LEVEL II SCOUR ANALYSIS FOR BRIDGE 29 (READTH00510029) on TOWN HIGHWAY 51, crossing MILL BROOK, READING, VERMONT

Open-File Report 98-402

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

U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world
LEVEL II SCOUR ANALYSIS FOR BRIDGE 29 (READTH00510029) on TOWN HIGHWAY 51, crossing MILL BROOK, READING, VERMONT

By RONDA L. BURNS and MATTHEW A. WEBER

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Pembroke, New Hampshire
1998
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## Conversion Factors, Abbreviations, and Vertical Datum

<table>
<thead>
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<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>
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<tr>
<td><strong>Slope</strong></td>
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<td></td>
</tr>
<tr>
<td>foot per mile (ft/mi)</td>
<td>0.1894</td>
<td>meter per kilometer (m/km)</td>
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<tr>
<td><strong>Area</strong></td>
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</tr>
<tr>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
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<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>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>
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</table>

## Other Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>bank full</td>
<td>LWW</td>
<td>left wingwall</td>
</tr>
<tr>
<td>cf/s</td>
<td>cubic feet per second</td>
<td>Max</td>
<td>maximum</td>
</tr>
<tr>
<td>D₅₀</td>
<td>median diameter of bed material</td>
<td>MC</td>
<td>main channel</td>
</tr>
<tr>
<td>DS</td>
<td>downstream</td>
<td>RAB</td>
<td>right abutment</td>
</tr>
<tr>
<td>elev.</td>
<td>elevation</td>
<td>RABUT</td>
<td>face of right abutment</td>
</tr>
<tr>
<td>f/p</td>
<td>flood plain</td>
<td>RB</td>
<td>right bank</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
<td>ROB</td>
<td>right overbank</td>
</tr>
<tr>
<td>ft/ft</td>
<td>feet per foot</td>
<td>RWW</td>
<td>right wingwall</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
<td>TH</td>
<td>town highway</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
<td>UB</td>
<td>under bridge</td>
</tr>
<tr>
<td>JCT</td>
<td>junction</td>
<td>US</td>
<td>upstream</td>
</tr>
<tr>
<td>LAB</td>
<td>left abutment</td>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>LABUT</td>
<td>face of left abutment</td>
<td>VTAOT</td>
<td>Vermont Agency of Transportation</td>
</tr>
<tr>
<td>LB</td>
<td>left bank</td>
<td>WSPRO</td>
<td>water-surface profile model</td>
</tr>
<tr>
<td>LOB</td>
<td>left overbank</td>
<td>yr</td>
<td>year</td>
</tr>
</tbody>
</table>

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 29 
(READTH00510029) ON TOWN HIGHWAY 51, 
CROSSING MILL BROOK, 
READING, 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 READTH00510029 on Town Highway 51 crossing Mill Brook, Reading, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (FHWA, 1993). Results of a Level I scour investigation also are included in appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the culvert, 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 eastern Vermont. The 9.56-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture upstream of the culvert and on the left bank downstream, while the immediate banks are tree or shrub covered. The downstream right bank is forested.

In the study area, Mill Brook has a sinuous channel with a slope of approximately 0.008 ft/ft, an average channel top width of 45 ft and an average bank height of 3 ft. The channel bed material is mainly gravel with a median grain size (D_{50}) of 77.5 mm (0.254 ft). The geomorphic assessment at the time of the Level I site visit on March 29, 1995 and Level II site visit on July 29, 1996, indicated that the reach was laterally unstable. There are cut-banks upstream and downstream of the culvert and heavy fluvial erosion on the downstream banks.

The Town Highway 51 crossing of Mill Brook is a 27-ft-long, one-lane structure consisting of a 25-foot span, steel, multi-plate arch culvert (Vermont Agency of Transportation, written communication, March 8, 1995). The opening length of the structure parallel to the culvert face is 24.7 ft. The channel is skewed approximately 30 degrees to the opening while the computed opening-skew-to-roadway is 20 degrees.
A scour hole 3.0 ft deeper than the mean thalweg depth was observed along the upstream end of the left side of the culvert during the Level I assessment. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) at the upstream and downstream corners of the culvert along the embankment. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

Scour depths and recommended rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and Davis, 1995) for the 100- and 500-year discharges. In addition, the incipient roadway-overtopping discharge was determined and analyzed as another potential worst-case scour scenario. Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 0.5 ft. The worst-case contraction scour occurred at the incipient roadway-overtopping discharge, which was less than the 100-year discharge. Left abutment scour ranged from 5.3 to 11.3 ft. Right abutment scour ranged from 12.9 to 19.2 ft. The worst-case abutment scour occurred at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the culvert is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and Davis, 1995, p. 46). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.
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**

<table>
<thead>
<tr>
<th>Structure Number</th>
<th>READTH00510029</th>
<th>Stream</th>
<th>Mill Brook</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Windsor</td>
<td>Road</td>
<td>TH 51</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>District</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**Description of Bridge**

- **Bridge length**: 27 ft
- **Bridge width**: -- ft
- **Max span length**: 25 ft
- **Alignment of bridge to road (on curve or straight)**: Straight
- **Abutment type**: N/A
- **Embankment type**: Sloping
- **Stone fill on abutment?**: No
- **Date of inspection**: 3/29/95
- **Description of stone fill**: Type-2, at the upstream and downstream ends of the culvert on the embankment.
- **Debris accumulation on bridge at time of Level I or Level II site visit:**
  - **Date of inspection**: Level I - 3/29/95, Level II - 7/29/96
  - **Percent of channel blocked horizontally**: 0
  - **Percent of channel blocked vertically**: 0
- **Is bridge skewed to flood flow according to Level I survey?**: Yes
- **Is bridge located on a bend in channel?**: There is a moderate channel bend in the upstream reach. The scour hole has developed in the location where the flow impacts the upstream left side of the culvert.
- **Debris accumulation on bridge at time of Level I or Level II site visit:**
  - **Date of inspection**: Level I - 3/29/95, Level II - 7/29/96
  - **Percent of channel blocked horizontally**: 0
  - **Percent of channel blocked vertically**: 0
- **Potential for debris**: Moderate. Some debris was caught at the upstream face of the culvert on 3/29/95.
- **Describe any features near or at the bridge that may affect flow (include observation date)**: None as of 7/29/96.
Description of the Geomorphic Setting

General topography
The channel is located in a high relief valley with a wide flood plain on the left.

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

Date of inspection 3/29/95

DS left: Steep channel bank to a wide flood plain and the VT 106 roadway
DS right: Steep valley wall
US left: Steep channel bank to a wide flood plain and the VT 106 roadway
US right: Moderately sloping channel bank to a steep valley wall

Description of the Channel

Average top width 45 ft
Average depth 3 ft
Predominant bed material Sand/Gravel
Predominant bed material Sinuous with semi-alluvial channel boundaries and irregular point and lateral bars.

Bank material Silt/Sand/Gravel

Vegetative cover on channel banks near bridge: Trees and brush with grass on the flood plain

DS left: Trees and brush
DS right: Shrubs and brush with grass on the flood plain
US left: Shrubs and brush with grass on the overbank
US right: No

Do banks appear stable? Cut-banks were observed upstream and downstream of the culvert on 3/29/95. There is heavy fluvial erosion with mass wasting on the banks downstream of the culvert.

Several trees were across the channel in the downstream reach as of 3/29/95 and 7/29/96.

Describe any obstructions in channel and date of observation.
### Hydrology

**Drainage area**  
9.56 mi²

**Percentage of drainage area in physiographic provinces: (approximate)**

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

**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**  
No

**Is there a lake/pond that will significantly affect hydrology/hydraulics?**

**Calculated Discharges**

<table>
<thead>
<tr>
<th>Q100</th>
<th>ft³/s</th>
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</thead>
<tbody>
<tr>
<td>2,500</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q500</th>
<th>ft³/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,580</td>
<td></td>
</tr>
</tbody>
</table>

The 100- and 500-year discharges are based on flood frequency estimates available from the VTAOT database (written communication, May 1995) for bridge number 25 in Reading. Bridge number 25 crosses Mill Brook upstream of this site and has a drainage area of 9.54 square miles. These values were within a range defined by flood frequency curves derived from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887). Each curve was extended graphically to the 500-year event.
Description of the Water-Surface Profile Model (WSPRO) Analysis

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

USGS survey

Datum tie between USGS survey and VTAOT plans

Subtract 8.8 ft from the USGS arbitrary survey datum to obtain the VTAOT plans’ datum.

