LEVEL II SCOUR ANALYSIS FOR BRIDGE 4 (ARLITH00010004) on TOWN HIGHWAY 1, crossing WARM BROOK, ARLINGTON, VERMONT

By SCOTT A. OLSON and MICHAEL A. IVANOFF

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Pembroke, New Hampshire
1997
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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

<table>
<thead>
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<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
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</tr>
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<td>mile (mi)</td>
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<td>kilometer (km)</td>
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<td>square kilometer (km²)</td>
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<tr>
<td>Volume</td>
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<td></td>
</tr>
<tr>
<td>cubic foot (ft³)</td>
<td>0.02832</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td>Velocity and Flow</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

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>BF</td>
<td>bank full</td>
</tr>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>D₅₀</td>
<td>median diameter of bed material</td>
</tr>
<tr>
<td>DS</td>
<td>downstream</td>
</tr>
<tr>
<td>elev.</td>
<td>elevation</td>
</tr>
<tr>
<td>f/p</td>
<td>flood plain</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
</tr>
<tr>
<td>ft/ft</td>
<td>feet per foot</td>
</tr>
<tr>
<td>JCT</td>
<td>junction</td>
</tr>
<tr>
<td>LAB</td>
<td>left abutment</td>
</tr>
<tr>
<td>LABUT</td>
<td>face of left abutment</td>
</tr>
<tr>
<td>LB</td>
<td>left bank</td>
</tr>
<tr>
<td>LOB</td>
<td>left overbank</td>
</tr>
<tr>
<td>LWW</td>
<td>left wingwall</td>
</tr>
<tr>
<td>MC</td>
<td>main channel</td>
</tr>
<tr>
<td>RAB</td>
<td>right abutment</td>
</tr>
<tr>
<td>RABUT</td>
<td>face of right abutment</td>
</tr>
<tr>
<td>RB</td>
<td>right bank</td>
</tr>
<tr>
<td>ROB</td>
<td>right overbank</td>
</tr>
<tr>
<td>RWW</td>
<td>right wingwall</td>
</tr>
<tr>
<td>TH</td>
<td>town highway</td>
</tr>
<tr>
<td>UB</td>
<td>under bridge</td>
</tr>
<tr>
<td>US</td>
<td>upstream</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>VTAOT</td>
<td>Vermont Agency of Transportation</td>
</tr>
<tr>
<td>WSPRO</td>
<td>water-surface profile model</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 4 (ARLITH00010004) ON TOWN HIGHWAY 1, CROSSING WARM BROOK, ARLINGTON, VERMONT

By Scott A. Olson and Michael A. Ivanoff

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure ARLITH00010004 on Town Highway 1 crossing Warm Brook, Arlington, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). Results of a Level I scour investigation also are included in Appendix E of this report. A Level I investigation provides a qualitative geomorphic characterization of the study site. Information on the bridge, gleaned from Vermont Agency of Transportation (VTAOT) files, was compiled prior to conducting Level I and Level II analyses and is found in Appendix D.

The site is in the Taconic section of the New England physiographic province in southwestern Vermont. The 12.1-mi² drainage area consists of a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is brush except for the upstream and downstream right banks which are covered by brush and grass.

In the study area, Warm Brook has an incised, straight channel with a slope of approximately 0.003 ft/ft, an average channel top width of 19 ft and an average bank height of 1 ft. The channel bed material ranges from sand to cobble with a median grain size \(D_{50}\) of 33.3 mm (0.109 ft). The geomorphic assessment at the time of the Level I and Level II site visit on July 30, 1996, indicated that the reach was stable.

The Town Highway 1 crossing of Warm Brook is a 49-ft-long, two-lane bridge consisting of one 44-foot steel-beam span (Vermont Agency of Transportation, written communication, January 30, 1996). The bridge is supported by vertical, concrete abutments with wingwalls. The abutments have been placed on top of the previous stone abutments. The channel is skewed approximately 0 degrees to the opening while the opening-skew-to-roadway is 20 degrees.

