LEVEL II SCOUR ANALYSIS FOR BRIDGE 2 (CRAFTH00590002) on TOWN HIGHWAY 59, crossing the BLACK RIVER, CRAFTSBURY, VERMONT

U.S. Geological Survey
Open-File Report 96-156

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION
LEVEL II SCOUR ANALYSIS FOR
BRIDGE 2 (CRAFTH00590002) on
TOWN HIGHWAY 59, crossing the
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CRAFTSBURY, VERMONT

By JOSEPH D. AYOTTE

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Pembroke, New Hampshire
1996
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<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inch (in.)</td>
<td>25.4</td>
<td>millimeter (mm)</td>
</tr>
<tr>
<td>foot (ft)</td>
<td>0.3048</td>
<td>meter (m)</td>
</tr>
<tr>
<td>mile (mi)</td>
<td>1.609</td>
<td>kilometer (km)</td>
</tr>
<tr>
<td><strong>Slope</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>foot per mile (ft/mi)</td>
<td>0.1894</td>
<td>meter per kilometer (m/km)</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cubic foot (ft³)</td>
<td>0.02832</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td><strong>Velocity and Flow</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>foot per second (ft/s)</td>
<td>0.3048</td>
<td>meter per second (m/s)</td>
</tr>
<tr>
<td>cubic foot per second (ft³/s)</td>
<td>0.02832</td>
<td>cubic meter per second (m³/s)</td>
</tr>
<tr>
<td>cubic foot per second per square mile</td>
<td>0.01093</td>
<td>cubic meter per second per square kilometer (m³/s)/km²</td>
</tr>
</tbody>
</table>

| OTHER ABBREVIATIONS      |            |                            |
| BF                       | bank full  |                            |
| cfs                      | cubic feet per second | MC                | main channel |
| D₅₀                      | 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  |
| ft²                      | 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 2
(CRAFTH00590002) ON TOWN HIGHWAY 59,
CROSSING THE BLACK RIVER, CRAFTSBURY,
VERMONT

By Joseph D. Ayotte

INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure CRAFTH00590002 on town highway 59 crossing the Black River, Craftsbury, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge, available from VTAOT files, was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the New England Upland physiographic province of north-central Vermont in the town of Craftsbury. The 35.5-mi$^2$ drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the banks have no woody vegetation coverage except for the upstream right bank, which has dense brush cover.

In the study area, the Black River is not incised, has a sinuous channel with a slope of approximately 0.0004 ft/ft, an average channel top width of 49 ft, and an average channel depth of 5 ft. The predominant channel bed material is sand ($D_{50}$ is 0.371 mm or 0.00122 ft). The geomorphic assessment at the time of the Level I and Level II site visit on June 8, 1995, indicated that the reach was laterally unstable.
The town highway 59 crossing of the Black River is a 32-ft-long, one-lane bridge consisting of one 29-foot clear-span timber and steel beam type structure with a timber deck (Vermont Agency of Transportation, written commun., August 3, 1994). The bridge is supported by log-crib abutments with no wingwalls. The channel is not skewed and the opening-skew-to-roadway is 5 degrees.

A scour hole 8 ft deeper than the mean thalweg depth was observed 50 ft downstream of the bridge during the Level I assessment. There is little to no protection at the site. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.
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.
CRAFTH00590002  Black River
Orleans  TH059  09

Bridge length  32  ft  Bridge width  15.1  ft  Max span length  29  ft
Alignment of bridge to road (on curve or straight)  Straight
Abutment type  No  Embankment type  Sloping
Stone fill on abutment?  No  Date of inspection  6/8/95

Abutments are log crib with stone and earth fill behind.

There is 1 ft of scour on the left abutment and 2 ft on the right abutment.

Is bridge skewed to flood flow according to Y ' survey?  Angle

There is a mild channel bend in the downstream reach. A scour hole has developed 50 ft downstream of the bridge.

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

<table>
<thead>
<tr>
<th>Date of inspection</th>
<th>Percent of channel blocked horizontally</th>
<th>Percent of channel blocked vertically</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/8/95</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Level I

Level II  Moderate.

