LEVEL II SCOUR ANALYSIS FOR BRIDGE 26 (ROYATH00540026) on TOWN HIGHWAY 54, crossing BROAD BROOK, ROYALTON, VERMONT

U.S. Geological Survey
Open-File Report 97-579

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

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By RONDA L. BURNS & MATTHEW A. WEBER

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

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

LEVEL II SCOUR ANALYSIS FOR BRIDGE 26 (ROYATH00540026) ON TOWN HIGHWAY 54, CROSSING BROAD BROOK, ROYALTON, VERMONT

By **Ronda L. Burns and Matthew A. Weber**

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure ROYATH00540026 on Town Highway 54 crossing Broad Brook, Royalton, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). 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 central Vermont. The 11.9-mi^2 drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover on the left bank upstream and downstream is pasture with trees and brush on the immediate banks. The right bank, upstream and downstream of the bridge, is forested.

In the study area, Broad Brook has an incised, sinuous channel with a slope of approximately 0.01 ft/ft, an average channel top width of 37 ft and an average bank height of 4 ft. The channel bed material ranges from sand to boulders with a median grain size (D_{50}) of 66.3 mm (0.218 ft). The geomorphic assessment at the time of the Level I site visit on April 13, 1995 and the Level II site visit on July 11, 1996, indicated that the reach was stable.

The Town Highway 54 crossing of Broad Brook is a 29-ft-long, one-lane bridge consisting of one 24-foot steel-beam span with a timber deck (Vermont Agency of Transportation, written communication, March 23, 1995). The opening length of the structure parallel to the bridge face is 23.3 ft. The bridge is supported by a vertical, concrete face laid-up stone abutment with concrete wingwalls on the left and a laid-up stone abutment on the right. The channel is skewed approximately 20 degrees to the opening while the opening-skew-to-roadway is zero degrees.

A scour hole 1.0 ft deeper than the mean thalweg depth was observed along the downstream end of the right abutment during the Level I assessment. Also, at the upstream end of the left abutment, the footing is exposed 0.5 ft. The scour protection measures at the site included type-2 stone fill (less than 36 inches diameter) along the upstream left bank, at the upstream end of the upstream left wingwall, along the entire length of the downstream left wingwall, and at the upstream end of the right abutment. 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 others, 1995). 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 1.4 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 2.2 to 7.4 ft on the left and from 14.7 to 17.7 ft on the right. The worst-case abutment scour occurred at the incipient roadway-overtopping discharge for the left and at the 500-year discharge for the right. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 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.

South Royalton, VT. Quadrangle, 1:24,000, 1981
Photoinspected 1983

NORTH

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

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

LEVEL II SUMMARY

Structure Number ROYATH00540026 ***Stream*** Broad Brook

County Windsor ***Road*** TH54 ***District*** 4

Description of Bridge

Bridge length 29 ***ft*** ***Bridge width*** 16 ***ft*** ***Max span length*** 24 ***ft***

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

Abutment type Vertical ***Embankment type*** sloping, right

Stone fill on abutment? None, left; ***Date of inspection***

Yes

Description of stone fill

04/13/95

Type-2, along the upstream end of the upstream left wingwall, along the baselength of the

downstream left wingwall, and at the upstream end of

Brief description of piers/abutments

the right abutment.

On the left, the abutment is concrete faced laid-up stone with concrete wingwalls. On the right,

the abutme

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

laid-up stone. There is a one foot deep scour hole at the downstream end of the right abutment.

Yes

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***
	20	Yes	There is
Level I	a mild channel	bend in	the
Level II			

upstream reach. The scour hole has developed in the location where

the bend impacts the right abutment.

Potential for debris

04/13/95

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

0

0

Description of the Geomorphic Setting

General topography The channel is located within a moderate relief valley with a narrow flood plain on the left and steep valley walls on both sides.

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

Date of inspection 04/13/95

DS left: Slightly irregular, narrow flood plain

DS right: Steep valley wall

US left: Steep channel bank to a narrow flood plain

US right: Steep valley wall

Description of the Channel

Average top width 37 ***ft***

Average depth 4 ***ft***

Predominant bed material Gravel/Cobbles

Bank material Gravel/Sand

Sinuous but stable with semi-alluvial channel boundaries.

04/13/95

Vegetative co Some trees and brush with short grass on the overbank

DS left: Trees and brush

DS right: Some trees and brush with short grass on the overbank

US left: Trees and brush

US right:

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

None as of 04/13/95.

Describe any obstructions in channel and date of observation.

Hydrology

Drainage area 11.9 ***mi²***

Percentage of drainage area in physiographic provinces: (approximate)

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

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

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

USGS gage description --

USGS gage number --

Gage drainage area -- ***mi²***

Is there a lake/p No

-

-

Calculated Discharges

Q100 2,200 ***ft³/s*** ***Q500*** 3,000 ***ft³/s***

The 100- and 500-year discharges are based on the median value defined by flood frequency curves which were developed from several empirical methods and extended to the 500-year event. (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887)

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 upstream left wingwall (elev. 499.33 ft, arbitrary survey datum). RM2 is a nail in a one foot diameter ash tree located 10 ft. east of the bridge along the road on the downstream right bank (elev. 505.82 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

[1]*Cross-section*	*Section Reference Distance (SRD) in feet*	[2]*Cross-section development*	*Comments*
EXITX	-29	1	Exit section
FULLV	0	2	Downstream Full-valley section (Templated from EXITX)
BRIDG	0	1	Bridge section
RDWAY	10	1	Road Grade section
APPRO	44	2	Modelled Approach section (Templated from APTEM)
APTEM	39	1	Approach section as surveyed (Used as a template)

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

Data and Assumptions Used in WSPRO Model

Hydraulic analyses of the reach were done by use of the Federal Highway Administration's WSPRO step-backwater computer program (Shearman and others, 1986, and Shearman, 1990). The 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 0.040 to 0.055, and overbank "n" values ranged from 0.045 to 0.060.

Normal depth at the exit section (EXITX) was assumed as the starting water surface. This depth was computed by use of the slope-conveyance method outlined in the user's manual for WSPRO (Shearman, 1990). The slope used was 0.0102 ft/ft which was estimated from points surveyed downstream of the bridge.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.0028 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 can be determined that the water surface profile does pass through critical depth within the bridge opening. Thus, the assumptions of critical depth at the bridge are satisfactory solutions.

Bridge Hydraulics Summary

Average bridge embankment elevation 499.9 ***ft***
Average low steel elevation 498.2 ***ft***

100-year discharge 2,200 ***ft^3/s***
Water-surface elevation in bridge opening 498.4 ***ft***
Road overtopping? Yes ***Discharge over road*** 657 ***ft^3/s***
Area of flow in bridge opening 183 ***ft^2***
Average velocity in bridge opening 8.4 ***ft/s***
Maximum WSPRO tube velocity at bridge 10.2 ***ft/s***

Water-surface elevation at Approach section with bridge 499.8
Water-surface elevation at Approach section without bridge 497.1
Amount of backwater caused by bridge 2.7 ***ft***

500-year discharge 3,000 ***ft^3/s***
Water-surface elevation in bridge opening 498.2 ***ft***
Road overtopping? Yes ***Discharge over road*** 1253 ***ft^3/s***
Area of flow in bridge opening 183 ***ft^2***
Average velocity in bridge opening 9.3 ***ft/s***
Maximum WSPRO tube velocity at bridge 12.9 ***/s***

Water-surface elevation at Approach section with bridge 500.4
Water-surface elevation at Approach section without bridge 498.3
Amount of backwater caused by bridge 2.1 ***ft***

Incipient overtopping discharge 1,550 ***ft^3/s***
Water-surface elevation in bridge opening 495.5 ***ft***
Area of flow in bridge opening 120 ***ft^2***
Average velocity in bridge opening 12.9 ***ft/s***
Maximum WSPRO tube velocity at bridge 16.0 ***ft/s***

Water-surface elevation at Approach section with bridge 498.4
Water-surface elevation at Approach section without bridge 496.2
Amount of backwater caused by bridge 2.2 ***ft***

Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

Scour depths were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

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

For the discharges resulting in orifice flow, estimates of contraction scour were also computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and others, 1995, p. 144) and presented in Appendix F. Furthermore, for those discharges resulting in unsubmerged orifice flow, contraction scour was computed by substituting estimates for the depth of flow at the downstream bridge face into the contraction scour equations. Results with respect to these substitutions are provided in Appendix F.