A scour hole approximately 1.0 ft deeper than the mean thalweg depth was observed mid-channel in the upstream reach within 30 ft of the bridge. The only scour protection measure at the site was type-2 stone fill (less than 36 inches diameter) along the upstream left bank approach to the bridge. 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, 1995). Total scour at a highway crossing is comprised of three components: 1) long-term streambed degradation; 2) contraction scour (due to accelerated flow caused by a reduction in flow area at a bridge) and; 3) local scour (caused by accelerated flow around piers and abutments). Total scour is the sum of the three components. Equations are available to compute depths for contraction and local scour and a summary of the results of these computations follows.

Contraction scour for all modelled flows ranged from 0.0 to 1.7 ft. The worst-case contraction scour occurred at the 500-year discharge. Abutment scour ranged from 8.3 to 11.9 ft. The worst-case abutment scour also 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 bridge is presented in figure 8. Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution.

It is generally accepted that the Froehlich equation (abutment scour) gives “excessively conservative estimates of scour depths” (Richardson and others, 1995, p. 47). Usually, computed scour depths are evaluated in combination with other information including (but not limited to) historical performance during flood events, the geomorphic stability assessment, existing scour protection measures, and the results of the hydraulic analyses. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein.
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>Stream</th>
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<tbody>
<tr>
<td>ARLITH00010004</td>
<td>Warm Brook</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>County</th>
<th>Road</th>
<th>District</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bennington</td>
<td>TH1</td>
<td>1</td>
</tr>
</tbody>
</table>

Description of Bridge

- **Bridge length**: 49 ft
- **Bridge width**: 27.6 ft
- **Max span length**: 44 ft
- **Alignment of bridge to road (on curve or straight)**: Right, straight; Left, curve.
- **Abutment type**: Vertical, concrete
- **Embankment type**: Sloping
- **Stone fill on abutment?**: No
- **Date of inspection**: 7/30/96
- **Date of inspection**: 7/30/96
- **Description of stone fill**: Type-2, along the upstream left bank approach to the bridge.
- **Debris accumulation on bridge at time of Level I or Level II site visit:**
  - **Date of inspection**: 7/30/96
  - **Percent of channel blocked horizontally**: 0
  - **Percent of channel blocked vertically**: 0
  - **Potential for debris**: Moderate. There is a beaver dam upstream of the bridge.

Abutments and wingwalls are concrete. The abutments sit on the previous stone abutments.

There is a mild channel bend through the reach.

July 30, 1996. The beaver dam upstream may affect flow. There is a dam approximately 700 ft downstream of the bridge as well as a comparable sized tributary approximately 500 ft downstream of the bridge.
Description of the Geomorphic Setting

**General topography**

The channel is located within an approximately 1000 foot-wide, flat to slightly irregular valley with moderate relief on either side.

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

**Date of inspection** 7/30/96

**DS left:** Moderately sloped overbank with road embankment.

**DS right:** Flood plain.

**US left:** Swamp.

**US right:** Flood plain.

Description of the Channel

<table>
<thead>
<tr>
<th>Average top width</th>
<th>Average depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 ft.</td>
<td>1 ft.</td>
</tr>
</tbody>
</table>

**Predominant bed material**

Gravel

**Bank material**

Straight, alluvial, and probably incised. The upstream left overbank is swampy.

**Vegetative cover on channel banks near bridge:**

**DS left:** Brush.

**DS right:** Brush and grass.

**US left:** Grass.

**US right:** Y

**Do banks appear stable?** Yes

**Date of observation:**

7/30/96

July 30, 1996. The abutments to a previous structure are located under the bridge. The old abutments significantly restrict flow (see Figure 8).
Hydrology

**Drainage area**  
12.1 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/Taconic</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**  
2,020 ft³/s  
2,730 ft³/s

The 100- and 500-year discharges were taken from the Flood Insurance Study for the Town of Arlington (Federal Emergency Management Agency, 1986). The discharges were within a range defined by flood frequency curves determined from several empirical methods (Benson, 1962; Johnson and Tasker, 1974; FHWA, 1983; Potter, 1957a&b; Talbot, 1887).
Description of the Water-Surface Profile Model (WSPRO) Analysis

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

USGS survey

*Datum tie between USGS survey and VTAOT plans*

Add 223.31 ft. to the arbitrary USGS survey datum to obtain sea level.