Description of reference marks used to determine USGS datum.

RM1 is a nail in telephone pole #170-1 on the downstream left bank, 50 ft from the culvert (elev. 494.65 ft, arbitrary survey datum). RM2 is a bolt on top of the culvert at the downstream end near the center (elev. 492.78 ft, arbitrary survey datum). RM3 is a bolt on top of the culvert at the upstream end to the left of center (elev. 493.27 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>1Cross-section</th>
<th>Section Reference Distance (SRD) in feet</th>
<th>2Cross-section development</th>
<th>Comments</th>
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<tbody>
<tr>
<td>EXITX</td>
<td>-22</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>Culvert section</td>
</tr>
<tr>
<td>RDWAY</td>
<td>21</td>
<td>1</td>
<td>Road Grade section</td>
</tr>
<tr>
<td>APPRO</td>
<td>67</td>
<td>2</td>
<td>Modelled Approach section (Templated from APTEM)</td>
</tr>
<tr>
<td>APTEM</td>
<td>80</td>
<td>1</td>
<td>Approach section as surveyed (Used as a template)</td>
</tr>
</tbody>
</table>

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 0.060, and overbank “n” values ranged from 0.041 to 0.050.

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 0.0083 ft/ft, which was estimated from thalweg points surveyed downstream of the culvert.

The surveyed approach section (APTEM) was moved along the approach channel slope (0.0041 ft/ft) to establish the modelled approach section (APPRO), one culvert length upstream of the upstream face as recommended by Shearman and others (1986). This location provides a consistent method for determining scour variables.

For this site, the culvert geometry was modified to create an “equivalent” bridge opening having the same area as the culvert. Bridge routines were then used to approximate the culvert flow with road overflow.
## Bridge Hydraulics Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average bridge embankment elevation</td>
<td>500.9 ft</td>
</tr>
<tr>
<td>Average low steel elevation</td>
<td>493.3 ft</td>
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<tr>
<td>100-year discharge</td>
<td>2,500 ft³/s</td>
</tr>
<tr>
<td>Water-surface elevation in bridge opening</td>
<td>493.3 ft</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>Yes</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>1,110 ft³/s</td>
</tr>
<tr>
<td>Area of flow in bridge opening</td>
<td>166 ft²</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>8.3 ft/s</td>
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<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>10.9 ft/s</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>495.0 ft</td>
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<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>491.2 ft</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>3.8 ft</td>
</tr>
<tr>
<td>500-year discharge</td>
<td>3,580 ft³/s</td>
</tr>
<tr>
<td>Water-surface elevation in bridge opening</td>
<td>493.3 ft</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>Yes</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>2,050 ft³/s</td>
</tr>
<tr>
<td>Area of flow in bridge opening</td>
<td>166 ft²</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>9.2 ft/s</td>
</tr>
<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>12.1 ft/s</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>495.7 ft</td>
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<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>492.1 ft</td>
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<tr>
<td>Amount of backwater caused by bridge</td>
<td>3.6 ft</td>
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<tr>
<td>Incipient overtopping discharge</td>
<td>1,000 ft³/s</td>
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<tr>
<td>Water-surface elevation in bridge opening</td>
<td>488.2 ft</td>
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<td>Area of flow in bridge opening</td>
<td>88 ft²</td>
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<tr>
<td>Average velocity in bridge opening</td>
<td>11.4 ft/s</td>
</tr>
<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>14.9 ft/s</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>493.2 ft</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>490.1 ft</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>3.1 ft</td>
</tr>
</tbody>
</table>
Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

Contraction scour for the incipient roadway-overtopping discharge was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). At this site, the 100- 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 Davis, 1995, p. 145-146).

For comparison, contraction scour for the discharges resulting in orifice flow also was computed by use of the Laursen clear-water contraction scour equation and the Umbrell pressure-flow equation (Richardson and Davis, 1995, p. 144). Results from these computations are presented in appendix F. Furthermore, for those discharges which resulted in unsubmerged orifice flow, contraction scour was computed by substituting estimates for the depth of flow at the culvert outlet in the contraction scour equations. Results with respect to these substitutions are provided in appendix F.

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

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

<table>
<thead>
<tr>
<th>Contraction scour:</th>
<th>100-year discharge</th>
<th>500-year discharge</th>
<th>Incipient overtopping discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Scour depths in feet)</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>
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<td>--</td>
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<tr>
<td>Clear-water scour</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
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<tr>
<td>Depth to armoring</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<tr>
<td>Left overbank</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Right overbank</td>
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<td></td>
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<tr>
<td><strong>Local scour:</strong></td>
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<tr>
<td>Abutment scour</td>
<td>9.5</td>
<td>11.3</td>
<td>5.3</td>
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<tr>
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<td>17.1</td>
<td>19.2</td>
<td>12.9</td>
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<tr>
<td>Right abutment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier scour</td>
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<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 1</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 2</td>
<td>--</td>
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<td>Pier 3</td>
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## Riprap Sizing

<table>
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<tr>
<th>Abutments:</th>
<th>100-year discharge</th>
<th>500-year discharge(D$_{50}$ in feet)</th>
<th>Incipient overtopping discharge</th>
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<td>2.2</td>
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<td>--</td>
<td>--</td>
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<td>Piers:</td>
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</tr>
<tr>
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<td>--</td>
<td>--</td>
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<tr>
<td>Pier 2</td>
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Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont.
Figure 8. Scour elevations for the 100- and 500-year discharges at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont.
Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont. [VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station¹</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation² (feet)</th>
<th>Bottom of footing/pile 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 scour² (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>493.3</td>
<td>480.3</td>
<td>484.1</td>
<td>0.0</td>
<td>9.5</td>
<td>--</td>
<td>9.5</td>
<td>474.6</td>
<td>-5.7</td>
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<tr>
<td>Right abutment</td>
<td>24.7</td>
<td>--</td>
<td>493.3</td>
<td>480.3</td>
<td>484.9</td>
<td>0.0</td>
<td>17.1</td>
<td>--</td>
<td>17.1</td>
<td>467.8</td>
<td>-12.5</td>
</tr>
</tbody>
</table>

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

100-year discharge is 2,500 cubic-feet per second

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure READTH00510029 on Town Highway 51, crossing Mill Brook, Reading, Vermont. [VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station¹</th>
<th>VTAOT minimum low-chord elevation (feet)</th>
<th>Surveyed minimum low-chord elevation² (feet)</th>
<th>Bottom of footing/pile 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 scour² (feet)</th>
<th>Remaining footing/pile depth (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left abutment</td>
<td>0.0</td>
<td>--</td>
<td>493.3</td>
<td>480.3</td>
<td>484.1</td>
<td>0.0</td>
<td>11.3</td>
<td>--</td>
<td>11.3</td>
<td>472.8</td>
<td>-7.5</td>
</tr>
<tr>
<td>Right abutment</td>
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<td>--</td>
<td>493.3</td>
<td>480.3</td>
<td>484.9</td>
<td>0.0</td>
<td>19.2</td>
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<td>19.2</td>
<td>465.7</td>
<td>-14.6</td>
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</tbody>
</table>