Scour at the right abutment and at the left abutment for the incipient road-overtopping discharge was computed by use of the Froehlich equation (Richardson and others, 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 left abutment for the 100-year and 500-year discharges was computed by use of the HIRE equation (Richardson and others, 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 incipient road-overtopping discharge, which is less than the 100-year discharge, does not flow into the flood plain on the left overbank, and scour was computed by use of the Froehlich equation. 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	0.1	1.4
Depth to armoring	6.5	5.6	N/A
Left overbank	--	--	--
Right overbank	--	--	--

Local scour:	*100-yr discharge*	*500-yr discharge*	*Incipient overtopping discharge*
Abutment scour			
Left abutment	2.2	2.9	7.4
Right abutment	15.8	17.7	14.7
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	2.1	2.1	2.2
Right abutment	2.1	2.1	2.2
Piers:			
Pier 1	--	--	--
Pier 2	--	--	--

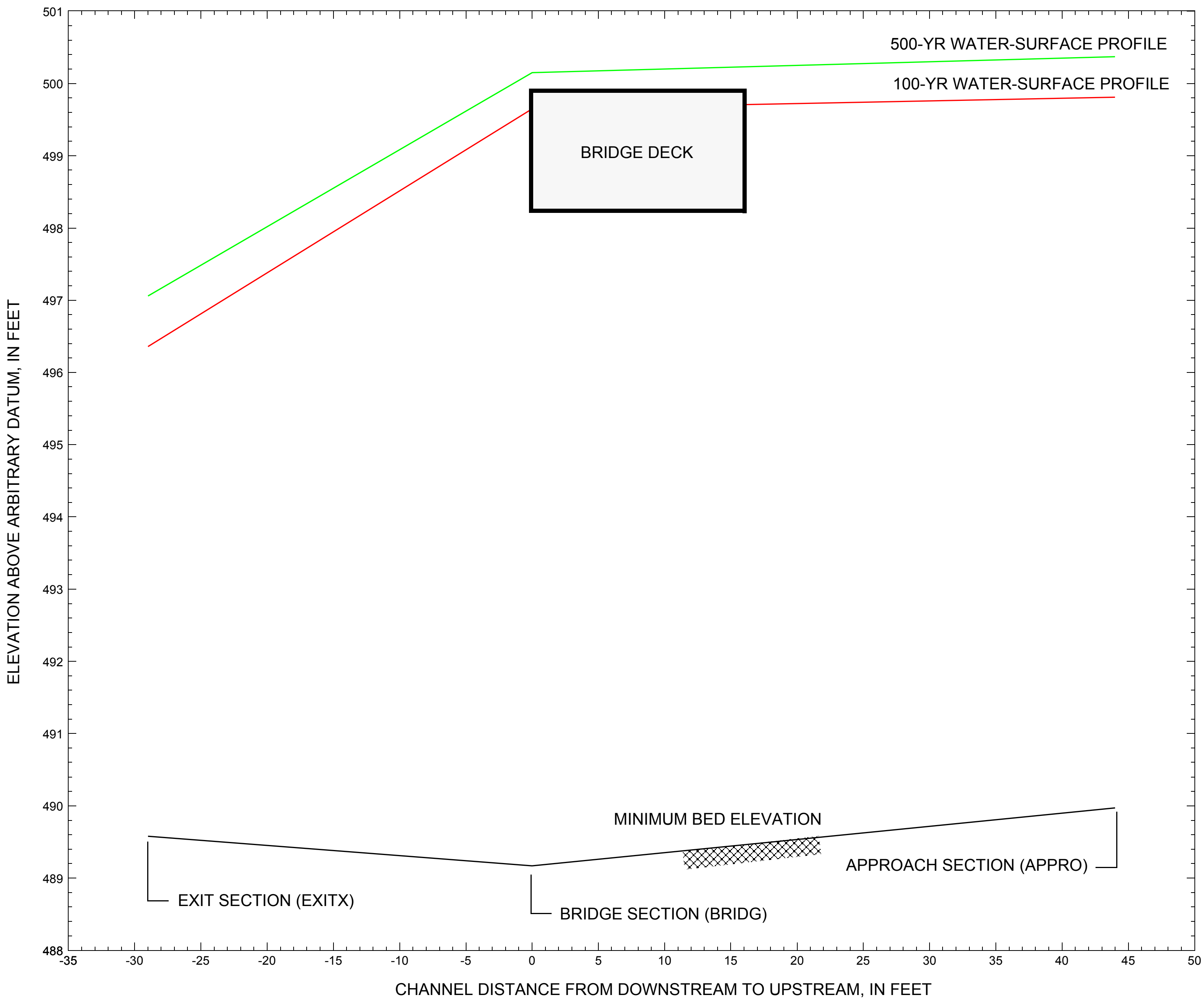

Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure ROYATH00540026 on Town Highway 54, crossing Broad Brook, Royalton, Vermont.

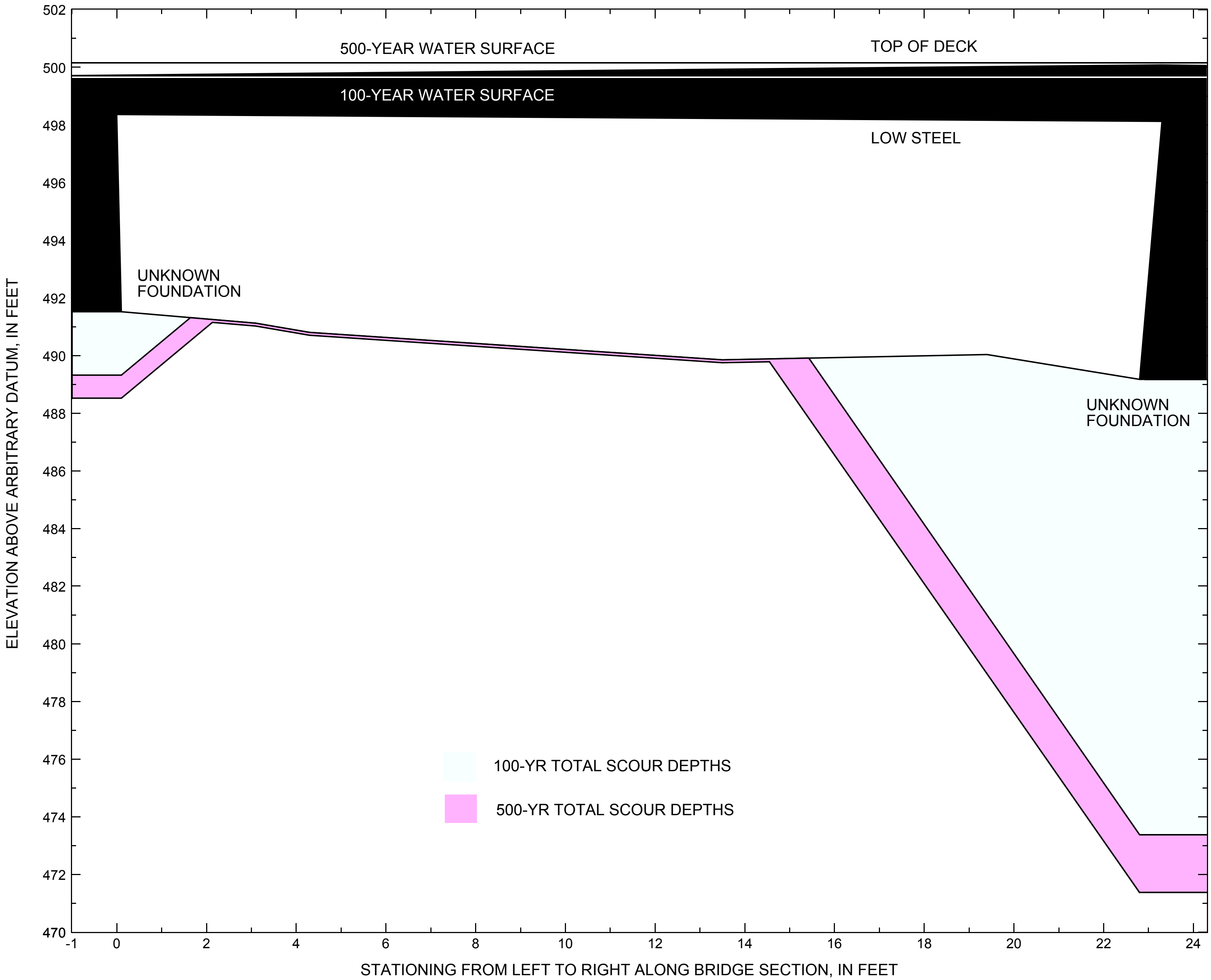

Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure ROYATH00540026 on Town Highway 54, crossing Broad Brook, Royalton, Vermont.

Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure ROYATH00540026 on Town Highway 54, crossing Broad Brook, Royalton, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
100-yr. discharge is 2,200 cubic-feet per second											
Left abutment	0.1	--	498.4	--	491.5	0.0	2.2	--	2.2	489.3	--
Right abutment	22.8	--	498.1	--	489.2	0.0	15.8	--	15.8	473.4	--

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 ROYATH00540026 on Town Highway 54, crossing Broad Brook, Royalton, Vermont.

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

Description	Station[1]	VTAOT minimum low-chord elevation (feet)	Surveyed minimum low-chord elevation[2] (feet)	Bottom of footing elevation[2] (feet)	Channel elevation at abutment/ pier[2] (feet)	Contraction scour depth (feet)	Abutment scour depth (feet)	Pier scour depth (feet)	Depth of total scour (feet)	Elevation of scour[2] (feet)	Remaining footing/pile depth (feet)
500-yr. discharge is 3,000 cubic-feet per second											
Left abutment	0.1	--	498.4	--	491.5	0.1	2.9	--	3.0	488.5	--
Right abutment	22.8	--	498.1	--	489.2	0.1	17.7	--	17.8	471.4	--

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

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U.S. Geological Survey, 1981, South Royalton, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps, Photoinspected 1983, Scale 1:24,000.

APPENDIX A:

WSPRO INPUT FILE

WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File roya026.wsp
T2        Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
T3        TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                         RLB
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           2200.0   3000.0   1550.0
SK          0.0102   0.0102   0.0102
*
XS   EXITX    -29           0.
GR         -195.2, 509.28   -180.9, 507.43   -163.9, 499.72   -151.4, 497.77
GR         -119.4, 497.80   -106.7, 498.19    -96.3, 498.95    -85.0, 498.39
GR          -80.3, 496.53    -68.6, 495.81    -38.8, 495.04    -17.6, 493.28
GR           -9.5, 493.86      0.0, 491.11      1.6, 490.87      6.3, 490.13
GR            8.5, 489.88     12.2, 489.58     14.9, 490.08     21.0, 490.52
GR           21.6, 491.04     27.1, 491.18     33.2, 494.08     40.8, 495.15
GR           47.9, 499.38     74.7, 501.70    114.7, 508.93
*
N           0.050        0.055        0.060
SA                  -9.5         33.2
*
XS   FULLV      0  * * *   0.0094
*
*            SRD     LSEL    XSSKEW
BR   BRIDG     0    498.24       0.0
GR            0.0, 498.36      0.1, 491.52      3.1, 491.12      4.3, 490.80
GR            8.8, 490.31     13.5, 489.85     19.4, 490.03     22.8, 489.17
GR           22.9, 491.12     23.3, 498.12      0.0, 498.36
*
*        BRTYPE  BRWDTH       WWANGL    WWWID
CD          1      26.8 * *     31.8      9.4
N           0.040
*
*            SRD    EMBWID   IPAVE
XR   RDWAY     10      16.0     2
GR         -209.9, 506.56   -182.3, 504.49   -166.4, 500.03   -118.2, 497.73
GR         -106.7, 498.81    -97.4, 499.43    -76.1, 498.41    -58.1, 498.21
GR            0.0, 499.73     22.8, 500.08     64.6, 503.59     85.0, 504.60
GR           90.2, 507.24
*
*    For the incipient over-topping model, a wall was created at station -5.2.
*
XT   APTEM     39           0.
GR         -226.1, 507.58   -162.5, 499.15   -112.3, 497.73   -101.0, 499.15
GR          -81.4, 499.24    -65.5, 497.79     -5.2, 498.66     -0.8, 495.48
GR           -0.2, 491.14      0.0, 490.62      5.0, 490.19      7.0, 489.96
GR           11.0, 490.35     12.5, 490.87     14.3, 491.19     22.5, 492.06
GR           26.7, 494.45     55.0, 495.22     61.8, 499.55     70.8, 499.85
GR           76.9, 504.97     98.4, 509.85    119.8, 514.27
*
*    For the incipient over-topping model, a wall was created at station -5.2,
*    the top of the left bank.
*
AS   APPRO     44  * * *  0.0028
GT
N           0.045        0.050        0.060
SA                  -5.2         26.7
*
HP 1 BRIDG   498.36 1 498.36
HP 2 BRIDG   498.36 * * 1541
HP 1 BRIDG   496.71 1 496.71
HP 2 RDWAY   499.65 * * 657
HP 1 APPRO   499.81 1 499.81
HP 2 APPRO   499.81 * * 2200
*
HP 1 BRIDG   498.24 1 498.24
HP 2 BRIDG   498.24 * * 1701
HP 1 BRIDG   497.41 1 497.41
```

APPENDIX B:

WSPRO OUTPUT FILE

WSPRO OUTPUT FILE

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       U.S. Geological Survey WSPRO Input File roya026.wsp
       Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
       TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                            RLB
          *** RUN DATE & TIME: 06-06-97  11:24

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     183.   14068.     0.    62.                           0.
 498.36           183.   14068.     0.    62.  1.00     0.    23.      0.

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      498.36     0.0    23.3   183.4   14068.    1541.   8.40

X STA.         0.0         2.3         3.7         5.0         6.1         7.2
  A(I)             15.8        10.2         9.3         8.5         8.4
  V(I)             4.88        7.56        8.28        9.07        9.22

X STA.         7.2         8.2         9.2        10.2        11.1        12.1
  A(I)              8.2         8.0         8.0         7.7         7.8
  V(I)             9.45        9.67        9.67       10.02        9.92

X STA.        12.1        13.0        13.9        14.9        15.8        16.8
  A(I)              7.8         7.6         7.8         8.0         7.9
  V(I)             9.92       10.15        9.90        9.62        9.77

X STA.        16.8        17.8        18.8        19.9        21.2        23.3
  A(I)              8.2         8.6         9.0        10.1        16.6
  V(I)             9.35        8.92        8.53        7.61        4.64

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     148.   14202.    23.    36.                        2117.
 496.71           148.   14202.    23.    36.  1.00     0.    23.   2117.

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      499.65  -158.4    -3.1   138.7    3917.     657.   4.74

X STA.      -158.4      -137.3      -131.2      -126.8      -123.2      -120.2
  A(I)             10.7         7.0         6.2         5.7         5.3
  V(I)             3.07        4.70        5.30        5.76        6.14

X STA.      -120.2      -117.4      -114.3      -110.1       -88.4       -79.8
  A(I)              5.2         5.2         5.7        12.3         7.3
  V(I)             6.35        6.27        5.79        2.67        4.50

X STA.       -79.8       -74.7       -70.2       -65.8       -61.6       -57.6
  A(I)              6.0         5.8         5.8         5.8         5.7
  V(I)             5.44        5.67        5.63        5.67        5.78

X STA.       -57.6       -53.2       -48.0       -41.6       -32.8        -3.1
  A(I)              6.0         6.5         7.0         7.9        11.5
  V(I)             5.49        5.06        4.68        4.17        2.85

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      44.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     212.    8374.   162.   162.                        1374.
            2     247.   25617.    32.    38.                        3892.
            3     158.    9206.    42.    44.                        1724.
 499.81           616.   43198.   237.   244.  1.51  -167.    69.   4591.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      44.

        WSEL     LEW     REW    AREA        K        Q    VEL
      499.81  -167.4    69.2   616.2   43198.    2200.   3.57

X STA.      -167.4      -118.2       -64.6       -38.7         0.2         2.8
  A(I)             58.0        61.0        46.8        65.6        24.1
  V(I)             1.90        1.80        2.35        1.68        4.56

X STA.         2.8         5.0         6.9         8.7        10.6        12.5
  A(I)             20.5        18.9        17.9        17.5        17.9
  V(I)             5.35        5.82        6.14        6.30        6.13

X STA.        12.5        14.5        16.7        18.9        21.2        23.8
  A(I)             17.7        18.3        18.0        18.4        20.1
  V(I)             6.21        6.02        6.10        5.97        5.46

X STA.        23.8        28.2        34.1        40.6        47.7        69.2
  A(I)             25.6        30.8        32.7        34.8        51.4
  V(I)             4.30        3.57        3.36        3.16        2.14
```

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       U.S. Geological Survey WSPRO Input File roya026.wsp
       Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
       TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                          RLB
          *** RUN DATE & TIME: 06-06-97  11:24

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     183.   16084.    12.    50.                       4105.
  498.24          183.   16084.    12.    50.  1.00     0.    23.   4105.