*Description of reference marks used to determine USGS datum.*

RM1 is a chiseled X on top of the downstream end of the right abutment (elev. 498.26 ft, arbitrary survey datum). RM2 is a bronze USGS tablet set in the downstream sidewalk at the left end of the bridge (elev. 500.10 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Reference Distance (SRD) in feet</th>
<th>Cross-section development</th>
<th>Comments</th>
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<tr>
<td>USDAM</td>
<td>-500</td>
<td>2</td>
<td>Section between confluence with Fayville Branch and DS dam. The section matches a section from the flood insurance study model (templated from EXITX)</td>
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<tr>
<td>XSEC1</td>
<td>-300</td>
<td>2</td>
<td>Section upstream of the confluence with Fayville Branch (templated from EXITX)</td>
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<td>EXITX</td>
<td>-41</td>
<td>1</td>
<td>Exit section (also named EXTEN)</td>
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<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>15</td>
<td>1</td>
<td>Road Grade section</td>
</tr>
<tr>
<td>APPRO</td>
<td>70</td>
<td>1</td>
<td>Approach section</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 0.043 to 0.048, and overbank “n” values ranged from 0.040 to 0.080.

The starting water surface elevations were taken from a rating curve developed from model output of a section between a dam and the confluence of Warm Brook and Fayville Branch downstream of this bridge for the Flood Insurance Study for the Town of Arlington (Federal Emergency Management Agency, 1986). The surveyed exit section (EXITX) was templated to a location just upstream of the confluence (XSEC1) and to the location in between the confluence and the downstream dam (USDAM) matching the rated section.

The surveyed approach section (APPRO) was located one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This location also provides a consistent method for determining scour variables.
## Bridge Hydraulics Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</tr>
<tr>
<td>Average low steel elevation</td>
<td>495.6</td>
</tr>
<tr>
<td>100-year discharge</td>
<td>2,020</td>
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<tr>
<td>Water-surface elevation in bridge opening</td>
<td>496.2</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>Y</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>929.7</td>
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<tr>
<td>Area of flow in bridge opening</td>
<td>141</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>7.9</td>
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<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>10.7</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>498.0</td>
</tr>
<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>495.5</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>2.5</td>
</tr>
<tr>
<td>500-year discharge</td>
<td>2,730</td>
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<tr>
<td>Water-surface elevation in bridge opening</td>
<td>495.9</td>
</tr>
<tr>
<td>Road overtopping?</td>
<td>Y</td>
</tr>
<tr>
<td>Discharge over road</td>
<td>1,420</td>
</tr>
<tr>
<td>Area of flow in bridge opening</td>
<td>140</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>9.6</td>
</tr>
<tr>
<td>Maximum WSPRO tube velocity at bridge</td>
<td>13.0</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>498.3</td>
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<tr>
<td>Water-surface elevation at Approach section without bridge</td>
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<tr>
<td>Amount of backwater caused by bridge</td>
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<tr>
<td>Incipient overtopping discharge</td>
<td>900</td>
</tr>
<tr>
<td>Water-surface elevation in bridge opening</td>
<td>496.2</td>
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<tr>
<td>Area of flow in bridge opening</td>
<td>141</td>
</tr>
<tr>
<td>Average velocity in bridge opening</td>
<td>6.3</td>
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<td>Maximum WSPRO tube velocity at bridge</td>
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<tr>
<td>Water-surface elevation at Approach section with bridge</td>
<td>496.8</td>
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<tr>
<td>Water-surface elevation at Approach section without bridge</td>
<td>494.2</td>
</tr>
<tr>
<td>Amount of backwater caused by bridge</td>
<td>2.6</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 others, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The results of the scour analysis are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.