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

500-year discharge is 3,580 cubic-feet per second
SELECTED REFERENCES


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
T1        U.S. Geological Survey WSPRO Input File read029.wsp
T2        Hydraulic analysis for structure READTH00510029   Date: 26-FEB-98
T3        TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB
  *  
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3  
  *  
Q          2500.0   3580.0   1000.0  
SK         0.0083   0.0083   0.0083  
  *  
XS EXITX   -22   0.  
GR         -290.9, 510.00   -290.9, 491.87   -282.3, 490.20   -116.1, 490.04  
GR         -97.1, 488.14   0.0, 489.68   4.2, 486.07   7.5, 484.86  
GR          11.0, 484.45   14.8, 484.17   18.2, 484.00   27.2, 484.44  
GR          28.7, 484.84   38.1, 485.62   70.3, 512.27   159.3, 517.55  
  *  
N          0.041   0.057  
SA         0.0  
  *  
XS FULLV   0   *   *   *   0.0045  
  *  
  *  
SRD   LSEL   SKEW  
BR BRIDG   0   493.30  20.0  
GR         0.0, 485.29   0.0, 484.13   8.4, 484.10  
GR        16.6, 483.64   19.5, 484.51   24.7, 484.90   24.7, 485.31  
GR        18.5, 493.30   6.2, 493.30  0.0, 485.29  
  *  
BRTYPE  BRWDTH  EMBSS  EMBELV  
CD         2   42.0  1.9  500.91  
N          0.040  
  *  
SRD   EMBWID   IPAVE  
XR RDWAY   21   17.5  2  
GR        -498.2, 495.30   -304.4, 492.80  
GR        -304.0, 510.00   -304.0, 494.08   -234.0, 493.15   -115.0, 493.69  
GR        -53.5, 496.07   0.0, 499.66   28.1, 502.15   91.3, 509.28  
GR        157.5, 518.13   275.7, 542.61  
  *  
XT APTEM   80   0.  
GR        -304.0, 510.00  
GR        -304.0, 494.08   -108.2, 491.52   -33.3, 490.41   0.0, 491.07  
GR         2.4, 487.73   8.4, 485.08   10.9, 484.51   17.3, 484.42  
GR         28.1, 485.20   35.7, 486.95   53.1, 488.76   84.2, 493.62  
GR         112.1, 504.54   148.1, 510.74  
  *  
AS APPRO   67   *   *   0.0041  
GT  
N          0.045   0.060  0.050  
SA         0.0   35.7  
  *  
HP 1 BRIDG 493.30 1 493.30  
HP 2 BRIDG 493.30   *   * 1370  
HP 1 BRIDG 490.92 1 490.92  
HP 2 RDWAY 494.71   *   * 1105  
HP 1 APPRO 495.00 1 495.00  
HP 2 APPRO 495.00   *   * 2500  
  *  
HP 1 BRIDG 493.30 1 493.30  
HP 2 BRIDG 493.30   *   * 1524  
HP 1 BRIDG 491.37 1 491.37  
HP 2 RDWAY 495.29   *   * 2047  
HP 1 APPRO 495.68 1 495.68  
HP 2 APPRO 495.68   *   * 3580  

WSPRO INPUT FILE
APPENDIX B:

WSPRO OUTPUT FILE
## Hydraulic Analysis for Structure READTH00510029

**Date:** 26-FEB-98

**Run Date & Time:** 03-16-98 10:59

### Cross-Section Properties: ISEQ = 3; SECID = BRIDG; SRD = 0.

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<th>LEW</th>
<th>REW</th>
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<td>-1.</td>
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### Cross-Section Properties: ISEQ = 4; SECID = RDWAY; SRD = 21.

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### Velocity Distribution: ISEQ = 5; SECID = APPRO; SRD = 67.

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U.S. Geological Survey WSPRO Input File read029.wsp

Hydraulic analysis for structure READTH00510029  Date: 26-FEB-98

TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT        RLB

*** RUN DATE & TIME: 03-16-98  10:59

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

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<th>LEW</th>
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VELOCITY DISTRIBUTION:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

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X STA. | 0.0 | 5.3 | 6.3 | 7.0 | 7.8 | 8.5 | 8.5 |
A(I)  | 23.1 | 7.7 | 6.3 | 6.6 | 6.4 | 6.6 |
V(I)  | 3.31 | 9.84 | 12.13 | 11.56 | 11.90 |

X STA. | 8.5 | 9.3 | 10.0 | 10.8 | 11.5 | 12.3 |
A(I)  | 6.6 | 6.5 | 6.5 | 6.7 | 6.7 | 6.7 |
V(I)  | 11.47 | 11.64 | 11.77 | 11.44 | 11.39 |

X STA. | 12.3 | 13.0 | 13.8 | 14.5 | 15.2 | 15.9 |
A(I)  | 6.6 | 6.6 | 6.5 | 6.5 | 6.4 | 6.4 |
V(I)  | 11.58 | 11.53 | 11.75 | 11.77 | 11.88 |

X STA. | 15.9 | 16.6 | 17.3 | 18.1 | 18.9 | 19.7 |
A(I)  | 6.5 | 6.4 | 6.6 | 7.0 | 23.6 |
V(I)  | 11.77 | 11.92 | 11.60 | 10.91 | 3.23 |

CROSS-SECTION PROPERTIES:  ISEQ =  4;  SECID = RDWAY;  SRD =      21.

<table>
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X STA. | -304.0 | -286.4 | -273.8 | -262.9 | -253.5 | -244.9 |
A(I)  | 23.4 | 19.2 | 18.3 | 16.3 | 16.0 | 16.6 |
V(I)  | 4.37 | 5.32 | 5.58 | 6.01 | 6.16 |

X STA. | -244.9 | -237.0 | -229.3 | -221.6 | -213.7 | -205.8 |
A(I)  | 16.3 | 16.3 | 16.2 | 16.3 | 16.0 | 16.0 |
V(I)  | 6.29 | 6.27 | 6.31 | 6.27 | 6.38 |

X STA. | -205.8 | -197.9 | -189.5 | -181.0 | -172.0 | -162.5 |
A(I)  | 15.7 | 16.4 | 16.4 | 16.9 | 17.4 |
V(I)  | 6.50 | 6.28 | 6.25 | 6.07 | 5.89 |

X STA. | -162.5 | -153.1 | -142.7 | -132.4 | -121.1 | -73.7 |
A(I)  | 17.0 | 18.1 | 17.6 | 18.6 | 43.0 |
V(I)  | 6.02 | 5.65 | 5.82 | 5.51 | 2.38 |

CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

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X STA. | -304.0 | -218.0 | -178.9 | -149.4 | -124.5 | -102.8 |
A(I)  | 190.6 | 118.6 | 102.6 | 95.7 | 89.8 |
V(I)  | 0.94 | 1.51 | 1.74 | 1.87 | 1.89 |

X STA. | -102.8 | -83.8 | -66.3 | -50.3 | -35.7 | -21.7 |
A(I)  | 84.3 | 82.2 | 79.4 | 75.2 | 73.5 |
V(I)  | 2.12 | 2.18 | 2.26 | 2.38 | 2.43 |

X STA. | -21.7 | -5.3 | 7.5 | 13.5 | 19.1 | 24.7 |
A(I)  | 80.8 | 86.3 | 66.5 | 62.8 | 61.7 |
V(I)  | 2.22 | 2.07 | 2.69 | 2.85 | 2.90 |

X STA. | 24.7 | 30.9 | 38.4 | 46.0 | 55.7 | 89.6 |
A(I)  | 64.4 | 68.3 | 62.2 | 69.5 | 129.4 |
V(I)  | 2.78 | 2.62 | 2.88 | 2.57 | 1.38 |
CROSS-SECTION PROPERTIES:  ISEQ =  3;  SECID = BRIDG;  SRD =       0.

**WSEL**  **SA#**  **AREA**  **K**  **TOPW**  **WETP**  **ALPH**  **LEW**  **REW**  **QCR**
1      88.    6394.   19.    32.                      1071.  1071.
488.20  88.    6394.   19.    32.  1.00     0.    25.   1071.

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

**WSEL**  **LEW**  **REW**  **AREA**  **K**  **Q**  **VEL**
488.20  0.0    24.7    87.8    6394.  1000.  11.39

X STA.         0.0        4.1        5.0        5.9        6.8        7.7
A(I)            12.7        3.5        3.4        3.5        3.5
V(I)            3.94       14.27       14.57       14.39       14.46
X STA.         7.7        8.6        9.5       10.4       11.3       12.2
A(I)            3.5        3.5        3.5        3.5        3.5
X STA.        12.2       13.0       13.9       14.7       15.5       16.3
A(I)            3.5        3.4        3.5        3.4        3.4
V(I)           14.22       14.51       14.47       14.70       14.89
X STA.        16.3       17.1       18.0       18.9       20.0       24.7
A(I)            3.4        3.5        3.6        3.6        12.5
V(I)           14.56       14.45       13.99       13.79       4.01

CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

**WSEL**  **SA#**  **AREA**  **K**  **TOPW**  **WETP**  **ALPH**  **LEW**  **REW**  **QCR**
1     365.   16029.   239.   239.                      2560.  2560.
2     273.   25088.    36.    38.                      4278.  4278.
3     158.   10603.    46.    46.                      1655.  1655.
   493.18  796.  51720.  321.  324.  1.33  -239.   82.  6159.

VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      67.

**WSEL**  **LEW**  **REW**  **AREA**  **K**  **Q**  **VEL**
493.18 -239.2    81.7    795.5    51720.  1000.  1.26

X STA.     -239.2    -92.6   -70.1   -52.0   -36.5   -22.2
A(I)        140.7     47.5     43.9     41.0     39.3
V(I)        0.36      1.05     1.14     1.22     1.27
X STA.     -22.2     -4.2      7.3      10.5     13.4     16.1
A(I)         43.4     51.1     26.4     24.9     23.5
V(I)        1.15      0.98     1.69     2.01     2.13
X STA.       16.1     18.9     21.9     24.9     28.1     31.7
A(I)         24.7     25.7     25.5     26.1     27.5
V(I)        2.02     1.94     1.96     1.92     1.82
X STA.       31.7     36.1     40.5     45.6     51.7     81.7
A(I)         29.4     26.4     28.0     30.3     70.3
V(I)        1.70     1.89     1.79     1.65     0.71
U.S. Geological Survey WSPRO Input File read029.wsp
Hydraulic analysis for structure READTH00510029 Date: 26-FEB-98
TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT RLB

*** RUN DATE & TIME: 03-16-98  10:59

XSID:CODE   SRDL    LEW     AREA   VHD    HF     EGL    CRWS       Q    WSEL
SRD   FLEN    REW        K  ALPH    HO     ERR     FR#     VEL
EXITX:XS ******* -285.  514.  0.51 ******* 491.15  490.04  2500.  490.64
-22. ******* 44.  27430.  1.39 ******* 0.81  4.86
FULLV:FV 22. -285.  572.  0.39  0.16  491.31  490.04  2500.  490.92
0.  22.  31467.  1.31  0.00 -0.01  0.67  4.37

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

FR#: 125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS =  0.80    1.08     491.18     491.07

FR#: 110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY =   490.42     510.69    0.50

FR#: 115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS =   490.42     510.69     491.07

FR#: 135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
"APPRO" KRATIO =  0.64

APPRO:AS 67. -89.  320.  1.18  0.66  492.36  491.07  2500.  491.18
67.  69.  20037.  1.24  0.39   0.00   1.08   7.82

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

FR#: 215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
WS1,WSSD,WS3,RGMIN =   501.76       0.00     491.38     493.15

FR#: 260 ATTEMPTING FLOW CLASS 4 SOLUTION.
FR#: 220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
WS3,WSIU,WS1,LSEL =   491.36     494.86     494.95     493.30

FR#: 245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.
<<<<<<RESULTS REFLECTING THE CONSTRICTED FLOW FOLLOW>>>>>

FIRST USER DEFINED TABLE.

SECOND USER DEFINED TABLE.
U.S. Geological Survey WSPRO Input File read029.wsp
Hydraulic analysis for structure READTH00510029 Date: 26-FEB-98
TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT RLB

*** RUN DATE & TIME: 03-16-98  10:59

XSID:CODE  SRDL  LEW  AREA  VHD  HF  EGL  CRWS  Q  WSEL
SRD  FLN  REW  K  ALPH  HO  ERR  FR#  VEL
EXIT:XS  -228.  671.  0.53  491.65  490.89  3580.  491.12
0.  45.  39287.  1.21  0.73  5.33

FULL:PV  22.  -288.  721.  0.45  491.82  3580.  491.37
0.  45.  43504.  1.17  0.64  4.97

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

---125 FR# EXCEEDS FNTST AT SECID "APPRO": TRIALS CONTINUED.
FNTST,FR#,WSEL,CRWS =  0.80  1.33  491.52  492.08

---110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY =   490.87  510.69  0.50

---115 WSEL NOT FOUND AT SECID "APPRO": USED WMIN = CRWS.
WSLIM1,WSLIM2,CRWS =   490.87  510.69  492.08

---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 =   492.08  510.69  492.08

APPRO:AS  67.  -155.  166.  1.11  494.62  493.30  3580.  493.30
67.  25.  1254.  0.63  9.20

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

---210 QUESTIONABLE CRITICAL-FLOW SOLUTION.
SECID "BRIDG" Q,CRWS =  3580.00  493.30

---230 REJECTED FLOW CLASS 1 SOLUTION.
WSL,WSEND,WS3 =   509.50  0.00  493.30

---240 NO DISCHARGE BALANCE IN 15 ITERATIONS.
W5,QBO,QRD =   496.62  0.00  3580.

---280 REJECTED FLOW CLASS 4 SOLUTION.

---245 ATTEMPTING FLOW CLASS 4 SOLUTION.

---250 ATTEMPTING FLOW CLASS 4 SOLUTION.

---254 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

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

XSID:CODE  SRDL  LEW  AREA  VHD  HF  EGL  CRWS  Q  WSEL
SRD  FLN  REW  K  ALPH  HO  ERR  FR#  VEL
BRID:BR  22.  0.  166.  1.32  494.62  489.30  1524.  493.30
0.  25.  12546.  1.00  0.63  9.20

TYPE PPCD FLOW  C  P/A  LSEL  BLN  XLAB  XRAB
2.  5.  493.30  1.6  1.6  1.6  1.6  1.6  1.6

XSID:CODE  SRD  FLN  HF  VHD  EGL  ERR  Q  WSEL
RDWAY:RG  21.  50.  0.03  0.07  495.72  0.00  2047.  495.29

Q  WLEN  LEW  REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
LT:   2047.  230.  -304.  -74.  2.1  1.6  6.5  5.5  2.0  3.0
RT:      0.  1.32  484.00  517.55  0.53  491.65  491.12

XSID:CODE  SRD  LEW  AREA  VHD  HF  EGL  CRWS  Q  WSEL
SRD  FLN  REW  K  ALPH  HO  ERR  FR#  VEL
APPRO:AS  25.  -304.  1743.  0.07  495.75  492.08  3580.  495.68
67.  90.  150665.  1.07  0.00  0.18  2.05

M(G)  M(K)  M(Q)  XLEKQ  XRKQ  OTEL

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

FIRST USERDEFINED TABLE.
XSID:CODE  SRD  LEW  Q  K  AREA  VEL  WSEL
EXIT:XS  -228.  45.  3580.  39287.  671.  5.33  491.12
FULL:PV  228.  45.  3580.  43504.  721.  4.97  491.37
BRID:BR  0.  25.  1524.  12566.  166.  9.20  493.30
RDWAY:RG  21.  2047.  0.00  2047.  495.29
APPRO:AS  67.  90.  3580.  150665.  1743.  2.05  495.68

SECOND USERDEFINED TABLE.
XSID:CODE  CRWS  FR#  YMIN  YMAX  HF  HO  VHD  EGL  WSEL
EXIT:XS  490.89  0.73  484.00  517.55  0.53  491.65  491.12
FULL:PV  489.30  0.63  483.64  493.30  1.32  494.62  493.30
BRID:BR  493.15  0.34  495.75  495.29
APPRO:AS  492.08  0.18  484.37  510.69  0.11  0.00  0.07  495.75  495.68
U.S. Geological Survey WSPRO Input File read029.wsp
Hydraulic analysis for structure READTH00510029 Date: 26-FEB-98
TH 51 CROSSING MILL BROOK IN READING, WINDSOR CO, VERMONT RLB

*** RUN DATE & TIME: 03-16-98  11:13

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

EXITX:XS  ******  0.  172.  0.53  ******  489.85  487.68  1000.  489.33
-22.  ******  43.  10971.  1.00  ******  0.51  5.82
FULLV:FV  22.  0.  177.  0.50  0.18  490.04  ******  1000.  489.54
0.  22.  43.  11445.  1.00  0.00  0.01  0.49  5.65
<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

APPRO:AS  67.  1.  210.  0.38  0.45  490.49  ******  1000.  490.11
67.  67.  12932.  1.07  0.00  0.00  0.47  4.76
<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

---215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
WS1,WSHD,WS3,RGMIN =  493.18  0.00  488.20  493.15

---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  22.  0.  88.  2.96  0.31  491.16  488.03  1000.  488.20
0.  25.  6391.  1.47  0.99  -0.01  1.13  11.39
TYPE PPCD FLOW  C  P/A  LSEL  BLEN  XLAB  XRAB
2. ****  4.  0.826 ******  493.30 ****** ****** ******

XSID:CODE  CRWS  FR#  YMIN  YMAX  HF  HO  VHD  EUL  WSEL
EXITX:XS  487.68  0.51  448.00  517.55  0.53  489.85  489.33
FULLY:FV  0.49  484.10  517.65  0.18  0.00  0.50  490.04  489.54
BRIDG:BR  488.03  1.13  483.64  493.30  0.11  0.99  2.96  491.18  488.20
RUNWAY:RG  493.15  542.61  0.02  0.03  493.20  493.18
APPRO:AS  488.40  0.16  484.37  510.69  0.09  1.97  0.03  493.21  493.18

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

FIRST USER DEFINED TABLE.