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      498.24     0.0    23.3   182.7   16084.    1701.   9.31

X STA.        0.0        2.3        3.6        4.6        5.6        6.5
  A(I)            15.5        9.1        7.8        7.3        6.8
  V(I)            5.50       9.33      10.88      11.61      12.43

X STA.        6.5        7.4        8.2        9.1        9.9       10.7
  A(I)             6.9        6.6        6.6        6.6        6.6
  V(I)           12.41      12.91      12.93      12.94      12.81

X STA.       10.7       11.6       12.6       13.7       14.8       15.9
  A(I)             6.8        8.8        8.9        9.0        9.4
  V(I)           12.52       9.64       9.56       9.49       9.05

X STA.       15.9       17.1       18.2       19.5       20.9       23.3
  A(I)             9.6        9.6       10.4       12.0       18.4
  V(I)            8.86       8.83       8.22       7.10       4.62

   CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     164.   16471.    23.    37.                       2473.
  497.41          164.   16471.    23.    37.  1.00     0.    23.   2473.

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

        WSEL     LEW     REW    AREA        K        Q    VEL
      500.15  -166.8    23.6   225.9    8031.    1253.   5.55

X STA.     -166.8     -141.8     -133.7     -127.8     -123.3     -119.3
  A(I)            17.4       12.0       10.7        9.5        9.0
  V(I)            3.60       5.21       5.86       6.62       6.94

X STA.     -119.3     -115.5     -110.8     -102.9      -86.7      -79.0
  A(I)             8.8        9.2       10.9       15.4       10.8
  V(I)            7.15       6.84       5.72       4.06       5.79

X STA.      -79.0      -73.4      -68.1      -63.2      -58.3      -53.3
  A(I)             9.6        9.5        9.2        9.3        9.4
  V(I)            6.52       6.60       6.82       6.76       6.63

X STA.      -53.3      -47.7      -41.2      -32.9      -21.7       23.6
  A(I)             9.8       10.3       11.5       12.7       20.9
  V(I)            6.39       6.08       5.44       4.93       3.00

   CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      44.
    WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
            1     304.   15014.   166.   167.                       2330.
            2     265.   28784.    32.    38.                       4323.
            3     183.   11331.    45.    46.                       2093.
  500.37          751.   55129.   243.   251.  1.42  -172.    71.   6292.

   VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      44.

        WSEL     LEW     REW    AREA        K        Q    VEL
      500.37  -171.6    71.4   750.9   55129.    3000.   4.00

X STA.     -171.6     -127.5     -107.0      -64.2      -44.3      -19.4
  A(I)            65.1       48.8       64.7       47.8       51.9
  V(I)            2.30       3.07       2.32       3.14       2.89

X STA.      -19.4        1.6        4.2        6.4        8.5       10.7
  A(I)            61.9       25.4       22.8       22.0       21.6
  V(I)            2.42       5.91       6.58       6.80       6.93

X STA.       10.7       12.9       15.2       17.7       20.3       23.1
  A(I)            21.7       21.8       22.2       22.2       23.6
  V(I)            6.93       6.87       6.75       6.76       6.36

X STA.       23.1       27.4       33.8       40.5       48.1       71.4
  A(I)            29.2       36.6       38.1       41.3       62.1
  V(I)            5.13       4.09       3.94       3.63       2.42
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     U.S. Geological Survey WSPRO Input File roya026.wsp
     Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
     TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                          RLB
        *** RUN DATE & TIME: 06-06-97  13:40

 CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
          1     120.   10515.    23.    33.                       1552.
495.51          120.   10515.    23.    33.  1.00     0.    23.   1552.

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

    WSEL     LEW     REW    AREA        K        Q    VEL
  495.51     0.0    23.2   120.0   10515.    1550.  12.92

X STA.        0.0        2.6        4.2        5.4        6.6        7.6
 A(I)            10.7        6.8        6.0        5.6        5.5
 V(I)            7.25      11.39      13.02      13.88      14.18

X STA.        7.6        8.7        9.6       10.6       11.5       12.4
 A(I)             5.2        5.2        5.0        4.9        4.8
 V(I)           14.89      15.03      15.54      15.76      16.00

X STA.       12.4       13.2       14.1       15.0       15.9       16.8
 A(I)             4.9        4.9        4.9        5.0        5.1
 V(I)           15.98      15.81      15.69      15.56      15.21

X STA.       16.8       17.7       18.7       19.9       21.0       23.2
 A(I)             5.4        5.5        6.1        6.8       11.8
 V(I)           14.45      14.09      12.65      11.37       6.55

 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      44.
  WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
          2     202.   18518.    32.    37.                       2902.
          3     109.    5832.    33.    34.                       1115.
498.41          311.   24350.    65.    72.  1.15    -5.    60.   3596.

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      44.

    WSEL     LEW     REW    AREA        K        Q    VEL
  498.41    -4.8    60.0   310.7   24350.    1550.   4.99

X STA.       -4.8        2.0        3.9        5.5        7.0        8.4
 A(I)            26.3       15.1       13.3       12.1       11.8
 V(I)            2.95       5.12       5.82       6.42       6.55

X STA.        8.4        9.8       11.2       12.7       14.2       15.8
 A(I)            11.4       11.2       11.5       11.2       11.6
 V(I)            6.77       6.90       6.75       6.90       6.69

X STA.       15.8       17.4       19.2       21.0       23.0       25.8
 A(I)            11.4       11.8       12.0       12.5       15.0
 V(I)            6.82       6.58       6.43       6.22       5.16

X STA.       25.8       30.9       36.3       42.3       48.8       60.0
 A(I)            20.0       20.5       21.7       22.1       28.2
 V(I)            3.88       3.78       3.58       3.51       2.74
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        U.S. Geological Survey WSPRO Input File roya026.wsp
        Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
        TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                          RLB
           *** RUN DATE & TIME: 06-06-97  11:24

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

 EXITX:XS   ******   -77.     335.  0.85 *****  497.20  495.69   2200.  496.36
       -29. ******    43.   21778.  1.26 ***** *******    0.78    6.57

 FULLV:FV      29.   -79.     344.  0.80  0.29  497.51 *******   2200.  496.71
         0.    29.    43.   22550.  1.26  0.00    0.02    0.75    6.39
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.15     496.67     497.07
  ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   496.21     514.28    0.50
  ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   496.21     514.28     497.07
  ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
              ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "APPRO"
                   WSBEG,WSEND,CRWS =   497.07     514.28     497.07

 APPRO:AS      44.    -3.     226.  1.76 *****  498.83  497.07   2200.  497.07
        44.    44.    58.   15865.  1.20 ***** *******    0.97    9.71
          <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

  ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   500.69       0.00     496.88     497.73
  ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
  ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   496.09     499.11     499.29     498.24
  ===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      29.     0.     183.  1.10 *****  499.46  495.49   1541.  498.36
         0. ******    23.   14068.  1.00 ***** *******    0.53    8.41

      TYPE PPCD FLOW       C     P/A    LSEL   BLEN   XLAB   XRAB
        1. ****   5.  0.439  0.000  498.24 ****** ****** ******

     XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
    RDWAY:RG      10.    28.  0.07  0.30  500.03    0.00    657.  499.65

              Q   WLEN    LEW     REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
    LT:    657.   155.  -158.     -3.   1.9   0.9   5.0   4.7   1.3   2.9
    RT:      0.     3.    12.     15.   0.0   0.0   2.7  40.6   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      17.  -167.     615.  0.30  0.11  500.11  497.07   2200.  499.81
        44.    19.    69.   43146.  1.51  0.59    0.00    0.48    3.57

        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
    EXITX:XS     -29.    -77.    43.   2200.    21778.     335.    6.57  496.36
    FULLV:FV       0.    -79.    43.   2200.    22550.     344.    6.39  496.71
    BRIDG:BR       0.     0.     23.   1541.    14068.     183.    8.41  498.36
    RDWAY:RG      10.*******    657.    657.*********       0.    2.00  499.65
    APPRO:AS      44.  -167.     69.   2200.    43146.     615.    3.57  499.81

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

  SECOND USER DEFINED TABLE.