The 100-year and the incipient road-overflow discharges resulted in unsubmerged orifice flow. The 500-year discharge resulted in submerged orifice flow. Contraction scour at bridges with orifice flow is best estimated by use of the Chang pressure-flow scour equation (oral communication, J. Sterling Jones, October 4, 1996). Therefore, contraction scour for each modeled discharge was computed by use of the Chang equation (Richardson and others, 1995, p. 145-146). The results of Laursen’s clear-water contraction scour (Richardson and others, 1995, p. 32, equation 20) for all the modeled events were also computed and can be found in appendix F. The 500-year discharge model resulted in the worst contraction scour. The computed depths to streambed armoring suggest armoring will not limit the depth of contraction scour.

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

<table>
<thead>
<tr>
<th>Contraction scour:</th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>Incipient overtopping discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Scour depths in feet)</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>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Clear-water scour</td>
<td>0.7</td>
<td>1.7</td>
<td>0.0</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>
<tr>
<td><strong>Local scour:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abutment scour</td>
<td>10.8</td>
<td>11.9</td>
<td>8.3</td>
</tr>
<tr>
<td>Left abutment</td>
<td>10.9</td>
<td>11.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Right abutment</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier scour</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>
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### Riprap Sizing

<table>
<thead>
<tr>
<th>Riprap Sizing</th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>Incipient overtopping discharge</th>
</tr>
</thead>
<tbody>
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<td>(D&lt;sub&gt;50&lt;/sub&gt; in feet)</td>
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<td></td>
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<td></td>
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<td>1.4</td>
<td>0.8</td>
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<tr>
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<td>--</td>
<td>--</td>
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<tr>
<td>Piers:</td>
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<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 ARLITH00010004 on Town Highway 1, crossing Warm Brook, Arlington, Vermont.
Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure ARLITH00010004 on Town Highway 1, crossing Warm Brook, Arlington, Vermont.
Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure AR Lith00010004 on Town Highway 1, crossing Warm Brook, Arlington, 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>496.2</td>
<td>--</td>
<td>489.1</td>
<td>0.7</td>
<td>10.8</td>
<td>--</td>
<td>11.5</td>
<td>477.6</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td>44.4</td>
<td>--</td>
<td>495.1</td>
<td>--</td>
<td>490.1</td>
<td>0.7</td>
<td>10.9</td>
<td>--</td>
<td>11.6</td>
<td>478.5</td>
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</tr>
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</table>

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

100-yr. discharge is 2,020 cubic-feet per second

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure AR Lith00010004 on Town Highway 1, crossing Warm Brook, Arlington, 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>
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</thead>
<tbody>
<tr>
<td>Left abutment</td>
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<td>--</td>
<td>496.2</td>
<td>--</td>
<td>489.1</td>
<td>1.7</td>
<td>11.9</td>
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<td>13.6</td>
<td>475.5</td>
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<tr>
<td>Right abutment</td>
<td>44.4</td>
<td>--</td>
<td>495.1</td>
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<td>490.1</td>
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<td>13.3</td>
<td>476.8</td>
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1. Measured along the face of the most constricting side of the bridge.
2. Arbitrary datum for this study.

500-yr. discharge is 2,730 cubic-feet per second
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
**WS PRO INPUT FILE**

<table>
<thead>
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<th>T1</th>
<th>U.S. Geological Survey WS PRO Input File arli004.wsp</th>
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<td>T2</td>
<td>Hydraulic analysis for structure ARLITH00010004 Date: 20-DEC-96</td>
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<tr>
<td>T3</td>
<td>ARLINGTON BRIDGE #4 OVER WARM BROOK (FAS 114) SAO</td>
</tr>
</tbody>
</table>