Potential for debris

None--6/8/95.
Description of the Geomorphic Setting

General topography

The channel is located within a 1500 foot-wide, flat to slightly irregular flood plain with steep valley walls on both sides.

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

Date of inspection 6/8/95

DS left:  Wide flood plain to steep, irregular valley wall

DS right:  Moderate flood plain to steep valley wall

US left:  Wide flood plain to steep, irregular valley wall

US right:  Moderate flood plain to steep valley wall

Description of the Channel

Average top width  49 ft  Average depth  5 ft

Predominant bed material  Sand

Bank material  Sinuous, laterally unstable with alluvial channel boundaries and a wide flood plain.

Vegetative cover on channel banks near bridge:  Date of inspection 6/8/95

DS left:  Pasture land

DS right:  Pasture land

US left:  Trees and brush

US right:  N

Do banks appear stable?  Date of observation

The US RB and the DS LB are affected by significant cut banks; the DS cut bank has severe erosion with block failure of bank material. The US cut bank is noted as eroded. There is also significant channel widening immediately DS of the bridge.

The assessment of 6/8/95 noted no channel obstructions

Describe any obstructions in channel and date of observation.
Hydrology

Drainage area \( 35.5 \text{ mi}^2 \)

Percentage of drainage area in physiographic provinces: (approximate)

<table>
<thead>
<tr>
<th>Physiographic province</th>
<th>Percent of drainage area</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England Upland</td>
<td>100</td>
</tr>
</tbody>
</table>

Is drainage area considered rural or urban? Rural

Describe any significant urbanization:

There are farm buildings on the DSLB overbank area, several hundred feet from the bridge.

Is there a USGS gage on the stream of interest? Yes

Black River at Coventry

USGS gage description 0429600

USGS gage number 122

Gage drainage area \( Y \) \text{ mi}^2

Is there a lake/pond? Yes

There is a large swamp 1,500 ft US of the bridge site and a .04 square mile pond 1,000 ft DS from the bridge.

Calculated Discharges

\[
\begin{align*}
Q_{100} & = 2,250 \text{ ft}^3/\text{s} \\
Q_{500} & = 2,590 \text{ ft}^3/\text{s}
\end{align*}
\]

The 100- and 500-year discharges are based on a drainage area relationship with the above mentioned gage using an exponent of 0.5. The exponent was derived using data at the gage and data from Craftsbury bridge 23. From the VTAOT data base, the 100-year discharge is estimated to be 2100 cubic feet per second and the drainage area is 30.9 square miles. The exponent of 0.5 was determined to be the slope of the line of the plot of discharge versus drainage area for these two sites.
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 nail in a telephone pole on RBUS, 28 ft bankward from abutment and 30 ft US from roadway centerline (elev. 896.79 ft, arbitrary datum). RM2 is a nail in top of log cribbing at DS RABUT (elev. 897.51 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Section Reference Distance (SRD) in feet</th>
<th>2Cross-section development</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXIT2</td>
<td>-150</td>
<td>2</td>
<td>Shift of APPRO channel data and EXITX over-bank data</td>
</tr>
<tr>
<td>EXITX</td>
<td>-28</td>
<td>1</td>
<td>Exit section</td>
</tr>
<tr>
<td>FULLV</td>
<td>0</td>
<td>2</td>
<td>Downstream Full-valley section (Templated from EXITX)</td>
</tr>
<tr>
<td>BRIDG</td>
<td>0</td>
<td>1</td>
<td>Bridge section</td>
</tr>
<tr>
<td>RDWAY</td>
<td>10</td>
<td>1</td>
<td>Road Grade section</td>
</tr>
<tr>
<td>APPRO</td>
<td>46</td>
<td>1</td>
<td>Surveyed approach section</td>
</tr>
</tbody>
</table>

1 For location of cross-sections see plan-view plot 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). Results of the hydraulic model are presented in the Bridge Hydraulic Summary, Appendix B, and figure 7.

Channel roughness factors (Manning’s “n”) used in the hydraulic model were estimated using field inspections at each cross section following the general guidelines described by Arcement, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel “n” values for the reach were **0.035**, and overbank “n” values were **0.045**.