     XSID:CODE     CRWS     FR#    YMIN    YMAX     HF     HO   VHD      EGL    WSEL
    EXITX:XS     495.69    0.78  489.58  509.28************  0.85  497.20  496.36
    FULLV:FV   ********    0.75  489.85  509.55  0.29  0.00  0.80  497.51  496.71
    BRIDG:BR     495.49    0.53  489.17  498.36************  1.10  499.46  498.36
    RDWAY:RG   ****************  497.73  507.24  0.07******  0.30  500.03  499.65
    APPRO:AS     497.07    0.48  489.97  514.28  0.11  0.59  0.30  500.11  499.81
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       U.S. Geological Survey WSPRO Input File roya026.wsp
       Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
       TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                          RLB
          *** RUN DATE & TIME: 06-06-97  11:24

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

EXITX:XS   ******   -82.     422.  0.96 *****  498.02  496.56   3000.  497.06
      -29. ******    44.   29703.  1.22 ***** *******    0.76    7.11

FULLV:FV      29.   -82.     431.  0.91  0.29  498.32 *******   3000.  497.41
        0.    29.    44.   30648.  1.21  0.00    0.02    0.73    6.95
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
             FNTEST,FR#,WSEL,CRWS =  0.80    1.39     496.95     498.34
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                  WSLIM1,WSLIM2,DELTAY =   496.91     514.28    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                  WSLIM1,WSLIM2,CRWS =   496.91     514.28     498.34
 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
             ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "APPRO"
                  WSBEG,WSEND,CRWS =   498.34     514.28     498.34

APPRO:AS      44.  -133.     325.  1.67 *****  500.01  498.34   3000.  498.34
       44.    44.    60.   24130.  1.26 ***** *******    1.17    9.22
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   503.13       0.00     498.14     497.73
 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
                  WS,QBO,QRD =   501.82         0.      3000.
 ===280 REJECTED FLOW CLASS 4 SOLUTION.
 ===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      29.     0.     183.  1.35 *****  499.59  495.84   1701.  498.24
        0. ******    23.   16084.  1.00 ***** *******    0.59    9.31

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****    5.  0.464  0.000  498.24 ****** ****** ******

    XSID:CODE     SRD   FLEN    HF    VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      10.    28.  0.08  0.35  500.64   -0.02   1253.  500.15

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:   1237.   179.  -167.    12.   2.4   1.3   5.9   5.5   1.7   3.0
   RT:     16.    12.    12.    24.   0.2   0.1   3.2   9.3   0.6   2.7

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

APPRO:AS      17.  -172.     751.  0.35  0.14  500.72  498.34   3000.  500.37
       44.    22.    71.   55149.  1.42  0.00   -0.02    0.48    3.99

       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
   EXITX:XS     -29.    -82.    44.   3000.   29703.     422.    7.11  497.06
   FULLV:FV       0.    -82.    44.   3000.   30648.     431.    6.95  497.41
   BRIDG:BR       0.      0.    23.   1701.   16084.     183.    9.31  498.24
   RDWAY:RG      10.******* 1237.   1253.*********       0.    2.00  500.15
   APPRO:AS      44.  -172.     71.   3000.   55149.     751.    3.99  500.37

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

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS     FR#    YMIN    YMAX    HF    HO  VHD     EGL    WSEL
   EXITX:XS    496.56    0.76  489.58  509.28************  0.96  498.02  497.06
   FULLV:FV  ********    0.73  489.85  509.55  0.29  0.00  0.91  498.32  497.41
   BRIDG:BR    495.84    0.59  489.17  498.36************  1.35  499.59  498.24
   RDWAY:RG  ****************  497.73  507.24  0.08******  0.35  500.64  500.15
   APPRO:AS    498.34    0.48  489.97  514.28  0.14  0.00  0.35  500.72  500.37
```
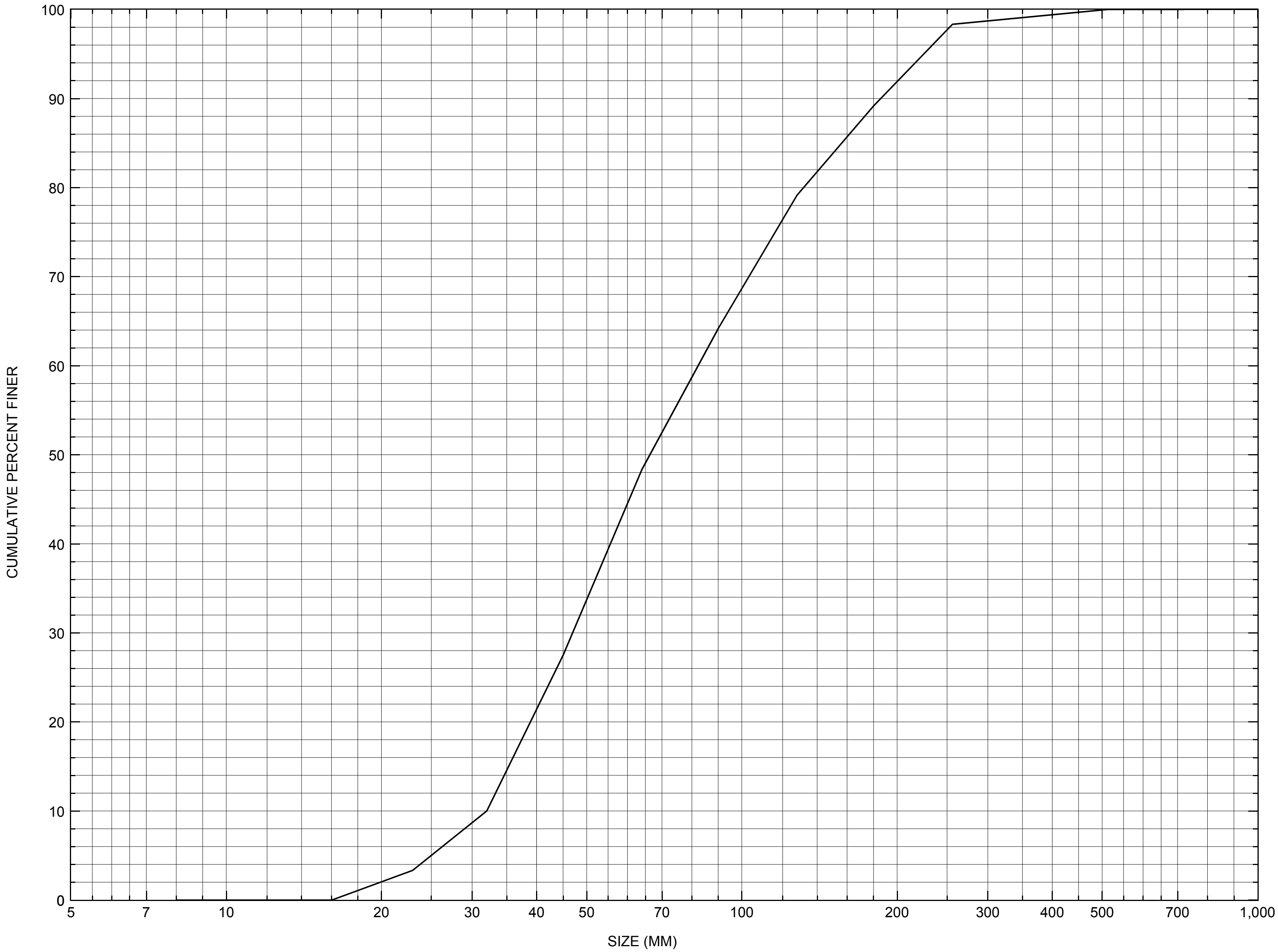

WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File roya026.wsp
        Hydraulic analysis for structure ROYATH00540026   Date: 16-APR-97
        TH 54 CROSSING BROAD BROOK IN ROYALTON, VT                        RLB
           *** RUN DATE & TIME: 06-06-97  13:40

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

EXITX:XS   ******   -61.     250.  0.73 *****  496.34  494.77   1550.  495.61
      -29. ******    42.   15339.  1.23 ***** *******    0.77    6.19

FULLV:FV      29.   -63.     255.  0.71  0.29  496.64 *******   1550.  495.93
        0.    29.    42.   15670.  1.24  0.00    0.00    0.76    6.07
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===125 FR# EXCEEDS FNTEST AT SECID "APPRO":  TRIALS CONTINUED.
              FNTEST,FR#,WSEL,CRWS =  0.80    1.05     496.10     496.20
 ===110 WSEL NOT FOUND AT SECID "APPRO":  REDUCED DELTAY.
                   WSLIM1,WSLIM2,DELTAY =   495.43     514.28    0.50
 ===115 WSEL NOT FOUND AT SECID "APPRO":  USED WSMIN = CRWS.
                   WSLIM1,WSLIM2,CRWS =   495.43     514.28     496.20
 ===130 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D  !!!!!
              ENERGY EQUATION  N_O_T  B_A_L_A_N_C_E_D  AT SECID "APPRO"
                   WSBEG,WSEND,CRWS =   496.20     514.28     496.20

APPRO:AS      44.    -2.     175.  1.50 *****  497.70  496.20   1550.  496.20
       44.    44.    57.   11398.  1.22 ***** *******    1.00    8.87
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===285 CRITICAL WATER-SURFACE ELEVATION  A _ S _ S _ U _ M _ E _ D !!!!!
                   SECID "BRIDG"     Q,CRWS =    1550.     495.51

            <<<<<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      29.     0.     120.  2.59 *****  498.10  495.51   1550.  495.51
        0.    29.    23.   10524.  1.00 ***** *******    1.00   12.91

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       1. ****   1.  1.000 ******  498.24 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      10.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS      17.    -5.     311.  0.45  0.17  498.85  496.20   1550.  498.41
       44.    18.    60.   24337.  1.15  0.58    0.00    0.43    4.99

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.603  0.192   19637.     0.    23.   498.29

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -29.   -61.    42.   1550.   15339.     250.    6.19  495.61
   FULLV:FV       0.   -63.    42.   1550.   15670.     255.    6.07  495.93
   BRIDG:BR       0.     0.    23.   1550.   10524.     120.   12.91  495.51
   RDWAY:RG      10.**************      0.*****************     2.00********
   APPRO:AS      44.    -5.    60.   1550.   24337.     311.    4.99  498.41

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       0.    23.   19637.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    494.77    0.77  489.58  509.28************  0.73  496.34  495.61
   FULLV:FV  ********    0.76  489.85  509.55  0.29  0.00  0.71  496.64  495.93
   BRIDG:BR    495.51    1.00  489.17  498.36************  2.59  498.10  495.51
   RDWAY:RG ****************  499.73  507.24**********************************
   APPRO:AS    496.20    0.43  489.97  514.28  0.17  0.58  0.45  498.85  498.41
```

APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION



Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure ROYATH00540026, in Royalton, Vermont.

APPENDIX D:

HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

Structure Number ROYATH00540026

General Location Descriptive

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

Date *(MM/DD/YY)* 03 / 23 / 95

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

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

Town *(FIPS place code; I - 4; nnnnn)* 60850

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

Waterway *(I - 6)* BROAD BROOK

Road Name *(I - 7):* -

Route Number TH054

Vicinity *(I - 9)* AT JCT TH 54 & TH 2

Topographic Map South Royalton

Hydrologic Unit Code: 01080105

Latitude *(I - 16; nnnn.n)* 43463

Longitude *(i - 17; nnnnn.n)* 72317

Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10141600261416

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

Maximum span length *(I - 48; nnnn)* 0024

Year built *(I - 27; YYYY)* 1930

Structure length *(I - 49; nnnnnn)* 000029

Average daily traffic, ADT *(I - 29; nnnnnn)* 000020

Deck Width *(I - 52; nn.n)* 160

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

Channel & Protection *(I - 61; n)* 6

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

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

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

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

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

Year Reconstructed *(I - 106)* 1992

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:

The structural inspection report of 6/21/94 indicates the structure is a steel stringer type bridge with a timber deck. Both abutments are "laid-up" stone, but the left abutment has newer concrete facing. The right abutment is reported as having some randomly distributed voids in the stone wall. The report notes that the upstream end apparently has shifted toward the stream slightly, but overall there are no areas of stones cracking or major displacement. The footing along the left abutment is reported as exposed but not undermined. The waterway makes a moderate bend into the crossing with a large portion of the flow directed into the upstream end of the left abutment. There is some large stone fill **(Continued, page 33)**

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)*: -

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*): U Frequency: -

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

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

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

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

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

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

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

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

Comments:

riprap placed in this area on the left abutment. The streambed is noted as consisting of stone and gravel with some randomly distributed boulders. Channel scour is noted as minor, while debris accumulation and bank erosion are noted as not evident.

USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **11.88** mi^2 Lake/pond/swamp area **0** mi^2

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

Bridge site elevation **820** ft Headwater elevation **1958** ft

Main channel length **5.42** mi

10% channel length elevation **870** ft 85% channel length elevation **1430** ft

Main channel slope *(S)* **121.8** ft / mi

Watershed Precipitation Data

Average site precipitation - in Average headwater precipitation - in

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

Average seasonal snowfall *(Sn)* - ft

Bridge Plan Data

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

Project Number -

Minimum channel bed elevation: -

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

Benchmark location description:
NO BENCHMARK INFORMATION

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? **Yes** *If no, type ctrl-n xs*

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

Comments: **The station and low chord to bed differences are from a sketch of the upstream face dated 6/22/94 that is attached to a bridge inspection report. The low chord coordinate is taken from the downstream face survey done for this report on 7/11/96.**

Station	0	1.42	1.43	5.43	12	20	24		-	-	-
Feature	LAB	-	-	-	-	-	RAB	-	-	-	-
Low cord elevation	498.2	498.2	498.2	498.2	498.2	498.2	498.2	-	-	-	-
Bed elevation	491.4	491.4	491.0	490.2	489.9	489.9	490.8	-	-	-	-
Low cord to bed length	6.8	6.8	7.2	8.0	8.3	8.3	7.4	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

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

Comments: -
-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

Station	-	-	-	-	-	-	-	-	-	-	-
Feature	-	-	-	-	-	-	-	-	-	-	-
Low cord elevation	-	-	-	-	-	-	-	-	-	-	-
Bed elevation	-	-	-	-	-	-	-	-	-	-	-
Low cord to bed length	-	-	-	-	-	-	-	-	-	-	-

APPENDIX E:

LEVEL I DATA FORM

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

Qa/Qc Check by: **RB** Date: **10/03/96**
Computerized by: **RB** Date: **10/03/96**
Reviewd by: **RB** Date: **06/11/97**

Structure Number **ROYATH00540026**

A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **M. WEBER** Date *(MM/DD/YY)* **04** / **13** / 19**95**

2. Highway District Number **04** Mile marker **0000**

County **027** Town **60850**

Waterway *(I - 6)* **BROAD BROOK** Road Name **-**

Route Number **TH054** Hydrologic Unit Code: **01080105**

3. Descriptive comments:

Located at the junction of TH54 and TH2.

