   V(I)            2.70        3.88        4.14        4.11        4.25

 X STA.      -45.7       -37.7       -29.6       -21.7       -13.5        -5.4
   A(I)             5.4         5.4         5.2         5.3         5.3
   V(I)            4.21        4.20        4.29        4.21        4.23

 X STA.       -5.4         3.1        10.6        16.6        21.4        25.5
   A(I)             5.6         5.6         5.1         4.7         4.4
   V(I)            4.03        4.01        4.38        4.82        5.14

 X STA.       25.5        29.1        32.2        35.0        37.5        42.1
   A(I)             4.1         3.8         3.8         3.5         4.4
   V(I)            5.43        5.86        5.99        6.43        5.14

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
    WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
            1       50      1754     84     84                          218
            2      369     35550     55     62                         5414
  502.58           419     37304    139    145  1.12   -102     36     3900

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
        WSEL     LEW     REW    AREA        K        Q    VEL
      502.58  -103.5    35.6   419.3   37304.    1850.   4.41
 X STA.     -103.5       -15.7        -4.4        -0.4         1.7         3.5
   A(I)            54.8        35.5        27.7        19.7        18.2
   V(I)            1.69        2.60        3.34        4.68        5.07

 X STA.        3.5         5.2         6.8         8.3         9.7        11.1
   A(I)            17.2        16.3        15.8        15.2        15.3
   V(I)            5.38        5.66        5.87        6.09        6.03

 X STA.       11.1        12.5        13.8        15.2        16.6        18.1
   A(I)            14.8        14.9        14.9        15.0        15.7
   V(I)            6.25        6.22        6.19        6.15        5.89

 X STA.       18.1        19.6        21.2        23.0        25.4        35.6
   A(I)            16.2        16.5        18.8        21.7        34.9
   V(I)            5.72        5.59        4.92        4.25        2.65
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WSPRO OUTPUT FILE (continued)

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        U.S. Geological Survey WSPRO Input File norw041.wsp
        Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
        Hydraulic analysis of bridge 41 over Bloody Brook

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
             1      134      8488     -2     54                            0
   499.11           134      8488     -2     54  1.00      0     21        0

    VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
         WSEL     LEW     REW    AREA        K        Q    VEL
       499.11     0.0    21.1   134.1    8488.    1170.   8.72
X STA.         0.0         2.8         4.0         5.0         6.0         6.9
  A(I)            12.4         7.5         6.7         6.4         5.9
  V(I)            4.73        7.81        8.77        9.20        9.94

X STA.         6.9         7.8         8.6         9.4        10.2        11.0
  A(I)             5.9         5.6         5.6         5.5         5.5
  V(I)            9.85       10.43       10.52       10.59       10.68

X STA.        11.0        11.7        12.4        13.1        13.8        14.5
  A(I)             5.3         5.4         5.4         5.5         5.5
  V(I)           10.99       10.76       10.80       10.64       10.59

X STA.        14.5        15.2        16.0        16.8        17.8        21.1
  A(I)             5.8         6.2         6.6         8.0        13.5
  V(I)           10.17        9.49        8.83        7.35        4.32

    CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
     WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
             1       97      7519     18     29                         1289
   497.06            97      7519     18     29  1.00      0     21     1289

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
     WSEL  SA#     AREA         K  TOPW   WETP  ALPH    LEW    REW      QCR
             2      284     24792     49     55                         3874
   500.98           284     24792     49     55  1.00    -15     33     3874

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      50.
         WSEL     LEW     REW    AREA        K        Q    VEL
       500.98   -16.2    33.1   284.4   24792.    1170.   4.11
X STA.       -16.2        -1.6         1.0         2.8         4.5         6.0
  A(I)            30.6        18.9        15.3        14.1        12.8
  V(I)            1.91        3.10        3.83        4.14        4.58

X STA.         6.0         7.4         8.7         9.9        11.2        12.3
  A(I)            12.4        11.9        11.4        11.2        10.9
  V(I)            4.72        4.92        5.12        5.23        5.35

X STA.        12.3        13.5        14.7        15.9        17.1        18.4
  A(I)            11.0        11.0        11.0        11.3        11.1
  V(I)            5.30        5.33        5.31        5.17        5.27

X STA.        18.4        19.7        21.1        22.7        24.7        33.1
  A(I)            11.9        12.5        13.5        15.9        25.7
  V(I)            4.93        4.69        4.34        3.68        2.27
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        U.S. Geological Survey WSPRO Input File norw041.wsp
        Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
        Hydraulic analysis of bridge 41 over Bloody Brook