Normal depth at the exit section (EXIT2) 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 **0.0004 ft/ft** which was estimated from the topographic map (U.S. Geological Survey, 1986). EXIT2 was templated from APPRO channel data and EXITX overbank data; this was done to obtain a representative exit cross section--the EXITX section was surveyed through an over-widened and over-deepend channel section and would not be valid for use with the slope-conveyance method.

The modeled 100- and 500-year discharges overtop the right roadway embankment but not the bridge deck.
### Bridge Hydraulics Summary

**Average bridge embankment elevation** 899.3 ft
**Average low steel elevation** 897.3 ft

100-year discharge 2,250 ft³/s
Water-surface elevation in bridge opening 895.8 ft
Road overtopping? Y
Discharge over road 720 ft³/s
Area of flow in bridge opening 243 ft²
Average velocity in bridge opening 6.3 ft/s
Maximum WSPRO tube velocity at bridge 8.0 ft/s

Water-surface elevation at Approach section with bridge 897.0 ft
Water-surface elevation at Approach section without bridge 895.8 ft
Amount of backwater caused by bridge 1.2 ft

500-year discharge 2,590 ft³/s
Water-surface elevation in bridge opening 896.2 ft
Road overtopping? Y
Discharge over road 1,020 ft³/s
Area of flow in bridge opening 252 ft²
Average velocity in bridge opening 6.2 ft/s
Maximum WSPRO tube velocity at bridge 7.9 ft/s

Water-surface elevation at Approach section with bridge 897.4 ft
Water-surface elevation at Approach section without bridge 896.1 ft
Amount of backwater caused by bridge 1.3 ft

Incipient overtopping discharge 1,210 ft³/s
Water-surface elevation in bridge opening 894.3 ft
Area of flow in bridge opening 203 ft²
Average velocity in bridge opening 6.0 ft/s
Maximum WSPRO tube velocity at bridge 7.4 ft/s

Water-surface elevation at Approach section with bridge 895.4 ft
Water-surface elevation at Approach section without bridge 894.5 ft
Amount of backwater caused by bridge 0.9 ft
Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

For the 100-year and incipient road over-flow discharges, contraction scour was computed by use of the clear-water contraction scour equation (Richardson and others, 1993, p. 35, equation 18). Contraction scour was computed by use of the live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16) for the 500-year discharge. For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour. In this case, the 100-year model resulted in the worst case contraction scour with a scour depth of 17.5 ft.

Abutment scour for the left abutment at all modelled discharges was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). The Froehlich equation gives “excessively conservative estimates of scour depths” (Richardson and others, 1993, p. 48). Variables for the Froehlich equation include the Froude number of the flow approaching the embankments, the length of the embankment blocking flow, and the depth of flow approaching the embankment less any roadway overtopping.

Scour at the right abutment for all modelled discharges was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. Variables for the HIRE abutment scour equation are the same as the Froehlich abutment scour equation.

In figure 8, only the 100-year total scour depths are shown. This is because the computed 500-year scour depths were not as great as the 100-year scour depths.
### Scour Results

**Contraction scour:**

<table>
<thead>
<tr>
<th></th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>500-yr discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Scour depths in feet)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Main channel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live-bed scour</td>
<td>17.5</td>
<td>15.1</td>
<td>14.1</td>
</tr>
<tr>
<td>Clear-water scour</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Depth to armoring</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Left overbank</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Right overbank</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Local scour:**

<table>
<thead>
<tr>
<th><strong>Abutment scour</strong></th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>500-yr discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>7.3</td>
<td>7.7</td>
<td>5.6</td>
</tr>
<tr>
<td>Right abutment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pier scour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Rock Riprap Sizing

**Incipient overtopping discharge**

<table>
<thead>
<tr>
<th></th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>500-yr discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abutments:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left abutment</td>
<td>1.4</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Right abutment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Piers:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure CRAFTH00590002 on town highway 59, crossing the Black River, Craftsbury, Vermont.
Figure 8. Scour elevations for the 100-yr discharge at structure CRAFTH00590002 on town highway 59, crossing the Black River, Craftsbury, Vermont.
Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure CRAFTH00590002 on Town Highway 59, crossing the Black River, Craftsbury, Vermont.