B. Bridge Deck Observations

4. Surface cover... LBUS **4** RBUS **6** LBDS **4** RBDS **6** Overall **6**

*(2b us,ds,lb,rb: **1**- Urban; **2**- Suburban; **3**- Row crops; **4**- Pasture; **5**- Shrub- and brushland; **6**- Forest; **7**- Wetland)*

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

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

7. Bridge length **29** *(feet)* Span length **24** *(feet)* Bridge width **16** *(feet)*

Road approach to bridge:

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

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

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

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

*Bank protection types: **0**- none; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*

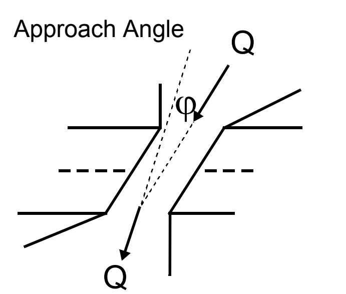
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

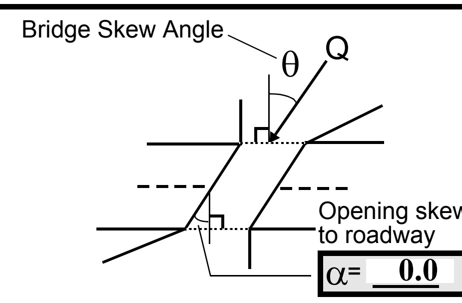
*Erosion: **0** - none; **1**- channel erosion; **2**- road wash; **3**- both; **4**- other*

*Erosion Severity: **0** - none; **1**- slight; **2**- moderate; **3**- severe*

Channel approach to bridge (BF):

15. Angle of approach: **10** 16. Bridge skew: **20**





17. Channel impact zone 1: Exist? **Y** *(Y or N)*

Where? **LB** *(LB, RB)* Severity **2**

Range? **3** feet **US** *(US, UB, DS)* to **50** feet **US**

Channel impact zone 2: Exist? **Y** *(Y or N)*

Where? **RB** *(LB, RB)* Severity **2**

Range? **10** feet **UB** *(US, UB, DS)* to **4** feet **DS**

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

18. Bridge Type: **1a**

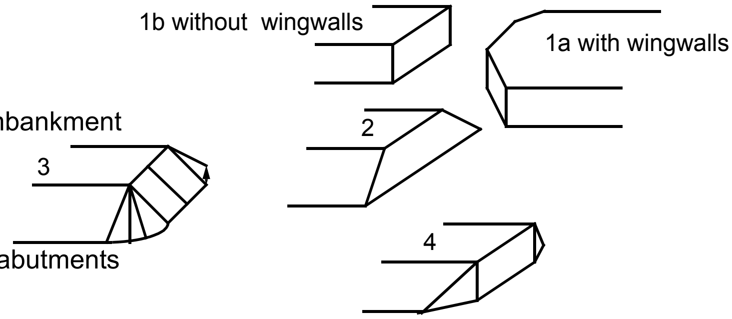
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls perpendicular 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. Values are from the VT AOT files. Measured bridge length is 26 ft, span length is 23 ft and the bridge width is 16 ft. Lengths were measured at the US bridge face. The structure length is from the left edge of the concrete of the left abutment to the right end of the wooden deck which overlaps the right abutment by 2 ft.
4. The left bank is pasture while the right bank is forested, however since the immediate banks are also forested on the left bank US and DS, the overall surface cover is forest.
11. The US left road approach protection is at the US end of the wingwall. Gravel road fill material is apparent at all road approaches.
18. On the right abutment, the wingwalls are parallel to the road.
The abutments were originally dry wall stonework. There is a newer concrete facing as well as concrete wingwalls on the left abutment.

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
23.5	**7.5**			**2.5**	**2**	**4**	**324**	**324**	**1**	**1**

23. Bank width	24. Channel width	25. Thalweg depth	29. Bed Material
55.0	**30.0**	**32.0**	**34**

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

31. Bank protection condition: LB **1** 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.):

26. The percent vegetation cover on the left bank US is minimal to 50 ft US, then the immediate bank becomes forested.
29. There are boulders and sand on the sides of the channel.
30. The left bank protection is placed type-2 native boulders extending from 10 ft US to 50 ft US, beginning at the middle of the US left wingwall.
The US left wingwall and part of the US left bank is impact zone 1.

33. Point/Side bar present? **Y** (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: **35** 35. Mid-bar width: **9**

36. Point bar extent: **10** feet **US** (US, UB) to **55** feet **US** (US, UB, DS) positioned **70** %LB to **100** %RB

37. Material: **324**

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

A small amount of grassy vegetation is on the bar.

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

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

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

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

NO CUT BANKS

45. Is channel scour present? **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) 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
23.0		1.0		2	7	7	-

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

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

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

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

345

63. The sides of the channel under the bridge are mostly sand.

Voids in the right abutment stonework mentioned in the historical form are not apparent. The US end of the right abutment is tipping very slightly towards the stream with a deviation from vertical less than 0.5 ft.

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? **2** ____ *(Y or N)* Ice Blockage Potential **N** ____ *(1- Low; 2- Moderate; 3- High)*

70. Debris and Ice Comments:

1

66. There are some branches and logs caught on the banks US and DS.

68. Since there are two impact zones near the bridge and the bank full width is constricted through the bridge, capture efficiency is moderate.

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	2	0	0.5	90.0
RABUT	1	20	90			2	1	23.5

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

0

2

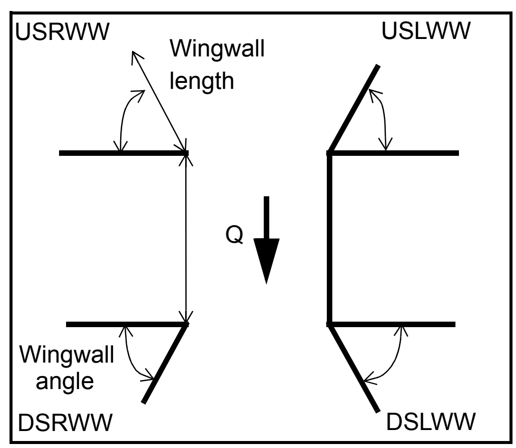
77. Both abutments were originally drywall. The left abutment now has a 1 ft thick concrete facing in front of the drywall.

74. Evidence of scour on the right abutment is at the DS end, this area is impact zone 2. Footing exposure on the left abutment is at the US end.

80. Wingwalls:

	Exist?	Material?	Scour Condition?	Scour depth?	Exposure depth?	81. Angle?	Length?
USLWW:						23.5	
USRWW:	Y		1		2	1.5	
DSLWW:	0		0.5		N	22.5	
DSRWW:	-		-		-	19.5	

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



82. Bank / Bridge Protection:

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

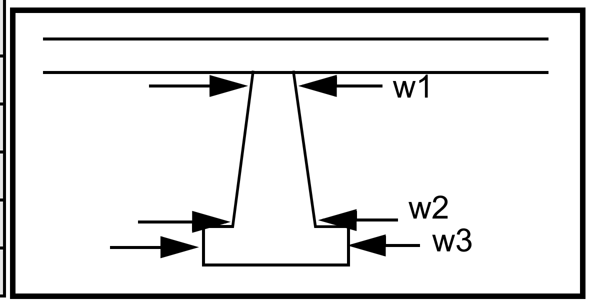
83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):

-
-
-
-
-
2
1
1
-
-
-

Piers:

84. Are there piers? **Th** *(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				**40.0**	**12.0**	**25.0**
Pier 2			**6.0**	**10.5**	**35.0**	**20.0**
Pier 3		-	-	**16.0**	-	-
Pier 4	-	-	-	-	-	-



Level 1 Pier Descr.	1	2	3	4	
86. Location (BF)	**ere are**	**end of**	**man**		*LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP*
87. Type	**a few**	**the**	**place**		***1**- Solid pier, **2**- column, **3**- bent*
88. Material	**sub-**	**right**	**d**		***1**- Wood; **2**- concrete; **3**- metal; **4**- stone*
89. Shape	**merg**	**abut**	**nativ**		***1**- Round; **2**- Square; **3**- Pointed*
90. Inclined?	**ed**	**ment**	**e**	**N**	*Y- yes; N- no*
91. Attack ∠ (BF)	**type-**	**.**	**boul-**	-	
92. Pushed	**2**	**Pro-**	**ders.**	-	*LB or RB*
93. Length (feet)	-	-	-	-	
94. # of piles	**boul-**	**tec-**		-	
95. Cross-members	**ders**	**tion**		-	***0**- none; **1**- laterals; **2**- diagonals; **3**- both*
96. Scour Condition	**at**	**in all**		-	***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed*
97. Scour depth	**the**	**cases**		-	
98. Exposure depth	**US**	**is**		-	

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

E. Downstream Channel Assessment

100.