 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1":  USED WSI = CRWS.
                           WSI,CRWS =   496.04     496.08

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

EXIT1:XS   ******    -37      155  1.31 *****  497.39  496.08    1300  496.08
       -34 ******     30     8907  1.19 ***** *******    1.08    8.41

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "FULLV"     KRATIO =  1.76

FULLV:FV       35    -75      265  0.48  0.42  497.81 *******    1300  497.33
         0     35     32    15692  1.29  0.00    0.00    0.63    4.91
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                           "APPRO"     KRATIO =  0.67

APPRO:AS       50     -3      143  1.28  0.51  498.71 *******    1300  497.43
        50     50     28    10535  1.00  0.40   -0.01    0.75    9.07
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   497.09     500.51     500.67     499.11
 ===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       35      0      134  1.44 *****  500.55  497.07    1290  499.11
         0 ******     21     8488  1.00 ***** *******    0.67    9.62

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.490  0.000  499.11 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      16.    24.  0.05  0.25  501.98    0.02     35.  501.78

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0.   102.   -91.    11.   0.5   0.3   3.4   3.8   0.6   3.0
   RT:     35.    27.    13.    40.   0.7   0.4   3.5   3.6   0.6   3.1

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

APPRO:AS       15    -18      325  0.25  0.11  502.02  496.58    1300  501.78
        50     16     34    29377  1.00  1.03    0.02    0.29    4.00

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

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

   FIRST USER DEFINED TABLE.
     XSID:CODE    SRD    LEW    REW      Q        K     AREA     VEL    WSEL
    EXIT1:XS     -35.   -38.    30.   1300.    8907.    155.    8.41  496.08
    FULLV:FV       0.   -76.    32.   1300.   15692.    265.    4.91  497.33
    BRIDG:BR       0.     0.    21.   1290.    8488.    134.    9.62  499.11
    RDWAY:RG      16.*******     0.     35.       0.*********   1.00  501.78
    APPRO:AS      50.   -19.    34.   1300.   29377.    325.    4.00  501.78

   SECOND USER DEFINED TABLE.
     XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD     EGL    WSEL
    EXIT1:XS    496.08    1.08  490.53  500.60************  1.31  497.39  496.08
    FULLV:FV  ********    0.63  490.53  500.60  0.42  0.00  0.48  497.81  497.33
    BRIDG:BR    497.07    0.67  489.75  499.11************  1.44  500.55  499.11
    RDWAY:RG  ****************  501.10  507.84  0.05******  0.25  501.98  501.78
    APPRO:AS    496.58    0.29  491.64  507.64  0.11  1.03  0.25  502.02  501.78
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       U.S. Geological Survey WSPRO Input File norw041.wsp
       Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
       Hydraulic analysis of bridge 41 over Bloody Brook

 ===015 WSI IN WRONG FLOW REGIME AT SECID "EXIT1":  USED WSI = CRWS.
                          WSI,CRWS =   496.82     497.05

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

EXIT1:XS   ******    -66      236  1.22 *****  498.27  497.05    1850  497.05
       -34 ******     32    13845  1.28 ***** *******    1.01    7.85

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                          "FULLV"     KRATIO =  1.64

FULLV:FV       35    -91      363  0.50  0.38  498.65 *******    1850  498.15
         0     35     34    22704  1.24  0.00    0.00    0.59    5.10

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    0.92     497.97     497.67
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   497.65     507.64    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   497.65     507.64     497.67
 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                          "APPRO"     KRATIO =  0.55

APPRO:AS       50     -4      161  2.05  0.61  500.03  497.67    1850  497.98
        50     50     29    12418  1.00  0.77    0.00    0.92   11.47
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   502.92       0.00     498.59     501.10
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
          WS3,WSIU,WS1,LSEL =   498.08     501.89     502.06     499.11
 ===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       35      0      134  1.68 *****  500.79  497.37    1395  499.11
         0 ******     21     8488  1.00 ***** *******    0.73   10.40

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   5.  0.496  0.000  499.11 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      16.    24.  0.06  0.34  502.86    0.00    450.  502.56

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:    297.   114.  -103.    11.   0.8   0.6   4.4   4.3   0.9   3.1
   RT:    154.    31.    11.    42.   1.5   1.1   5.4   4.6   1.4   3.1

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

APPRO:AS       15   -102      419  0.34  0.14  502.92  497.67    1850  502.58
        50     16     36    37245  1.12  1.05    0.00    0.48    4.42