XSID:CODE  CRWS  FR#  YMIN  YMAX  HF  HO  VHD  EUL  WSEL
EXITX:XS  487.68  0.51  448.00  517.55  0.53  489.85  489.33
FULLY:FV  0.49  484.10  517.65  0.18  0.00  0.50  490.04  489.54
BRIDG:BR  488.03  1.13  483.64  493.30  0.11  0.99  2.96  491.18  488.20
RUNWAY:RG  493.15  542.61  0.02  0.03  493.20  493.18
APPRO:AS  488.40  0.16  484.37  510.69  0.09  1.97  0.03  493.21  493.18

SECOND USER DEFINED TABLE.
APPENDIX C:

BED-MATERIAL PARTICLE-SIZE DISTRIBUTION
Appendix C: Bed material particle size distribution for a pebble count in the channel approach of structure READTH00510029, in Reading, Vermont.
APPENDIX D:

HISTORICAL DATA FORM
The structural inspection report of 9/10/93 indicates the structure is a multi-plate arch culvert. Both concrete abutment footings are exposed at the surface. At the upstream end of the left abutment footing there is a deep scour hole. The footing at the left abutment may be slightly undermined. There is large boulder fill in this area for protection. The waterway is noted as “somewhat poorly aligned” with the structure. The flow is directed into the upstream end of the left abutment and then deflected into the downstream end of the right abutment. The streambed material is composed of mainly stone and gravel. There is a point bar noted on the left bank just downstream of the structure. Road embankment erosion and settlement are indicated in the report as not evident. The culvert has mitered openings.
Bridge Hydrologic Data

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

Terrain character:  - 

Stream character & type:  - 

Streambed material:  **Stones and gravel**

Discharge Data (cfs):  
<table>
<thead>
<tr>
<th>Q_{2.33}</th>
<th>Q_{10}</th>
<th>Q_{25}</th>
<th>Q_{50}</th>
<th>Q_{100}</th>
<th>Q_{500}</th>
</tr>
</thead>
</table>

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-immediately upstream of the site)

Water Surface Elevation Estimates for Existing Structure:

<table>
<thead>
<tr>
<th>Peak discharge frequency</th>
<th>Q_{2.33}</th>
<th>Q_{10}</th>
<th>Q_{25}</th>
<th>Q_{50}</th>
<th>Q_{100}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water surface elevation (ft)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Velocity (ft/sec)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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} (ft³/sec):  - 

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

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

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

Clear span (ft):  -  
Clear Height (ft):  -  
Full Waterway (ft²):  - 

-
Downstream distance (miles): ___________ Town: _________________ Year Built: ______
Highway No.: ________________ Structure No.: ______ Structure Type: ________________
Clear span (ft): ______ Clear Height (ft): ______ Full Waterway (ft²): ______

Comments: -

---

**USGS Watershed Data**

**Watershed Hydrographic Data**

- Drainage area (DA) **9.56** mi²
- Watershed storage (ST) **0.1** %
- Bridge site elevation **940** ft
- Main channel length **5.53** mi
  - 10% channel length elevation **980** ft
  - 85% channel length elevation **1880** ft
- Main channel slope (S) **227.61** ft / mi

- Lake/pond/swamp area **0.01** mi²
- Headwater elevation **2290** ft

**Watershed Precipitation Data**

- Average site precipitation **-** in
- Average headwater precipitation **-** in

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

- Average seasonal snowfall (Sn) **-** ft
BM#1, Spike in root of an 18 inch elm tree, located about 75 feet right bankward from the right abutment on the roadway and about 15 feet from the roadway centerline upstream, elevation 500.0 feet.

The footings are set in a dense to very dense sand with some gravel and silt.

Comments:
The low superstructure elevations given are for the tops of the concrete footings. The plans showed the channel was to be excavated and leveled at 476.1 ft at the upstream end and 475.5 ft at the downstream end with a 1% grade or slope.

*The upstream footing bottom elevation is 472.09 ft and the downstream end is at an elevation of 471.48 ft.
## Cross-sectional Data

Is cross-sectional data available? \( \text{Y} \)  
*If no, type ctrl-n xs

Source (FEMA, VTAOT, Other)? \( \text{VTAOT} \)

Comments: *Upstream arch face channel cross section. *Point of contact where the steel arch meets the concrete footing.

<table>
<thead>
<tr>
<th>Station</th>
<th>-12.5</th>
<th>-12.5</th>
<th>-7.5</th>
<th>+2.5</th>
<th>+5.5</th>
<th>+12.5</th>
<th>+12.5</th>
<th>-</th>
<th>-</th>
<th>-</th>
<th>-</th>
<th>-</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>footing bottom</td>
<td>LCL*</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>LCR*</td>
<td>footing bottom</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low chord elevation</td>
<td>476.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>476.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bed elevation</td>
<td>472</td>
<td>475.3</td>
<td>474.7</td>
<td>475.5</td>
<td>476.0</td>
<td>476.0</td>
<td>472.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Low chord to bed</td>
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<td>-</td>
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<td>-</td>
</tr>
</tbody>
</table>

Source (FEMA, VTAOT, Other)? \( \text{VTAOT} \)

Comments: *Downstream arch face channel cross section. *Point of contact where the steel arch meets the concrete footing.

<table>
<thead>
<tr>
<th>Station</th>
<th>-12.5</th>
<th>-12.5</th>
<th>+2.5</th>
<th>+12.5</th>
<th>+12.5</th>
<th>-</th>
<th>-</th>
<th>-</th>
<th>-</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Feature</td>
<td>footing bottom</td>
<td>LCL*</td>
<td>-</td>
<td>LCR*</td>
<td>footing bottom</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low chord elevation</td>
<td>476.2</td>
<td>-</td>
<td>476.2</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Bed elevation</td>
<td>471.5</td>
<td>475.7</td>
<td>475.6</td>
<td>475.5</td>
<td>471.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
<td>Low chord to bed</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>
APPENDIX E:

LEVEL I DATA FORM
Structure Number  READTH00510029

A. General Location Descriptive

1. Data collected by (First Initial, Full last name)  M WEBER  Date (MM/DD/YY)  3 / 29 / 1995
2. Highway District Number 04  County WINDSOR (027)
   Waterway (I - 6) MILL BROOK  Route Number TH051
3. Descriptive comments:
   This structure is a multi-plate arch culvert. It is located 0.06 miles from the junction with VT 106.