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

Bank width (BF) - Channel width (Amb) - Thalweg depth (Amb) - 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):
-
-
-

NO PIERS

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

Point bar extent: ______ feet ____ *(US, UB, DS)* to ______ feet ____ *(US, UB, DS)* positioned **2** %LB to **4** %RB

Material: **234**

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

234
1
1
324

Is a cut-bank present? **0** *(Y or if N type ctrl-n cb)* Where? **0** *(LB or RB)* Mid-bank distance: **-**

Cut bank extent: **-** feet **A** *(US, UB, DS)* to **drai** feet **nag** *(US, UB, DS)*

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

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

channel for road wash from the right road approach enters at 20 ft DS on the right bank. The percent vegetation cover on the left bank DS is minimal between 15 ft DS and 25 ft DS. There are also some boulders in the channel and on the banks.

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

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

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

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

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

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

Confluence comments (eg. confluence name):

RE

F. Geomorphic Channel Assessment

107. Stage of reach evolution _____

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

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

Y
15
5
10
UB
25
DS
0
15
2

109. G. Plan View Sketch

- T

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: ROYATH00540026 Town: ROYALTON
Road Number: TH 54 County: WINDSOR
Stream: BROAD BROOK

Initials RLB Date: 5/2/97 Checked: RF

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	2200	3000	1550
Main Channel Area, ft2	247	265	202
Left overbank area, ft2	212	304	0
Right overbank area, ft2	158	183	109
Top width main channel, ft	32	32	32
Top width L overbank, ft	162	166	0
Top width R overbank, ft	42	45	33
D50 of channel, ft	0.218	0.218	0.218
D50 left overbank, ft	--	--	--
D50 right overbank, ft	--	--	--
y1, average depth, MC, ft	7.7	8.3	6.3
y1, average depth, LOB, ft	1.3	1.8	ERR
y1, average depth, ROB, ft	3.8	4.1	3.3
Total conveyance, approach	43198	55129	24350
Conveyance, main channel	25617	28784	18518
Conveyance, LOB	8374	15014	0
Conveyance, ROB	9206	11331	5832
Percent discrepancy, conveyance	0.0023	0.0000	0.0000
Qm, discharge, MC, cfs	1304.6	1566.4	1178.8
Ql, discharge, LOB, cfs	426.5	817.0	0.0
Qr, discharge, ROB, cfs	468.8	616.6	371.2
Vm, mean velocity MC, ft/s	5.3	5.9	5.8
Vl, mean velocity, LOB, ft/s	2.0	2.7	ERR
Vr, mean velocity, ROB, ft/s	3.0	3.4	3.4
Vc-m, crit. velocity, MC, ft/s	9.5	9.6	9.2
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 others, 1995, p. 32, eq. 20, 20a)
```

Bridge Section	Q100	Q500	Other Q
(Q) total discharge, cfs	2200	3000	1550
(Q) discharge thru bridge, cfs	1541	1701	1550
Main channel conveyance	14068	16084	10515
Total conveyance	14068	16084	10515
Q2, bridge MC discharge,cfs	1541	1701	1550
Main channel area, ft2	183	183	120
Main channel width (normal), ft	23.3	23.3	23.2
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	23.3	23.3	23.2
y_bridge (avg. depth at br.), ft	7.85	7.85	5.17
Dm, median (1.25*D50), ft	0.2725	0.2725	0.2725
y2, depth in contraction,ft	6.52	7.10	6.58
ys, scour depth (y2-ybridge), ft	-1.33	-0.76	1.41

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	2200	3000	1550
Q, thru bridge MC, cfs	1541	1701	1550
Vc, critical velocity, ft/s	9.48	9.60	9.17
Va, velocity MC approach, ft/s	5.28	5.91	5.84
Main channel width (normal), ft	23.3	23.3	23.2
Cum. width of piers in MC, ft	0.0	0.0	0.0
W, adjusted width, ft	23.3	23.3	23.2
qbr, unit discharge, ft2/s	66.1	73.0	66.8
Area of full opening, ft2	183.0	183.0	120.0
Hb, depth of full opening, ft	7.85	7.85	5.17
Fr, Froude number, bridge MC	0.53	0.59	1
Cf, Fr correction factor (<=1.0)	1.00	1.00	1.00
**Area at downstream face, ft2	148	164	N/A
**Hb, depth at downstream face, ft	6.35	7.04	N/A
**Fr, Froude number at DS face	0.73	0.69	ERR
**Cf, for downstream face (<=1.0)	1.00	1.00	N/A

Elevation of Low Steel, ft	498.24	498.24	498.24
Elevation of Bed, ft	490.39	490.39	493.07
Elevation of Approach, ft	499.81	500.37	498.41
Friction loss, approach, ft	0.11	0.14	0.17
Elevation of WS immediately US, ft	499.70	500.23	498.24
ya, depth immediately US, ft	9.31	9.84	5.17
Mean elevation of deck, ft	499.91	499.91	499.91
w, depth of overflow, ft (>=0)	0.00	0.32	0.00
Cc, vert contrac correction (<=1.0)	0.96	0.95	1.00
**Cc, for downstream face (<=1.0)	0.900441	0.923804	ERR
Ys, scour w/Chang equation, ft	-0.58	0.13	2.11
Ys, scour w/Umbrell equation, ft	-0.64	0.09	-0.83

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

**Ys, scour w/Chang equation, ft	1.39	1.20	N/A
**Ys, scour w/Umbrell equation, ft	0.86	0.90	N/A

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	6.52	7.10	6.58
WSEL at downstream face, ft	496.71	497.41	--
Depth at downstream face, ft	6.35	7.04	N/A
Ys, depth of scour (Laursen), ft	0.17	0.06	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	1541	1701	1550
Main channel area (DS), ft2	148	164	120
Main channel width (normal), ft	23.3	23.3	23.2
Cum. width of piers, ft	0.0	0.0	0.0
Adj. main channel width, ft	23.3	23.3	23.2
D90, ft	0.6098	0.6098	0.6098
D95, ft	0.7389	0.7389	0.7389
Dc, critical grain size, ft	0.4657	0.4432	0.7815
Pc, Decimal percent coarser than Dc	0.178	0.193	N/A
Depth to armoring, ft	6.45	5.56	N/A

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	2200	3000	1550	2200	3000	1550
a', abut.length blocking flow, ft	167.4	171.6	4.8	45.9	48.1	36.8
Ae, area of blocked flow ft2	92.36	120.47	18.56	179.17	205.8	126.43

Qe, discharge blocked abut.,cfs	--	--	54.71	571.15	--	459.46

(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)

Ve, (Qe/Ae), ft/s	1.90	2.65	2.95	3.19	3.61	3.63
ya, depth of f/p flow, ft	0.55	0.70	3.87	3.90	4.28	3.44

--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)

K1	0.82	0.82	0.82	1	1	1

--Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)

theta	90	90	90	90	90	90
K2	1.00	1.00	1.00	1.00	1.00	1.00
Fr, froude number f/p flow	0.285	0.334	0.264	0.284	0.307	0.346
ys, scour depth, ft	6.13	7.82	7.37	15.78	17.66	14.74

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)	167.4	171.6	4.8	45.9	48.1	36.8
y1 (depth f/p flow, ft)	0.55	0.70	3.87	3.90	4.28	3.44
a'/y1	303.41	244.43	1.24	11.76	11.24	10.71
Skew correction (p. 49, fig. 16)	1.00	1.00	1.00	1.00	1.00	1.00
Froude no. f/p flow	0.29	0.33	0.26	0.28	0.31	0.35
Ys w/ corr. factor K1/0.55:						
vertical	2.65	3.56	ERR	ERR	ERR	ERR
vertical w/ ww's	2.17	2.92	ERR	ERR	ERR	ERR
spill-through	1.46	1.96	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)

Downstream bridge face property	Q100	Q500	Other Q	Q100	Q500	Other Q
Fr, Froude Number	0.73	0.69	1	0.73	0.69	1
y, depth of flow in bridge, ft	6.35	7.04	5.17	6.35	7.04	5.17
Median Stone Diameter for riprap at:	left abutment			right abutment, ft		
Fr<=0.8 (vertical abut.)	2.09	2.07	ERR	2.09	2.07	ERR
Fr>0.8 (vertical abut.)	ERR	ERR	2.16	ERR	ERR	2.16
Fr<=0.8 (spillthrough abut.)	1.83	1.81	ERR	1.83	1.81	ERR
Fr>0.8 (spillthrough abut.)	ERR	ERR	1.91	ERR	ERR	1.91