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

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXIT1:XS     -35.   -67.    32.   1850.   13845.     236.    7.85  497.05
   FULLV:FV       0.   -92.    34.   1850.   22704.     363.    5.10  498.15
   BRIDG:BR       0.     0.    21.   1395.    8488.     134.   10.40  499.11
   RDWAY:RG      16.*******   297.    450.       0.       0.    1.00  502.56
   APPRO:AS      50.  -103.    36.   1850.   37245.     419.    4.42  502.58

 SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
   EXIT1:XS    497.05    1.01  490.53  500.60************  1.22  498.27  497.05
   FULLV:FV  ********    0.59  490.53  500.60  0.38  0.00  0.50  498.65  498.15
   BRIDG:BR    497.37    0.73  489.75  499.11************  1.68  500.79  499.11
   RDWAY:RG  ****************  501.10  507.84  0.06******  0.34  502.86  502.56
   APPRO:AS    497.67    0.48  491.64  507.64  0.14  1.05  0.34  502.92  502.58
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WSPRO OUTPUT FILE (continued)

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        U.S. Geological Survey WSPRO Input File norw041.wsp
        Hydraulic analysis for structure NORWTH00160041   Date: 12-NOV-97
        Hydraulic analysis of bridge 41 over Bloody Brook

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

EXIT1:XS   ******    -29      137  1.30 *****  497.11  495.71    1170  495.81
       -34 ******     30     7882  1.15 ***** *******    1.06    8.52

 ===135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
                         "FULLV"     KRATIO =  1.76

FULLV:FV       35    -67      237  0.49  0.44  497.54 *******    1170  497.06
         0     35     32    13898  1.28  0.00    0.00    0.64    4.94
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       50     -3      137  1.14  0.50  498.36 *******    1170  497.22
        50     50     27     9852  1.00  0.33   -0.01    0.72    8.56
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   496.71     499.95     500.11     499.11
 ===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       35      0      134  1.15 *****  500.26  496.67    1152  499.11
         0 ******     21     8488  1.00 ***** *******    0.60    8.59

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   2.  0.469  0.000  499.11 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR      Q    WSEL
   RDWAY:RG      16.        <<<<<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       15    -15      284  0.26  0.11  501.24  496.30    1170  500.98
        50     16     33    24770  1.00  1.02   -0.02    0.30    4.12

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     ****** ****** ******** ****** ******   500.92

                     <<<<<END OF BRIDGE COMPUTATIONS>>>>>
  FIRST USER DEFINED TABLE.
    XSID:CODE    SRD    LEW    REW      Q       K     AREA     VEL   WSEL
   EXIT1:XS     -35.   -30.    30.   1170.    7882.     137.    8.52  495.81
   FULLV:FV       0.   -68.    32.   1170.   13898.     237.    4.94  497.06
   BRIDG:BR       0.     0.    21.   1152.    8488.     134.    8.59  499.11
   RDWAY:RG      16.**************      0.       0.*********    1.00********
   APPRO:AS      50.   -16.    33.   1170.   24770.     284.    4.12  500.98