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

| Q | 3400 4600 1510 |
| WS | 493.8 494.3 492.9 |

| XT | EXTEM | -41 |
| GR | -157.8, 504.28 | -51.8, 497.02 | -32.8, 496.20 | -27.3, 494.22 |
|    | -6.3, 491.96  | 6.1, 492.08  | 15.2, 491.26  | 15.3, 489.92  |
|    | 20.6, 488.45  | 24.7, 488.48  | 29.7, 489.07  | 30.9, 489.42  |
|    | 31.1, 490.67  | 35.9, 491.80  | 102.9, 491.98 | 252.3, 494.98 |
|    | 505.6, 499.55 |

| XS | USDAM | -500 |
| GT | -1.19 |
| N  | 0.060 | 0.048 | 0.040 |
| SA | 15.2  | 35.9  |

| XS | XSEC1 | -300 |
| GT | -0.67 |
| N  | 0.060 | 0.048 | 0.040 |
| SA | 15.2  | 35.9  |

| Q | 2020 2730 900 |

| XS | EXITX | -41 |
| GT | 0 |
| N  | 0.060 | 0.048 | 0.040 |
| SA | 15.2  | 35.9  |

| XS | FULLV | 0 |
| GT | 0.14 |
| N  | 0.060 | 0.048 | 0.040 |
| SA | 15.2  | 35.9  |

| BR | BRIDG | 0 495.62 20 |
| GR | 0.0, 496.15 | 0.0, 495.57 | 15.3, 495.56 | 16.2, 489.07 |
|    | 25.3, 488.62 | 30.3, 489.55 | 36.0, 490.08 | 36.8, 493.56 |
|    | 44.2, 493.65 | 44.4, 494.97 | 44.4, 495.10 | 0.0, 496.15 |
|    | 0.043 |
| CD | 1 35.3 * * 75 3.3 |

| XR | RDWAY | 15 28 |
| GR | -383.9, 514.98 | -300.6, 511.04 | -173.4, 505.66 | -93.5, 502.11 |
|    | -18.4, 500.40 | -2.6, 499.55 | -2.4, 500.48 | 45.9, 499.47 |
|    | 46.1, 498.49 | 130.3, 497.30 | 290.2, 496.81 | 401.6, 497.20 |
|    | 492.3, 498.70 | 557.1, 499.58 | 576.4, 500.06 |

<p>| AS | APPRO | 70 |
| GR | -101.2, 503.77 | -42.8, 491.42 | -11.7, 491.95 | 15.3, 491.43 |
|    | 16.2, 489.34 | 18.4, 489.21 | 23.0, 489.16 | 28.1, 489.38 |
|    | 31.9, 490.19 | 32.3, 490.87 | 32.8, 491.17 | 51.5, 491.65 |
|    | 53.6, 493.39 | 105.5, 494.49 | 135.2, 494.65 | 194.7, 494.79 |
|    | 274.9, 496.27 | 366.4, 495.88 | 460.9, 497.26 | 482.2, 498.71 |</p>
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HP 2 BRIDG    496.15 * * 1112
HP 2 RDWAY    497.84 * * 929
HP 1 APPRO    498.04 1 498.04
HP 2 APPRO    498.04 * * 2020

* HP 1 BRIDG    495.94 1 495.94
HP 2 BRIDG    495.94 * * 1335
HP 2 RDWAY    498.09 * * 1421
HP 1 APPRO    498.33 1 498.33
HP 2 APPRO    498.33 * * 2730

* HP 1 BRIDG    496.15 1 496.15
HP 2 BRIDG    496.15 * * 900
HP 1 APPRO    496.77 1 496.77
HP 2 APPRO    496.77 * * 900

* EX
ER
APPENDIX B:

WSPRO OUTPUT FILE
CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = BRIDG;  SRD =       0.

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<th>LEW</th>
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VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = BRIDG;  SRD =       0.

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<th>AREA</th>
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<td>8.23</td>
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X STA.  | 22.5| 23.4| 24.3| 25.1| 25.9| 26.7 |
| A(I)   | 5.9 | 5.6 | 5.4 | 5.3 | 5.2 |
| V(I)   | 9.45| 10.00|10.30|10.47|10.73|

X STA.  | 26.7| 27.6| 28.4| 29.3| 30.3| 31.3 |
| A(I)   | 5.2 | 5.2 | 5.2 | 5.3 | 5.4 |
| V(I)   | 10.74|10.70|10.69|10.48|10.22|

X STA.  | 31.3| 32.3| 33.5| 34.7| 36.4| 44.4 |
| A(I)   | 5.6 | 5.9 | 6.6 | 7.9 | 12.2|
| V(I)   | 9.89| 9.39| 8.49| 7.03| 4.56|

VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = RDWAY;  SRD =      15.