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Station</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation (feet)</th>
<th>Bottom of footing elevation (feet)</th>
<th>Channel elevation at abutment/ pier (feet)</th>
<th>Contraction scour depth (feet)</th>
<th>Abutment scour depth (feet)</th>
<th>Pier scour depth (feet)</th>
<th>Depth of total scour (feet)</th>
<th>Elevation of scour (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>897.4</td>
<td>--</td>
<td>889.6</td>
<td>17.5</td>
<td>7.3</td>
<td>--</td>
<td>24.8</td>
<td>864.8</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td>26.4</td>
<td>--</td>
<td>897.2</td>
<td>--</td>
<td>888.0</td>
<td>17.5</td>
<td>15.1</td>
<td>--</td>
<td>32.6</td>
<td>855.4</td>
<td>--</td>
</tr>
</tbody>
</table>

100-yr. discharge is 2,250 cubic-feet per second

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 CRAFTH00590002 on Town Highway 59, crossing the Black River, Craftsbury, Vermont.

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Station</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation (feet)</th>
<th>Bottom of footing elevation (feet)</th>
<th>Channel elevation at abutment/ pier (feet)</th>
<th>Contraction scour depth (feet)</th>
<th>Abutment scour depth (feet)</th>
<th>Pier scour depth (feet)</th>
<th>Depth of total scour (feet)</th>
<th>Elevation of scour (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>897.4</td>
<td>--</td>
<td>889.6</td>
<td>15.1</td>
<td>7.7</td>
<td>--</td>
<td>22.8</td>
<td>866.8</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td>26.4</td>
<td>--</td>
<td>897.2</td>
<td>--</td>
<td>888.0</td>
<td>15.1</td>
<td>15.8</td>
<td>--</td>
<td>30.9</td>
<td>857.1</td>
<td>--</td>
</tr>
</tbody>
</table>

500-yr. discharge is 2,590 cubic-feet per second

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


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


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


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


APPENDIX A:

WSPRO INPUT FILE
U.S. Geological Survey WSPRO Input File craf002.wsp

Hydraulic analysis for structure crafth00590002  Date: 29-JAN-96

craftsbury, town highway 59, bridge 2...JDA...01/29/31

Q  2250,  2590,  1210
SK  0.0004, 0.0004, 0.0004,

J3  6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3

XS  EXIT2  -150  0.
*  NOTE: EXIT2 channel data are from APPRO main channel with correction
  of -0.896 ft (slope of 0.0004 over 224 ft) and from EXITX
  data with corr. of 0.0488 ft (.0004 over 122 ft)
  orig. EXITX channel data included over-wide channel and
  approx. 4 ft scour hole.

GR  -155.8, 900.23  -25.1, 894.29  0.0, 893.66  1.3, 887.64
GR   4.2, 886.32  14.3, 886.49  24.4, 886.69  28.2, 887.64
GR  33.0, 892.68  54.0, 893.04  71.7, 893.73  146.1, 892.47
GR  172.7, 891.79  186.9, 892.50  243.0, 891.78  273.8, 892.59
GR  330.9, 891.91
N  0.045  0.035  0.045
SA    0.0  33.0

XS  EXITX  -28  0.
GR  -155.7, 900.28  -25.1, 894.34  -22.5, 893.41  -10.3, 892.44
GR   0.0, 887.62   8.3, 882.22   15.1, 881.71   21.7, 882.20
GR  27.8, 882.91  34.5, 883.77  41.6, 887.65  44.9, 891.45
GR  54.0, 893.09  71.7, 893.78  146.1, 892.52  172.6, 891.84
GR  186.8, 892.55  242.9, 891.83  273.8, 892.64  330.9, 891.96
N  0.045  0.035  0.045
SA   -10.3  44.9

XS  FULLV  0  * * *  0.000
*

SRD  LSEL  XSSKEW
BR  BRIDG  0  897.3  5.0
GR   0.0, 897.42   0.7, 889.56   3.4, 887.65   7.4, 885.61
GR   14.5, 886.49  19.6, 884.56  25.5, 887.70  26.3, 887.95
GR   26.4, 897.19   0.0, 897.42
*