  SECOND USER DEFINED TABLE.
    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXIT1:XS    495.71    1.06  490.53  500.60************  1.30  497.11  495.81
   FULLV:FV   ********   0.64  490.53  500.60  0.44  0.00  0.49  497.54  497.06
   BRIDG:BR    496.67    0.60  489.75  499.11************  1.15  500.26  499.11
   RDWAY:RG   ****************  501.10  507.84************  0.24  501.44********
   APPRO:AS    496.30    0.30  491.64  507.64  0.11  1.02  0.26  501.24  500.98
```
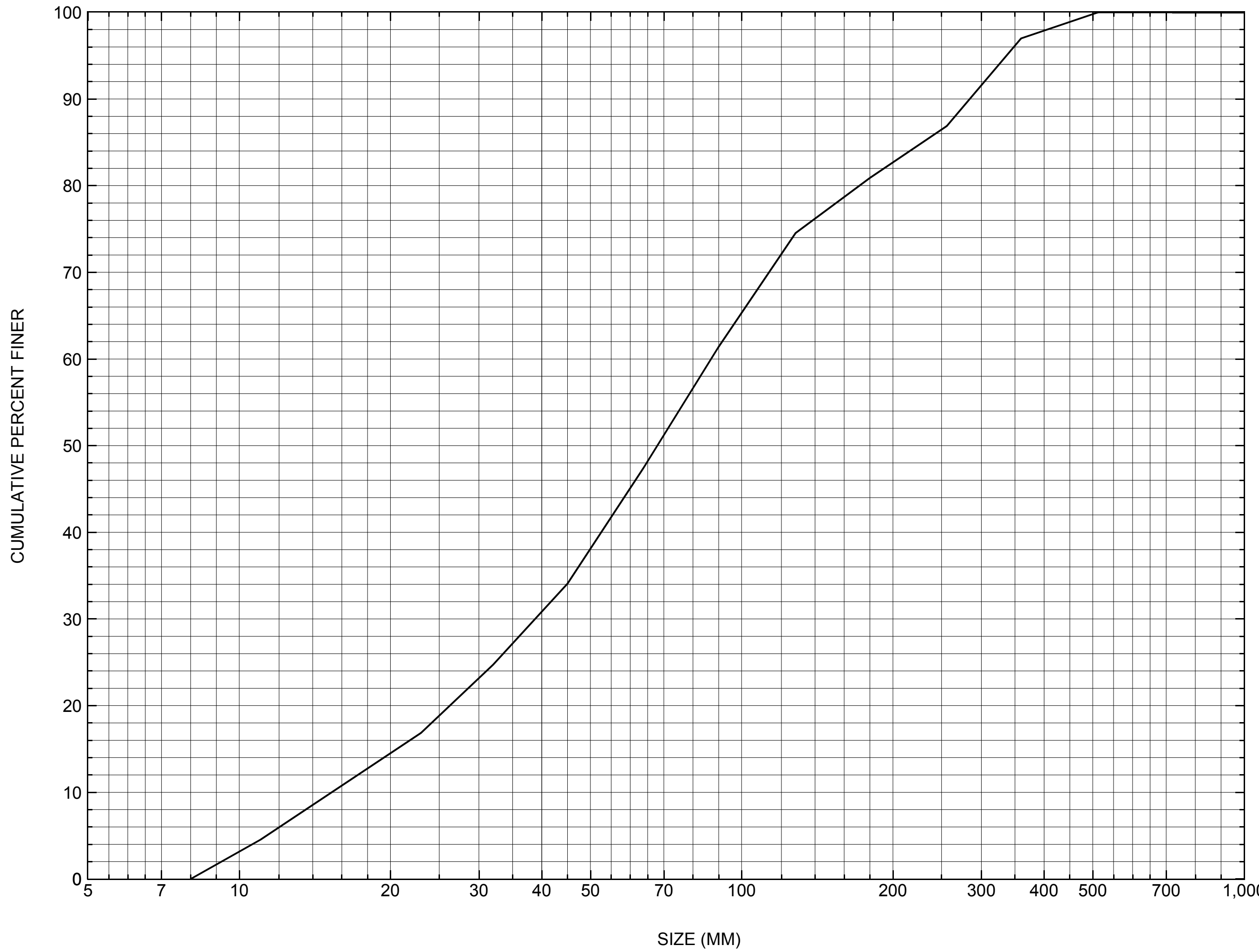

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure NORWTH00160041, in Norwich, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number NORWTH00160041

General Location Descriptive

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

Date *(MM/DD/YY)* 07 / 29 / 94

Highway District Number *(I - 2; nn)* 04

County *(FIPS county code; I - 3; nnn)* 027

Town *(FIPS place code; I - 4; nnnnn)* 52900

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

Waterway *(I - 6)* BLOODY BROOK

Road Name *(I - 7):* -

Route Number TH016

Vicinity *(I - 9)* 0.25 MI TO JCT W C3 TH36

Topographic Map Hanover

Hydrologic Unit Code: 01080104

Latitude *(I - 16; nnnn.n)* 43445

Longitude *(i - 17; nnnnn.n)* 72193

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10141100411411

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

Maximum span length *(I - 48; nnnn)* 0025

Year built *(I - 27; YYYY)* 1931

Structure length *(I - 49; nnnnnn)* 000027

Average daily traffic, ADT *(I - 29; nnnnnn)* 000400

Deck Width *(I - 52; nn.n)* 257

Year of ADT *(I - 30; YY)* 90

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

Opening skew to Roadway *(I - 34; nn)* 30

Waterway adequacy *(I - 71; n)* 6

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

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

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

Year Reconstructed *(I - 106)* 1988

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

Clear span (*nnn.n ft*) -

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

Vertical clearance from streambed (*nnn.n ft*) 008.0

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

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

Comments:

Some moderate scour conditions were noted in the inspection report of 6/11/92. The waterway is somewhat constricted by the bridge. Partial undermining was noted at the right end of abutment 1 (as labelled in inspection) with water flowing out from underneath.

Bridge Hydrologic Data

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

Terrain character: -

Stream character & type: -

Streambed material: -

Discharge Data *(cfs)*: $Q_{2.33}$ - Q_{10} - Q_{25} -

Q_{50} - Q_{100} - Q_{500} -

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

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

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

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

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

Describe any significant site conditions upstream or downstream that may influence the stream's stage: -

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

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

Water Surface Elevation Estimates for Existing Structure:

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

Long term stream bed changes: -

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

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

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

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

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

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

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

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

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

Comments:

-

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **5.74** mi^2