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X STA.  | 219.7|233.1|245.5|257.4|268.2|278.6 |
| A(I)   | 11.1| 10.9| 10.8| 10.2| 10.2|
| V(I)   | 4.17| 4.27| 4.29| 4.56| 4.55|

X STA.  | 278.6|288.4|298.3|308.5|319.4|331.0 |
| A(I)   | 9.9 | 10.0| 10.1| 10.3| 10.6|
| V(I)   | 4.68| 4.65| 4.59| 4.53| 4.38|

X STA.  | 331.0|343.8|358.1|373.6|392.3|440.3 |
| A(I)   | 11.0| 11.7| 11.9| 13.2| 18.5|
| V(I)   | 4.22| 3.98| 3.89| 3.53| 2.51|

CROSS-SECTION PROPERTIES:  ISEQ =  7;  SECID = APPRO;  SRD =      70.

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<th>SA#</th>
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VELOCITY DISTRIBUTION:  ISEQ =  7;  SECID = APPRO;  SRD =      70.

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<th>REW</th>
<th>AREA</th>
<th>K</th>
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<th>VEL</th>
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<tbody>
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X STA.  | 19.3| 24.6| 30.1| 37.9| 46.6| 58.8 |
| A(I)   | 46.4| 47.3| 56.1| 57.3| 67.3|
| V(I)   | 2.18| 2.14| 1.80| 1.76| 1.60|

X STA.  | 58.8| 76.2| 96.6|120.8|147.0|174.0 |
| A(I)   | 75.9| 80.6| 86.2| 89.2| 89.9|
| V(I)   | 1.33| 1.26| 1.17| 1.13| 1.12|

X STA.  | 174.0|202.7|241.1|304.5|364.1|472.4 |
| A(I)   | 93.1|105.7|124.5|120.7|148.3|
| V(I)   | 1.09| 0.96| 0.81| 0.84| 0.68|
### Cross-Section Properties

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<th>SECID</th>
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<th>WSEL</th>
<th>SA#</th>
<th>AREA</th>
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### Velocity Distribution

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<th>VEL</th>
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#### ISEQ = 6; SECID = RDWAY; SRD = 15.

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#### ISEQ = 7; SECID = APPRO; SRD = 70.

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<th>V(I)</th>
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1 141. 6377. 0. 94. 0. 0. 496.15
496.15 141. 6377. 0. 94. 1.00 0. 44. 0.

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = BRIDG; SRD = 0.
WSHEL LEW REW AREA K Q VEL
496.15 0.0 44.4 140.6 6377. 900. 6.40
X STA. 0.0 17.8 19.2 20.5 21.5 22.5
A(I) 18.5 9.4 7.9 6.8 6.3
V(I) 2.43 4.81 5.73 6.66 7.14

X STA. 22.5 23.4 24.3 25.1 25.9 26.7
A(I) 5.9 5.6 5.4 5.3 5.2
V(I) 7.65 8.09 8.34 8.48 8.68

X STA. 26.7 27.6 28.4 29.3 30.3 31.3
A(I) 5.2 5.2 5.2 5.3 5.4
V(I) 8.69 8.66 8.65 8.48 8.27

X STA. 31.3 32.3 33.5 34.7 36.4 44.4
A(I) 5.6 5.9 6.6 7.9 12.2
V(I) 8.00 7.60 6.87 5.69 3.69

CROSS-SECTION PROPERTIES: ISEQ = 7; SECID = APPRO; SRD = 70.
WSHEL S# AREA K TOPW WETP ALPH LEW REW QCR
1 363. 17940. 83. 84. 4297.
2 127. 13829. 17. 19. 1948.
3 634. 29383. 395. 395. 4555.
496.77 1124. 61152. 495. 499. 1.49 -68. 427. 7861.