B. Bridge Deck Observations

4. Surface cover...  LBUS 4 RBUS 4 LBDS 4 RBDS 6 Overall 4
   (2b us,ds,lb,rb: 1- Urban; 2- Suburban; 3- Row crops; 4- Pasture; 5- Shrub- and brushland; 6- Forest; 7- Wetland)
5. Ambient water surface...US 2 UB 1 DS 2 (1- pool; 2- riffle)
6. Bridge structure type 7 ( 1- single span; 2- multiple span; 3- single arch; 4- multiple arch; 5- cylindrical culvert; 6- box culvert; or 7- other)
7. Bridge length 27 (feet)  Span length 25 (feet)  Bridge width -- (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 --

<table>
<thead>
<tr>
<th>Protection</th>
<th>Type</th>
<th>Cond.</th>
<th>Erosion</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBUS</td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>RBUS</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RBDS</td>
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<td>0</td>
</tr>
<tr>
<td>LBDS</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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):

Approach Angle
Bridge Skew Angle

17. Channel impact zone 1:
   Exist? Y  (Y or N)
   Where? LB  Severity 2
   Range? 5 feet US (US, UB, DS) to 50 feet US

Channel impact zone 2:
   Exist? Y  (Y or N)
   Where? RB  Severity 3
   Range? 75 feet DS (US, UB, DS) to 100 feet DS

Impact Severity: 0- none to very slight; 1- Slight; 2- Moderate; 3- Severe
C. Upstream Channel Assessment


<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>RB</th>
<th>LB</th>
<th>RB</th>
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</thead>
<tbody>
<tr>
<td>20. SRD</td>
<td>33.0</td>
<td>3.5</td>
<td>1.5</td>
<td>2</td>
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<tr>
<td>23. Bank width</td>
<td>50.0</td>
<td>24. Channel width</td>
<td>10.0</td>
<td>25. Thalweg depth</td>
</tr>
<tr>
<td>29. Bed Material</td>
<td>32</td>
<td></td>
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</tbody>
</table>

30. Bank protection type:  

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>RB</th>
</tr>
</thead>
</table>

31. Bank protection condition:  

<table>
<thead>
<tr>
<th></th>
<th>LB</th>
<th>RB</th>
</tr>
</thead>
</table>

SRD - Section ref. dist. to US face  

% Vegetation (Veg) cover:  

1- 0 to 25%; 2- 26 to 50%; 3- 51 to 75%; 4- 76 to 100%

Bed and bank Material:  

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

Bank Erosion:  

0- not evident; 1- light fluvial; 2- moderate fluvial; 3- heavy fluvial / mass wasting

Bank protection types:  

0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee

Bank protection conditions:  

1- good; 2- slumped; 3- eroded; 4- failed

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

27. The bank material is sand and gravel with occasional boulders on the RB.

29. The bed material is gravel and sand.

All US distances are measured from the US culvert face, which is about 12 feet US from the US edge of the road and about 10 feet DS of the US right and left culvert ends.
33. Point/Side bar present?  Y  (Y or N. if N type ctrl-n pb) 34. Mid-bar distance:  40  35. Mid-bar width:  7
36. Point bar extent:  0 _feet US (US, UB) to  70 _feet US (US, UB, DS) positioned  80 %LB to  100 %RB
37. Material:  2
38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):
Point bar material is sand and gravel. Some shrubs are growing on the bar.

39. Is a cut-bank present?  Y  (Y or if N type ctrl-n cb) 40. Where?  LB  (LB or RB)
41. Mid-bank distance:  5  42. Cut bank extent:  5 _feet US (US, UB) to  50 _feet US (US, UB, DS)
43. Bank damage:  1  ( 1- eroded and/or creep; 2- slip failure; 3- block failure)
44. Cut bank comments (eg. additional cut banks, protection condition, etc.):
The greatest damage is up against the stone embankment on the left side of the culvert. Some stones have slumped.

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.):
Local scour exists at the upstream end of the culvert. The upstream left culvert footing is threatened.

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)
  Confluence 2: Distance - Enters on - (LB or RB)  53. 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  - -  (1- natural bank; 2- abutment; 3- artificial levee)
56. Height (BF)  25.5  57. Angle (BF)  0.5  61. Material (BF)  2  62. Erosion (BF)  7
  LB RB LB RB
  2  7  7  -
58. Bank width (BF) -  59. Channel width -  60. Thalweg depth  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.):
3
The culvert is a corrugated, galvanized steel arch with stone fill around the arch perimeter, including the sides above the concrete footings.
63. The bed material is sand in the US scoured area and gravel and sand elsewhere.
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)  
70. **Ice Blockage Potential**  N____ ( 1- Low; 2- Moderate; 3- High)  

There is a large bank failure DS with trees lying in the stream. There are some small sticks at the US right culvert corner, but nothing substantial. The stream meanders in a wide floodplain and although the US reach is a riffle, the culvert is not in the uplands. Lateral movement could cause trees to fall into the stream. The culvert will block some of the bank full flow and the low sides may trap debris.

### Wingwalls:

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>USLWW:</td>
<td>____ ____</td>
<td>____ ____ ____</td>
<td>____ ____</td>
<td>____ ____ ____</td>
</tr>
<tr>
<td>USRWW:</td>
<td>N ____ ____</td>
<td>- ____ ____</td>
<td>- ____</td>
<td>- ____</td>
</tr>
<tr>
<td>DSLWW:</td>
<td>- ____ ____</td>
<td>- ____</td>
<td>N ____</td>
<td>____</td>
</tr>
<tr>
<td>DSRWW:</td>
<td>____ ____</td>
<td>- ____</td>
<td>____</td>
<td>- ____</td>
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</tbody>
</table>

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

### Bank / Bridge Protection:

<table>
<thead>
<tr>
<th>Location</th>
<th>USLWW</th>
<th>USRWW</th>
<th>LABUT</th>
<th>RABUT</th>
<th>LB</th>
<th>RB</th>
<th>DSLWW</th>
<th>DSRWW</th>
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</thead>
<tbody>
<tr>
<td>Type</td>
<td>-</td>
<td>-</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Condition</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Extent</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>2</td>
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</table>

**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.):
- 
- 
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- 

Piers:
84. Are there piers? **Th** (Y or if N type ctrl-n pr)

<table>
<thead>
<tr>
<th>Pier no.</th>
<th>width (w) feet</th>
<th>elevation (e) feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w1</td>
<td>w2</td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
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<tr>
<td>Pier 2</td>
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<tr>
<td>Pier 3</td>
<td></td>
<td></td>
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<tr>
<td>Pier 4</td>
<td></td>
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</tbody>
</table>

85. Location (BF)  ere is  the  fill is  the
86. Type  stone  cul-  not  cul-
87. Material  fill at  vert  in  vert
88. Shape  the  on  the  wher
89. Inclined?  upst  the  chan  e the
90. Attack (BF)  ream  left  nel,  cul-
91. Pushed  and  and  but  vert
92. Length (feet)  -   -   -   -
93. # of piles  dow  right  is  meet
94. Cross-members  nstre  sides  piled  s the
95. Scour Condition  am  .  on  bank
96. Scour depth  ends  This  top  .  In
97. Exposure depth  of  stone  of  addi-

LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP
1- Solid pier, 2- column, 3- bent
1- Wood; 2- concrete; 3- metal; 4- stone
1- Round; 2- Square; 3- Pointed
Y- yes; N- no

LB or RB
0- none; 1- laterals; 2- diagonals; 3- both
0- not evident; 1- evident (comment);
2- footing exposed; 3- piling exposed;
4- undermined footing; 5- settled; 6- failed
E. Downstream Channel Assessment

<table>
<thead>
<tr>
<th>SRD</th>
<th>Bank height (BF)</th>
<th>Bank angle (BF)</th>
<th>% Veg. cover (BF)</th>
<th>Bank material (BF)</th>
<th>Bank erosion (BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LB</td>
<td>RB</td>
<td>LB</td>
<td>RB</td>
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<tr>
<td>Bank width (BF)</td>
<td></td>
<td>Channel width</td>
<td></td>
<td>Thalweg depth</td>
<td></td>
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</tbody>
</table>

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.):

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

- There is some stone fill in the channel at the upstream left end of the culvert. The stone fill in that area has slumped from channel erosion.