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

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

Bridge site elevation **690** ft

Headwater elevation **1851** ft

Main channel length **4.24** mi

10% channel length elevation **740** ft

85% channel length elevation **1390** ft

Main channel slope *(S)* **204** 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)* **6.25** ft

Bridge Plan Data

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

Project Number -

Minimum channel bed elevation: -

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

Benchmark location description:
-

Reference Point (*MSL, Arbitrary, Other*): -

Datum (*NAD27, NAD83, Other*): -

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

If 1: Footing Thickness - Footing bottom elevation: -

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

If 3: Footing bottom elevation: -

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

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

Briefly describe material at foundation bottom elevation or around piles:
NO FOUNDATION MATERIAL INFORMATION

Comments:
NO PLANS

Cross-sectional Data

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

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

Comments: NO CROSS SECTION INFORMATION

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

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

Comments: NO CROSS SECTION INFORMATION

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

APPENDIX E:

LEVEL I DATA FORM

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

Qa/Qc Check by: **DLS** Date: **2/8/95**

Computerized by: **MAI** Date: **3/22/95**

Reviewd by: **SAO** Date: **4/27/98**

Structure Number **NORWTH00160041**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **S. OLSON** Date *(MM/DD/YY)* **8** / **3** / 19**94**

2. Highway District Number **04** Mile marker **0**

County **WINDSOR (027)** Town **NORWICH (52900)**

Waterway *(I - 6)* **BLOODY BROOK** Road Name **TURNPIKE ROAD**

Route Number **TH016** Hydrologic Unit Code: **01080104**

3. Descriptive comments:

Located 0.25 miles to the junction of TH 16 and TH 36.

Supplemental data collected on 8/22/94 by D. Song and on 10/31/94 by M. Ivanoff.

B. Bridge Deck Observations

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

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

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

7. Bridge length **27** *(feet)* Span length **25** *(feet)* Bridge width **25.7** *(feet)*

Road approach to bridge:

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

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

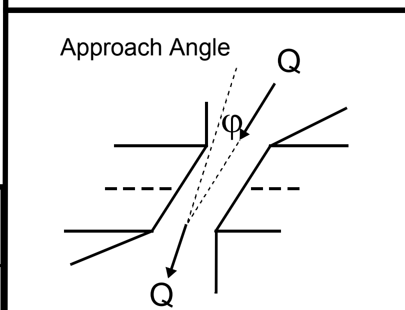
10. Embankment slope (*run / rise in feet / foot*):
US left **3.1:1** US right **4.5:1**

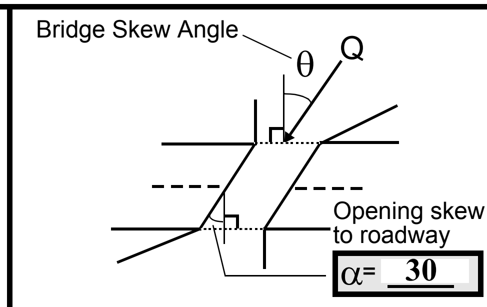
	Protection			
	11.Type	12.Cond.	13.Erosion	14.Severity
LBUS	0	-	0	0
RBUS	2	1	2	1
RBDS	2	1	0	0
LBDS	0	-	0	0

*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: **30** 16. Bridge skew: **50**





17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **RB** *(LB, RB)* Severity **0**
Range? **10** feet **US** *(US, UB, DS)* to **10** feet **UB**

Channel impact zone 2: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **0**
Range? **20** feet **DS** *(US, UB, DS)* to **60** feet **DS**

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

18. Bridge Type: **1a**

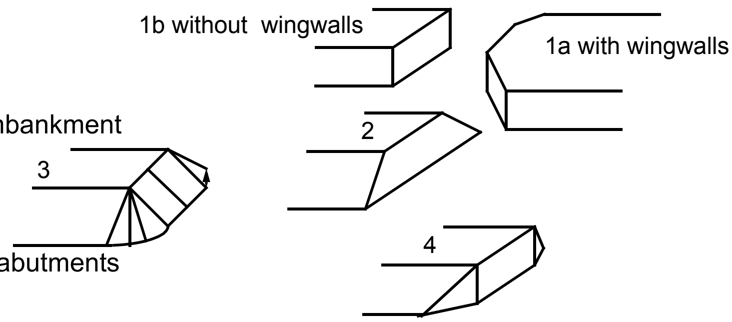
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

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

3- Spill through abutments

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



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

4. LBUS: forested except for paved roadway on left overbank. LBDS is lawn. RBDS is brush up to paved roadway.

7. Measured bridge length: 26.5, span: 25, and width: 26 feet.

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