BRTYPE  BRWDTH
CD   1  19.9
N   0.035
*

SRD  EMBWID  IPAve
XR  RDWAY  10  15.1  2
GR  -343.4, 905.94   -104.2, 901.18   0.0, 899.38   27.6, 899.16
GR   63.3, 898.60   180.3, 895.37  248.6, 895.52  347.8, 897.53
*

AS  APPRO  46  0.
GR  -190.2, 902.81  -62.1, 897.13  -23.4, 893.88   0.0, 893.74
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| HP 1 BRIDG | 895.83 | 1 | 895.83 |
| HP 2 BRIDG | 895.83 | * | 1530 |
| HP 2 RDWAY | 896.79 | * | 720 |
| HP 1 APPRO | 897.04 | 1 | 897.04 |
| HP 2 APPRO | 897.04 | * | 2250 |
| *           |          |          |          |          |
| HP 1 BRIDG | 896.18 | 1 | 896.18 |
| HP 2 BRIDG | 896.18 | * | 1569 |
| HP 2 RDWAY | 897.05 | * | 1021 |
| HP 1 APPRO | 897.36 | 1 | 897.36 |
| HP 2 APPRO | 897.36 | * | 2590 |
| *           |          |          |          |          |
| HP 1 BRIDG | 894.28 | 1 | 894.28 |
| HP 2 BRIDG | 894.28 | * | 1210 |
| HP 1 APPRO | 895.41 | 1 | 895.41 |
| HP 2 APPRO | 895.41 | * | 1210 |
| *           |          |          |          |          |
| EX          |          |          |          |          |
| ER          |          |          |          |          |
APPENDIX B:

WSPRO OUTPUT FILE
CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

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<th>AREA</th>
<th>K</th>
<th>TOPW</th>
<th>WETP</th>
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HP 2 BRIDG 895.83 ** 1530

VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.

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X STA. | A(I) | V(I) |
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HP 2 RDWAY 896.79 ** 720

VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = RDWAY;  SRD =  10.

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X STA. | A(I) | V(I) |
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HP 1 APPRO 897.04 1 897.04

CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =  46.

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HP 2 APPRO 897.04 ** 2250

VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =  46.

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<th>K</th>
<th>Q</th>
<th>VEL</th>
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X STA. | A(I) | V(I) |
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<td>127.2</td>
<td>97.7</td>
<td>-9.7</td>
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V(I)             1.15       1.16       1.20       1.17       1.16
X STA.       208.2      225.0      243.1      260.9      280.7      316.1
A(I)             97.3      102.9       99.0      108.2      131.9
V(I)             1.16       1.09       1.14       1.04       0.85
1
HP 1 BRIDG 896.18 1 896.18
CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
MSL  SA#     AREA        X TOPW   WETP  ALPH    LEW    REW     QCR
986.18 252.4 35085. 26. 43. 1.00 0. 26. 4443.1
HP 2 BRIDG 896.18 * * 1569
VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =       0.
MSL  LEW    REW    AREA        K    Q    VEL
896.18 0.1 252.4 35085. 1569. 6.22
X STA.       0.1       3.6        5.3        6.6        7.7        8.7
A(I)             24.3       15.0       12.6       11.6       10.6
V(I)             3.23       5.22       6.21       6.74       7.39
X STA.       8.7       9.7       10.7       11.7       12.7       13.8
A(I)             10.5       10.1       10.0       10.1       10.0
V(I)             7.44       7.80       7.85       7.76       7.86
X STA.       13.8      14.8      15.8      16.8      17.8      18.7
A(I)             10.0       10.3       10.1       10.4       10.3
V(I)             7.82       7.61       7.78       7.53       7.65
HP 1 APPRO 897.36 1 897.36
CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =      46.
MSL  SA#     AREA        X TOPW   WETP  ALPH    LEW    REW     QCR
987.36 155.9 8983.  67.  67. 1341.  1
HP 2 APPRO 897.36 * * 2590
1
1
1
1
1
WSPRO OUTPUT FILE (continued)

X STA.       25.2  38.9  64.0  87.6  109.1  128.2
A(I)           91.1 119.8 117.8 114.1 108.7
V(I)            1.42  1.08  1.10  1.14  1.19

X STA.       128.2 144.9 160.7 176.5 192.7 209.1
A(I)          102.2 100.9 101.4 101.5 101.9
V(I)            1.27  1.28  1.28  1.28  1.27

X STA.       209.1 226.4 244.1 261.8 281.6 316.1
A(I)          105.3 105.9 104.6 114.4 138.0
V(I)            1.23  1.22  1.24  1.13  0.94

1
*
HP 1 BRIDG 894.28 1 894.28

1

CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = BRIDG;  SRD =  0.