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

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

102. Distance: ______ feet

103. Drop: ______ feet 

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

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

- 
- 
- 
- 
-
106. **Point/Side bar present?**  (Y or N. if N type ctrl-n pb)
Mid-bar distance:  
Mid-bar width:  
Point bar extent:  foot  (US, UB, DS) to  foot  (US, UB, DS) positioned  %LB to  %RB 
Material:  
Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

107. **Is a cut-bank present?**  (Y or if N type ctrl-n cb)
Where?  (LB or RB)  
Mid-bank distance:  
Cut bank extent:  foot  (US, UB, DS) to  foot  (US, UB, DS) 
Bank damage:   (1- eroded and/or creep; 2- slip failure; 3- block failure) 
Cut bank comments (eg. additional cut banks, protection condition, etc.):

108. **Is channel scour present?**  (Y or if N type ctrl-n cs)
Mid-scout distance:  
Scour dimensions: Length  Width  Depth:  Positioned  %LB to  %RB 
Scour comments (eg. additional scour areas, local scouring process, etc.):

109. **Are there major confluences?**  (Y or if N type ctrl-n mc)
How many?  
Confluence 1: Distance  is  Enters on  (LB or RB)  Type  (1- perennial; 2- ephemeral) 
Confluence 2: Distance  wast-  Enters on  (LB or RB)  Type  (1- perennial; 2- ephemeral) 
Confluence comments (eg. confluence name):
both banks DS, especially on the right bank, exposing clay with gravel bank material. Where bank wasting is not occurring, the banks are silty. The bed material is gravel except in the scour hole downstream where clay

### 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):

Gravel is exposed. Downstream measurements are made from the DS face of the culvert, which is 12 feet DS of the DS edge of the road and 10 feet US of the DS culvert corners.
109. G. Plan View Sketch

- Point bar (pb)
- Cut-bank (cb)
- Scour hole
- Debris
- Rip rap or stone fill
- Flow (Q)
- Cross-section
- Ambient channel
- Stone wall
- Other wall
APPENDIX F:

SCOUR COMPUTATIONS
SCOUR COMPUTATIONS

Structure Number: READTH00510029  Town: READING
Road Number: TH 51  County: WINDSOR
Stream: MILL BROOK

Initials RLB  Date: 3/16/98  Checked: EMB

Analysis of contraction scour, live-bed or clear water?

Critical Velocity of Bed Material (converted to English units)
\[ V_c = 11.21 \times y_1^{0.1667} \times D_{50}^{0.33} \text{ with } S_s = 2.65 \]
(Richardson and Davis, 1995, p. 28, eq. 16)

Approach Section

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>100 yr</th>
<th>500 yr</th>
<th>other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total discharge, cfs</td>
<td>2500</td>
<td>3580</td>
<td>1000</td>
</tr>
<tr>
<td>Main Channel Area, ft²</td>
<td>338</td>
<td>362</td>
<td>273</td>
</tr>
<tr>
<td>Left overbank area, ft²</td>
<td>891</td>
<td>1098</td>
<td>365</td>
</tr>
<tr>
<td>Right overbank area, ft²</td>
<td>248</td>
<td>284</td>
<td>158</td>
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<tr>
<td>Top width main channel, ft</td>
<td>36</td>
<td>36</td>
<td>36</td>
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<tr>
<td>Top width L overbank, ft</td>
<td>304</td>
<td>304</td>
<td>239</td>
</tr>
<tr>
<td>Top width R overbank, ft</td>
<td>52</td>
<td>54</td>
<td>46</td>
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<td>D50 of channel, ft</td>
<td>0.2544</td>
<td>0.2544</td>
<td>0.2544</td>
</tr>
<tr>
<td>D50 left overbank, ft</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>D50 right overbank, ft</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>y1, average depth, MC, ft</td>
<td>9.4</td>
<td>10.1</td>
<td>7.6</td>
</tr>
<tr>
<td>y1, average depth, LOB, ft</td>
<td>2.9</td>
<td>3.6</td>
<td>1.5</td>
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<td>y1, average depth, ROB, ft</td>
<td>4.8</td>
<td>5.3</td>
<td>3.4</td>
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<td>Total conveyance, approach</td>
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<td>150820</td>
<td>51720</td>
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<td>35820</td>
<td>40213</td>
<td>25088</td>
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<tr>
<td>Conveyance, LOB</td>
<td>60294</td>
<td>85240</td>
<td>16029</td>
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<tr>
<td>Conveyance, ROB</td>
<td>20704</td>
<td>25367</td>
<td>10603</td>
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<tr>
<td>Percent discrepancy, conveyance</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
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<tr>
<td>Qm, discharge, MC, cfs</td>
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<td>954.5</td>
<td>485.1</td>
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<td>Ql, discharge, LOB, cfs</td>
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<td>2023.3</td>
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<td>Qr, discharge, ROB, cfs</td>
<td>443.1</td>
<td>602.1</td>
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<td>Vm, mean velocity MC, ft/s</td>
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<td>2.6</td>
<td>1.8</td>
</tr>
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<td>Vl, mean velocity, LOB, ft/s</td>
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<td>1.8</td>
<td>0.8</td>
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<tr>
<td>Vr, mean velocity, ROB, ft/s</td>
<td>1.8</td>
<td>2.1</td>
<td>1.3</td>
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<tr>
<td>Vc-m, crit. velocity, MC, ft/s</td>
<td>10.3</td>
<td>10.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Vc-l, crit. velocity, LOB, ft/s</td>
<td>ERR</td>
<td>ERR</td>
<td>ERR</td>
</tr>
<tr>
<td>Vc-r, crit. velocity, ROB, ft/s</td>
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<td>ERR</td>
<td>ERR</td>
</tr>
</tbody>
</table>

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

\[ y_2 = \left(\frac{Q_2^2}{131 D_m^{2/3} W_2^2}\right)^{3/7} \]  
converted to English Units

\[ y_s = y_2 - y_{\text{bridge}} \]

(Richardson and Davis, 1995, p. 32, eq. 20, 20a)

<table>
<thead>
<tr>
<th>Bridge Section</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q) total discharge, cfs</td>
<td>2500</td>
<td>3580</td>
<td>1000</td>
</tr>
<tr>
<td>(Q) discharge thru bridge, cfs</td>
<td>1370</td>
<td>1524</td>
<td>1000</td>
</tr>
<tr>
<td>Main channel conveyance</td>
<td>12566</td>
<td>12566</td>
<td>6394</td>
</tr>
<tr>
<td>Total conveyance</td>
<td>12566</td>
<td>12566</td>
<td>6394</td>
</tr>
<tr>
<td>Q2, bridge MC discharge, cfs</td>
<td>1370</td>
<td>1524</td>
<td>1000</td>
</tr>
<tr>
<td>Main channel area, ft(^2)</td>
<td>166</td>
<td>166</td>
<td>88</td>
</tr>
<tr>
<td>Main channel width (normal), ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>Cum. width of piers in MC, ft</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W, adjusted width, ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>y(_{\text{bridge}}), avg. depth at br., ft</td>
<td>7.14</td>
<td>7.14</td>
<td>3.78</td>
</tr>
<tr>
<td>Dm, median (1.25*D50), ft</td>
<td>0.318</td>
<td>0.318</td>
<td>0.318</td>
</tr>
<tr>
<td>y2, depth in contraction, ft</td>
<td>5.66</td>
<td>6.20</td>
<td>4.32</td>
</tr>
<tr>
<td>y(<em>s), scour depth (y2-y(</em>{\text{bridge}})), ft</td>
<td>-1.48</td>
<td>-0.94</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Pressure Flow Scour (contraction scour for orifice flow conditions)

Chang pressure flow equation

\[ H_b + Y_s = C_q q_{br} / V_c \]

\[ C_q = 1/C_f C_c \]

\[ C_f = 1.5 Fr^{0.43} \quad (<=1) \]

\[ C_c = \text{SQRT}[0.10(\text{H}_b/(\text{ya-w})-0.56)] + 0.79 \quad (<=1) \]

Umbrell pressure flow equation

\[ (H_b + Y_s)/ya = 1.1021 \times [(1-w/ya) \times (V_a/V_c)]^{0.6031} \]

(Richardson and Davis, 1995, p. 144-146)