53.5	**8.0**			**5.0**	**2**	**3**	**432**	**324**	**1**	**3**

23. Bank width **15.0** 24. Channel width **40.0** 25. Thalweg depth **47.5** 29. Bed Material **435**

30 .Bank protection type: LB **2** RB **0** 31. Bank protection condition: LB **2** 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*

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

27. Bank material LB: cobble and gravel with some sand, RB: gravel and sand with some boulders.

28. RB: mass wasting erosion 200 ft upstream of the bridge. The hillside is failing from up to 50 ft above the streambed down to the edge of water. Many trees have been downed by the slide.

29. Bed material consists of cobble and gravel with some boulders.

33. Point/Side bar present? Y (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: 30 35. Mid-bar width: 10

36. Point bar extent: 6 feet US (US, UB) to 45 feet US (US, UB, DS) positioned 0 %LB to 65 %RB

37. Material: 432

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

Cobbles and gravel with some sand.

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

41. Mid-bank distance: 35 42. Cut bank extent: 10 feet UB (US, UB) to 60 feet US (US, UB, DS)

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

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

Severe cutbank 200 ft upstream of the bridge on the right bank with mass wasting block failure.

45. Is channel scour present? 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.):

NO CHANNEL SCOUR

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

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

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

54. Confluence comments (eg. confluence name):

NO MAJOR CONFLUENCES

D. Under Bridge Channel Assessment

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

56. Height (BF)		57 Angle (BF)		61. Material (BF)		62. Erosion (BF)	
LB	RB	LB	RB	LB	RB	LB	RB
14.5		0.5		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.):

453

63. Bed material consists of cobble and boulder with some gravel.

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 3____ *(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

67. There is debris accumulation upstream of the bridge and trees failing along the upstream right bank.
68. This is a high gradient stream and the span length is 80% of the upstream bank width and thus given a low capture efficiency.

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		-	80	2	2	0	3	90.0
RABUT	1	25	80			2	2	18.0

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

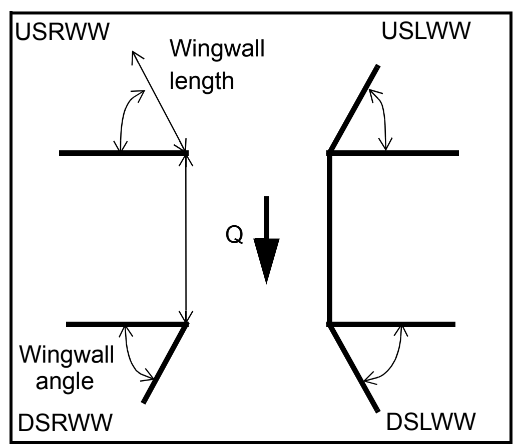
79. Abutment comments (eg. undermined penetration, unusual scour processes, debris, etc.):

1.5
4.5
1
76. At the left abutment, exposure depth is at the upstream and downstream ends; At the right abutment, the exposure depth is along the abutment's entire length.

80. **Wingwalls**:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						18.0	
USRWW:	Y		1		1	0.5	
DSLWW:	0.5		0		Y	33.5	
DSRWW:	1		2		0	29.5	

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	4	3	Y	0	1	1	1	-
Condition	Y	0	1	4	4	2	4	-
Extent	1	0.1	2	2	2	1	0	-

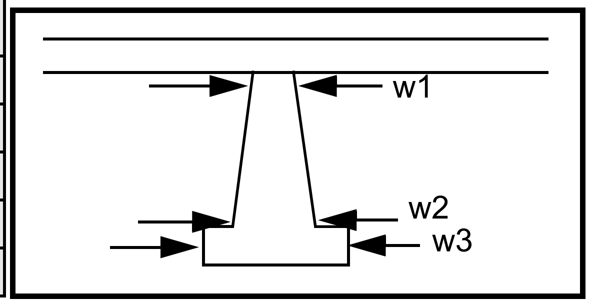
Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee
Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed
Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
-
-
-
-
-
3
1
3
1
1
3

Piers:

84. Are there piers? **80.** *(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	**0.0**		**8.0**	**20.0**	**125.0**	**125.0**
Pier 2	**9.5**		**-**	**20.0**	**12.5**	**-**
Pier 3	**-**	**-**	**-**	**-**	**-**	**-**
Pier 4	**-**	**-**	**-**	**-**	**-**	**-**



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	**The**	**hori-**	**tion**	**except**	*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	**dow**	**zon-**	**exte**	**for 6**	***1**- Solid pier, **2**- column, **3**- bent*
88. Material	**nstre**	**tal**	**nds**	**ft**	***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	**am**	**pen-**	**alon**	**near**	***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	**left**	**etra-**	**g all**	**the**	*Y- yes; N- no*