WSEL  SA#  AREA   K  TOPW  WETP  ALPH  LEW  REW  QCR
1     203.  25932.  26.  39.  1.00  0.00  26.3   3212.

HP 2 BRIDG 894.28 1 1210

1

VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =  0.

WSEL   LEW   REW   AREA   K    Q    VEL
894.28  0.3   26.4  202.7  25932.  1210.  5.97

X STA.     0.3   3.8   5.4   6.7   7.8   8.8
A(I)        18.9  11.7  10.0   9.4   8.8
V(I)         3.19  5.16  6.02  6.44  6.88

X STA.     1210

1

CROSS-SECTION PROPERTIES:  ISEQ =  6;  SECID = APPRO;  SRD =  46.

WSEL  SA#   AREA   K  TOPW  WETP  ALPH  LEW  REW  QCR
1     51.   1956.  42.  42.                        324.
2     265.  39430.  33.  40.                       4253.
3   1015.  79709.  277.  278.                      11015.

HP 1 APPRO 895.41 1 895.41

1

VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =  46.

WSEL   LEW   REW   AREA   K    Q    VEL
895.41 -41.6  310.4  1330.9  121094.  1210.  0.91

X STA.   -41.6   5.2   9.5  13.5  17.5  21.6
A(I)       90.9  38.5  35.8  35.2  35.3
V(I)        0.67  1.57  1.69  1.72  1.71

X STA.   139.3  155.4  170.5  186.3  203.0
A(I)       73.3  70.7  67.4  69.3  71.3
V(I)        0.82  0.86  0.90  0.87  0.85

X STA.   203.0  220.0  237.8  256.3  276.4  310.4
A(I)       71.2  72.7  73.6  77.4  93.8
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<th>LEW</th>
<th>AREA</th>
<th>VHD</th>
<th>HF</th>
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---135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.

"EXITX" KRATIO = 1.62

---140 AT SECID "EXITX": END OF CROSS SECTION EXTENDED VERTICALLY.

WSEL,YLT,YRT = 895.76 900.28 891.96

EXITX:XS 122. -56. 1570. 0.06 0.03 895.82 ***** 2250. 895.76
-28. 122. 331. 182319. 1.88 0.00 0.00 0.17 1.43

---140 AT SECID "FULLV": END OF CROSS SECTION EXTENDED VERTICALLY.

WSEL,YLT,YRT = 895.77 900.28 891.96

FULLV:FX 28. -56. 1573. 0.06 0.00 895.83 ***** 2250. 895.77
0. 28. 331. 182668. 1.88 0.00 0.00 0.17 1.43

<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

APPRO:AS 46. -46. 1464. 0.05 0.01 895.83 ***** 2250. 895.78
46. 46. 312. 138866. 1.33 0.00 0.00 0.15 1.54

<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

---215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.

WS1,WSDF,WS3,RGMIN = 897.90 0.00 895.32 895.37

---260 ATTEMPTING FLOW CLASS 4 SOLUTION.

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

XSID:CODE SRD FLEN HF VHD EGL ERR Q WSEL
RDWAY:RG 10. 31. 0.00 0.03 897.08 0.00 720. 896.79

Q WLEN LEW REW DMAX DAVG VMAX VAVG HAVG CAVG
LT: 0. ***** ***** ***** ***** ***** ***** *****
RT: 720. 183. 129. 311. 1.4 0.9 4.9 4.3 1.2 3.0

---140 AT SECID "APPRO": END OF CROSS SECTION EXTENDED VERTICALLY.

WSEL,YLT,YRT = 897.04 902.8 896.6

XSID:CODE SRD FLEN HF VHD EGL ERR Q WSEL
APPRO:AS 26. -61. 1926. 0.03 0.07 897.07 892.82 2250. 897.04
46. 57. 316. 207286. 1.24 0.04 0.00 0.10 1.17

M(G) M(K) KQ XLKQ XRKQ OTEL
0.927 0.929 14786. 110. 136. *******

<<<END OF BRIDGE COMPUTATIONS>>>>

FIRST USER DEFINED TABLE.