<table>
<thead>
<tr>
<th>Q, total, cfs</th>
<th>Q100</th>
<th>Q500</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, thru bridge MC, cfs</td>
<td>1370</td>
<td>1524</td>
<td>1000</td>
</tr>
<tr>
<td>Vc, critical velocity, ft/s</td>
<td>10.32</td>
<td>10.44</td>
<td>9.96</td>
</tr>
<tr>
<td>Va, velocity MC approach, ft/s</td>
<td>2.27</td>
<td>2.64</td>
<td>1.78</td>
</tr>
<tr>
<td>Main channel width (normal), ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>Cum. width of piers in MC, ft</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W, adjusted width, ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>qbr, unit discharge, ft(^2)/s</td>
<td>59.1</td>
<td>65.7</td>
<td>43.1</td>
</tr>
<tr>
<td>Area of full opening, ft(^2)</td>
<td>165.7</td>
<td>165.7</td>
<td>87.8</td>
</tr>
<tr>
<td>Hb, depth of full opening, ft</td>
<td>7.14</td>
<td>7.14</td>
<td>3.78</td>
</tr>
<tr>
<td>Fr, Froude number, bridge MC</td>
<td>0.56</td>
<td>0.63</td>
<td>0</td>
</tr>
<tr>
<td>Cf, Fr correction factor (&lt;=1.0)</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>**Area at downstream face, ft(^2)</td>
<td>134</td>
<td>141</td>
<td>N/A</td>
</tr>
<tr>
<td>**Hb, depth at downstream face, ft</td>
<td>5.78</td>
<td>6.08</td>
<td>N/A</td>
</tr>
<tr>
<td>**Fr, Froude number at DS face</td>
<td>0.75</td>
<td>0.77</td>
<td>ERR</td>
</tr>
<tr>
<td>**Cf, for downstream face (&lt;=1.0)</td>
<td>1.00</td>
<td>1.00</td>
<td>N/A</td>
</tr>
<tr>
<td>Elevation of Low Steel, ft</td>
<td>493.3</td>
<td>493.3</td>
<td>0</td>
</tr>
</tbody>
</table>
### Elevation of Bed, ft
486.16  486.16  -3.78
### Elevation of Approach, ft
495  495.68  0
### Friction loss, approach, ft
0.08  0.11  0
### Elevation of WS immediately US, ft
494.92  495.57  0.00
### ya, depth immediately US, ft
8.76  9.41  3.78
### Mean elevation of deck, ft
500.91  500.91  0
### w, depth of overflow, ft (>=0)
0.00  0.00  0.00
### Cc, vert contrac correction (<=1.0)
0.95  0.93  1.00
**Cc, for downstream face (<=1.0)**
0.889587  0.88258  ERR

**Ys, scour w/Chang equation, ft**
-1.12  -0.38  N/A
**Ys, scour w/Umbrell equation, ft**
-3.27  -2.62  N/A

**=for UNsubmerged orifice flow using estimated downstream bridge face properties.**
**Ys, scour w/Chang equation, ft**
0.66  1.05  N/A
**Ys, scour w/Umbrell equation, ft**
-1.90  -1.55  ERR

In UNsubmerged orifice flow, an adjusted scour depth using the Laursen equation results and the estimated downstream bridge face properties can also be computed (ys=y2-ybridgeDS):

- **y2, from Laursen’s equation, ft**
  5.66  6.20  4.32
- **WSEL at downstream face, ft**
  490.92  491.37  --
- **Depth at downstream face, ft**
  5.78  6.08  N/A

**Ys, depth of scour (Laursen), ft**
-0.11  0.13  N/A

### Armoring

\[ Dc = \left( \frac{1.94 \cdot V^2}{5.75 \cdot \log(12.27 \cdot y/D90)} \right)^2 \left( \frac{0.03 \cdot (165-62.4)}{0.03} \right) \]

Depth to Armoring=3*(1/Pc-1)

(Federal Highway Administration, 1993)

### Downstream bridge face property

<table>
<thead>
<tr>
<th></th>
<th>100-yr</th>
<th>500-yr</th>
<th>Other Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, discharge thru bridge MC, cfs</td>
<td>1370</td>
<td>1524</td>
<td>1000</td>
</tr>
<tr>
<td>Main channel area (DS), ft2</td>
<td>134</td>
<td>141</td>
<td>87.8</td>
</tr>
<tr>
<td>Main channel width (normal), ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>Cum. width of piers, ft</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Adj. main channel width, ft</td>
<td>23.2</td>
<td>23.2</td>
<td>23.2</td>
</tr>
<tr>
<td>D90, ft</td>
<td>0.5081</td>
<td>0.5081</td>
<td>0.5081</td>
</tr>
<tr>
<td>D95, ft</td>
<td>0.5645</td>
<td>0.5645</td>
<td>0.5645</td>
</tr>
<tr>
<td>Dc, critical grain size, ft</td>
<td>0.4333</td>
<td>0.4744</td>
<td>0.6431</td>
</tr>
<tr>
<td>Pc, Decimal percent coarser than Dc</td>
<td>0.176</td>
<td>0.133</td>
<td>0.026</td>
</tr>
</tbody>
</table>

### Depth to armoring, ft

6.09  9.28  N/A

### Abutment Scour

Froehlich’s Abutment Scour

\[ Ys/Y1 = 2.27 \cdot K1 \cdot K2 \cdot (a'/Y1)^{0.43} \cdot Fr1^{0.61} + 1 \]

(Richardson and Davis, 1995, p. 48, eq. 28)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Left Abutment</th>
<th>Right Abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qt, total discharge, cfs</td>
<td>2500 3580 1000</td>
<td>2500 3580 1000</td>
</tr>
<tr>
<td>a’, abut.length blocking flow, ft</td>
<td>234.8 234.8 240</td>
<td>63.9 65.6 57.7</td>
</tr>
</tbody>
</table>
### Ae, area of blocked flow ft\(^2\)
- 618.12
- 703.14
- 378.02
- 357.22
- 401.51
- 245.65

### Qe, discharge blocked abut., cfs
- 321.74
- 697.5
- 917.38
- 365

(If using Q\text{total_overbank} to obtain Ve, leave Qe blank and enter Ve and Fr manually)

### Ve, (Qe/Ae), ft/s
- 1.45
- 1.84
- 0.85
- 1.95
- 2.28
- 1.49

### ya, depth of f/p flow, ft
- 2.63
- 2.99
- 1.58
- 5.59
- 6.12
- 4.26

--- Coeff., K\text{1}, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)
- 1
- 1
- 1
- 1
- 1
- 1

--- Angle (theta) of embankment (<90 if abut. points DS; >90 if abut. points US)
- 70
- 70
- 70
- 110
- 110
- 110

### Fr, froude number f/p flow
- 0.148
- 0.170
- 0.120
- 0.146
- 0.163
- 0.127

### ys, scour depth, ft
- 15.07
- 17.56
- 9.80
- 17.05
- 19.19
- 12.89

**HIRE equation (a'/ya > 25)**
\[ ys = 4 \times Fr^{0.33} \times y_1 \times K/0.55 \]
(Richardson and Davis, 1995, p. 49, eq. 29)

### a' (abut length blocked, ft)
- 234.8
- 234.8
- 240
- 63.9
- 65.6
- 57.7

### y_1 (depth f/p flow, ft)
- 2.63
- 2.99
- 1.58
- 5.59
- 6.12
- 4.26

### a'/y_1
- 89.19
- 78.41
- 152.37
- 11.43
- 10.72
- 13.55

### Skew correction (p. 49, fig. 16)
- 0.93
- 0.93
- 0.93
- 1.04
- 1.04
- 1.04

### Fr, froude number f/p flow
- 0.148
- 0.170
- 0.120
- 0.146
- 0.163
- 0.127

### ys, scour depth, ft
- 15.07
- 17.56
- 9.80
- 17.05
- 19.19
- 12.89

**Abutment riprap Sizing**

**Isbash Relationship**
\[ D_{50} = y \times K \times Fr^2 / (S_s - 1) \] and \[ D_{50} = y \times K \times (Fr^2)^{0.14} / (S_s - 1) \]
(Richardson and Davis, 1995, p.112, eq. 81,82)

### Characteristic
- Q\text{100}
- Q\text{500}
- Other Q
- Q\text{100}
- Q\text{500}
- Other Q

### Fr, Froude Number
- 0.75
- 0.77
- 1.13
- 0.75
- 0.77
- 1.13

### y, depth of flow in bridge, ft
- 5.78
- 6.08
- 3.78
- 5.78
- 6.08
- 3.78

### Median Stone Diameter for riprap at: left abutment
- 2.01
- 2.23
- ERR
- 2.01
- 2.23
- ERR

### right abutment, ft
- ERR
- ERR
- 1.64
- ERR
- ERR
- 1.64

50