91. Attack ∠ (BF)	**wing**	**tion**	**of**	**upst**	
92. Pushed	**wall**	**up to**	**the**	**ream**	*LB or RB*
93. Length (feet)	**-**	**-**	**-**	**-**	
94. # of piles	**is**	**1 ft.**	**USL**	**end**	
95. Cross-members	**unde**		**WW**	**of**	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	**rmin**	**82.**	**and**	**the**	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	**ed**	**Pro-**	**LAB**	**abut**	
98. Exposure depth	**with**	**tec-**	**UT**	**ment**	

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

.

N

-

E. Downstream Channel Assessment

100.

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

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

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

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

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

-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

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

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

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

-
-
-
-
-
-

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: -____

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

-
-
-

NO PIERS

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

Cut bank extent: _____ 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.):

2
2
452

Is channel scour present? **452** *(Y or if N type ctrl-n cs)* Mid-scour distance: **1**

Scour dimensions: Length **0** Width **453** Depth: **0** Positioned **0** %LB to - %RB

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

-

Left bank material is cobbles and boulders with some sand; Right bank material is boulders and cobble with some gravel.
Bed material cobble and boulder with some gravel.

Are there major confluences? _____ *(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):

F. Geomorphic Channel Assessment

107. Stage of reach evolution ____

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

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

N
-
NO DROP STRUCTURE

Y
-5
6
23

109. G. Plan View Sketch

\- U

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: NORWTH00160041 Town: Norwich
Road Number: TH0016 County: Windsor
Stream: Bloody Brook

Initials SAO Date: 12/4/97 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 others, 1995, p. 28, eq. 16)

Approach Section

Characteristic	100 yr	500 yr	other Q
Total discharge, cfs	1300	1850	1170
Main Channel Area, ft2	326	369	284
Left overbank area, ft2	0	50	0
Right overbank area, ft2	0	0	0
Top width main channel, ft	54	55	49
Top width L overbank, ft	0	84	0
Top width R overbank, ft	0	0	0
D50 of channel, ft	0.223	0.223	0.223
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	6.0	6.7	5.8
y1, average depth, LOB, ft	ERR	0.6	ERR
y1, average depth, ROB, ft	ERR	ERR	ERR
Total conveyance, approach	29404	37304	24792
Conveyance, main channel	29404	35550	24792
Conveyance, LOB	0	1754	0
Conveyance, ROB	0	0	0
Percent discrepancy, conveyance	0.0000	0.0000	0.0000
Qm, discharge, MC, cfs	1300.0	1763.0	1170.0
Ql, discharge, LOB, cfs	0.0	87.0	0.0
Qr, discharge, ROB, cfs	0.0	0.0	0.0
Vm, mean velocity MC, ft/s	4.0	4.8	4.1
Vl, mean velocity, LOB, ft/s	ERR	1.7	ERR
Vr, mean velocity, ROB, ft/s	ERR	ERR	ERR
Vc-m, crit. velocity, MC, ft/s	9.2	9.3	9.1
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

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	1290	1395	1170
Main channel area (DS), ft2	102	117	97
Main channel width (normal), ft	18.3	18.3	18.3
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	18.3	18.3	18.3
D90, ft	0.9327	0.9327	0.9327
D95, ft	1.1039	1.1039	1.1039
Dc, critical grain size, ft	0.8764	0.7315	0.8162
Pc, Decimal percent coarser than Dc	0.119	0.155	0.136
Depth to armoring, ft	19.56	12.00	15.56

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 others, 1995, p. 32, eq. 20, 20a)