XSID:CODE SRD LEW REM Q K AREA VEL WSEL
EXIT2:XS -150. -56. 331. 2250. 112483. 1292. 1.74 895.72
EXITX:XS -28. -56. 331. 2250. 182319. 1570. 1.43 895.76
FULLV:FX 0. -56. 331. 2250. 182668. 1573. 1.43 895.77
BRIDG:BR 0. 0. 26. 1530. 33355. 243. 6.30 895.83
RDWAY:RG 10. ***** 0. 720. 0.****** 2.00 896.79
APPRO:AS      46.   -61.   316.   2250.  207286.    1926.    1.17  897.04

XSID:CODE XLKQ XRKQ   KQ
APPRO:AS    110.   136.   14786.

SECOND USER DEFINED TABLE.

XSID:CODE  CRWS     FR#    YMIN    YMAX    HF    HO  VHD      EGL    WSEL
EXIT2:XS    893.41    0.21  886.32  900.23********  0.07  895.79  895.72
EXITX:XS   -50.10  1078.32  900.28  0.03  0.00  0.06  895.82  895.75
FULLV:FV    ********  886.32  900.42  1.10  1.13  896.96  895.83
RDWAY:KG    **********  895.37  905.94  0.00**  0.03  897.08  896.79
APPRO:AS    893.82    0.10  886.40  902.81  0.07  0.04  0.03  897.07  897.04

XSID:CODE  SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL
EXIT2:XS   ********  -64.    1430.  0.08 *****  896.14  893.62   2590.  896.07
EXITX:XS   ********  331.  129443.  1.52 ***** *******    0.21    1.81

---135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
"EXITX"   KRATIO =  1.56

---140 AT SECID "EXITX":  END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL,YLT,YRT =   896.11  900.28  891.96

---140 AT SECID "FULLV":  END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL,YLT,YRT =   896.12  900.28  891.96

FULLV:FV   28.    0.00  896.18  2590.  896.12
0.    28.    0.00  896.18  2590.  896.12

---215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
WS1,WSSD,WS3,RGMIN =   898.67       0.00     895.60     895.37

---260 ATTEMPTING FLOW CLASS 4 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   28.    0.    252.  1.10  0.04  897.29  892.99   2590.  897.36
0.    28.    26.    35096.  1.84  1.07  0.00  0.48  6.22

---140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL,YLT,YRT =   897.36  902.8  896.6

---140 AT SECID "APPRO":  END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL,YLT,YRT =   897.36  902.8  896.6

<<<<<END OF BRIDGE COMPUTATIONS>>>>>
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--- 135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.

"EXITX" KRATIO = 2.00

--- 140 AT SECID "EXITX": END OF CROSS SECTION EXTENDED VERTICALLY.

WSEL, YLT, YRT = 894.46 900.28 891.96

--- 140 AT SECID "FULLV": END OF CROSS SECTION EXTENDED VERTICALLY.

WSEL, YLT, YRT = 894.47 900.28 891.96

--- 215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.

WS1, WSSD, WS3, RGMIN = 895.41 0.00 894.28 895.37

--- 260 ATTEMPTING FLOW CLASS 4 SOLUTION.

WSEL, YLT, YRT = 894.46 900.28 891.96

TYPE PPCD FLOW

C    P/A    LSEL   BLEN   XLAB   XRAB
1.  4.    0.306  22151.  1.50  0.00  0.15  1.20

--- 260 ATTEMPTING FLOW CLASS 4 SOLUTION.

WSEL, YLT, YRT = 894.46 900.28 891.96

TYPE PPCD FLOW

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1.  4.    0.742  897.30 0.00  0.00  0.00  2.5
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END OF FILE ON PRIMARY INPUT UNIT 55
APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION
Appendix C. Bed material particle-size distribution for fine-bed bulk sample at the approach cross-section for structure CRAFTH00590002, in Craftsbury, Vermont.
APPENDIX D:

HISTORICAL DATA FORM