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	1300	1850	1170
(Q) discharge thru bridge, cfs	1290	1395	1170
Main channel conveyance	8488	8488	8488
Total conveyance	8488	8488	8488
Q2, bridge MC discharge,cfs	1290	1395	1170
Main channel area, ft2	134	134	134
Main channel width (normal), ft	18.3	18.3	18.3
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	18.3	18.3	18.3
y_bridge (avg. depth at br.), ft	7.32	7.32	7.32
Dm, median (1.25*D50), ft	0.27875	0.27875	0.27875
y2, depth in contraction,ft	6.84	7.32	6.29
ys, scour depth (y2-ybridge), ft	-0.48	-0.01	-1.03

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	1300	1850	1170
Q, thru bridge MC, cfs	1290	1395	1170
Vc, critical velocity, ft/s	9.17	9.34	9.11
Va, velocity MC approach, ft/s	3.99	4.78	4.12
Main channel width (normal), ft	18.3	18.3	18.3
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	18.3	18.3	18.3
qbr, unit discharge, ft2/s	70.5	76.2	63.9
Area of full opening, ft2	134.0	134.0	134.0
Hb, depth of full opening, ft	7.32	7.32	7.32
Fr, Froude number, bridge MC	0.67	0.73	0.6
Cf, Fr correction factor (<=1.0)	1.00	1.00	1.00
**Area at downstream face, ft2	102	117	97
**Hb, depth at downstream face, ft	5.57	6.39	5.30
**Fr, Froude number at DS face	0.94	0.83	0.92
**Cf, for downstream face (<=1.0)	1.00	1.00	1.00
Elevation of Low Steel, ft	499.11	499.11	499.11
Elevation of Bed, ft	491.79	491.79	491.79
Elevation of Approach, ft	501.78	502.58	500.98
Friction loss, approach, ft	0.11	0.14	0.11
Elevation of WS immediately US, ft	501.67	502.44	500.87
ya, depth immediately US, ft	9.88	10.65	9.08
Mean elevation of deck, ft	501.72	501.72	501.72
w, depth of overflow, ft (>=0)	0.00	0.72	0.00
Cc, vert contrac correction (<=1.0)	0.92	0.92	0.95
**Cc, for downstream face (<=1.0)	0.810024	0.881485	0.838586
Ys, scour w/Chang equation, ft	**0.99**	**1.52**	**0.09**
Ys, scour w/Umbrell equation, ft	-0.73	0.19	-1.12

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

**Ys, scour w/Chang equation, ft	3.91	2.87	3.07
**Ys, scour w/Umbrell equation, ft	1.02	1.12	0.90

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	6.84	7.32	6.29
WSEL at downstream face, ft	497.33	498.15	497.06
Depth at downstream face, ft	5.57	6.39	5.30
Ys, depth of scour (Laursen), ft	1.27	0.92	0.99

Abutment Scour

Froehlich's Abutment Scour

Ys/Y1 = 2.27*K1*K2*(a'/Y1)^0.43*Fr1^0.61+1

(Richardson and others, 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	1300	1850	1170	1300	1850	1170
a', abut.length blocking flow, ft	20.8	21.2	17.6	14.7	15.9	13.4
Ae, area of blocked flow ft2	68.5	68.8	52.9	73	71.7	67.6
Qe, discharge blocked abut.,cfs	169	--	130	--	--	234
(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)						
Ve, (Qe/Ae), ft/s	2.47	3.25	2.46	3.41	4.01	3.46
ya, depth of f/p flow, ft	3.29	3.25	3.01	4.97	4.51	5.04
--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)						
K1	0.82	0.82	0.82	0.82	0.82	0.82
--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)						
theta	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	0.240	0.290	0.250	0.260	0.295	0.272
ys, scour depth, ft	8.67	9.28	7.88	11.69	11.62	11.74

HIRE equation (a'/ya > 25)

ys = 4*Fr^0.33*y1*K/0.55

(Richardson and others, 1995, p. 49, eq. 29)

a'(abut length blocked, ft)	20.8	21.2	17.6	14.7	15.9	13.4
y1 (depth f/p flow, ft)	3.29	3.25	3.01	4.97	4.51	5.04
a'/y1	6.32	6.53	5.86	2.96	3.53	2.66
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.24	0.29	0.25	0.26	0.30	0.27
Ys w/ corr. factor K1/0.55:						
vertical	ERR	ERR	ERR	ERR	ERR	ERR
vertical w/ ww's	ERR	ERR	ERR	ERR	ERR	ERR
spill-through	ERR	ERR	ERR	ERR	ERR	ERR

Abutment riprap Sizing

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

Characteristic	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	0.94	0.83	0.92	0.94	0.83	0.92
y, depth of flow in bridge, ft	5.57	6.39	5.30	5.57	6.39	5.30

Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	ERR	ERR	ERR	ERR	ERR	ERR
Fr>0.8 (vertical abut.)	2.29	2.54	2.17	2.29	2.54	2.17