VELOCITY DISTRIBUTION: ISEQ = 7; SECID = APPRO; SRD = 70.
WSHEL LEW REW AREA K Q VEL
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V(I) 0.56 0.74 0.77 0.77 0.80

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A(I) 56.2 27.7 25.7 26.1 26.7
V(I) 0.80 1.63 1.75 1.72 1.69

X STA. 30.7 36.8 43.8 51.7 67.5 88.2
A(I) 35.3 38.2 41.0 52.9 59.2
V(I) 1.28 1.18 1.10 0.85 0.76

X STA. 88.2 114.3 147.0 182.6 232.1 427.3
A(I) 62.5 70.3 73.0 85.4 129.0
V(I) 0.72 0.64 0.62 0.53 0.35
### U.S. Geological Survey WSPRO Input File arli004.wsp

**Hydraulic analysis for structure ARLITH00010004**  
Date: 20-DEC-96

**ARLINGTON BRIDGE #4 OVER WARM BROOK**  
(FAS 114)  
SAO

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**XSEC1:XS**  
-30. 817. 0.11 494.97 493.19 3400. 493.80 253. 40692. 1.13 656. 0.48 494.28 493.19 3400. 493.80

**EXITX:XS**  
-30. 735. 0.13 495.40 493.19 3400. 493.80 259. 40692. 1.14 656. 0.48 494.28 493.19 3400. 493.80

**FULLV:FV**  
0. 41. 264. 45751. 1.15 0.00 0.34 2.82

---135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.  
**APPRO**  
KRATIO = 0.66

---215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.  
WS3,WSIU,WS1,RGMIN = 495.69 497.86 497.99 495.62

---260 ATTEMPTING FLOW CLASS 4 SOLUTION.

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.  
WS3,WSIU,WS1,LSEL = 495.69 497.86 497.99 495.62

---245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

**FIRST USER DEFINED TABLE.**

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**WSPRO OUTPUT FILE (continued)**
### U.S. Geological Survey WSPRO Input File arli004.wsp

Hydraulic analysis for structure ARLITH00010004   Date: 20-DEC-96

#### ARLINGTON BRIDGE #4 OVER WARM BROOK  (FAS 114)  SAO

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**Conveyance Ratio Out of Recommended Limits.**

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**Attemping Flow Class 3 (6) Solution.**

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**End of Bridge Computations.**

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**End of Bridge Computations.**

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U.S. Geological Survey WSPRO Input File arli004.wsp
Hydraulic analysis for structure ARLI10001004 Date: 20-DEC-96
ARLINGTON BRIDGE #4 OVER WARM BROOK (PAS 114) SAO

XSID:CODE SRDL LEW AREA VHD HF EQL CRWS Q WSEL
SRD FLEN REW K ALPH HO ERR FR# VEL
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-500. 208. 22675. 1.26 ****** 0.52 3.57
XSEC1:XS 200. -27. 464. 0.07 0.50 493.66 ****** 900. 493.59
-300. 202. 25580. 1.23 0.00 0.01 0.28 1.94
EXITX:XS 259. -25. 398. 0.10 0.39 494.08 ****** 900. 493.98
-41. 259. 20920. 1.27 0.01 0.01 0.34 2.26
FULLY:FV 41. -24. 384. 0.11 0.08 494.17 ****** 900. 494.06
0. 41. 199. 19948. 1.28 0.00 0.36 2.35
<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

APPRO:AS 70. -56. 317. 0.21 0.19 494.41 ****** 900. 494.19
70. 70. 91. 14667. 1.70 0.05 -0.01 0.45 2.84
<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
  WS3,WSIU,WS1,LSEL = 493.71 496.19 496.32 495.62

---245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.

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

XSID:CODE SRDL LEW AREA VHD HF EQL CRWS Q WSEL
SRD FLEN REW K ALPH HO ERR FR# VEL
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0. ****** 44. 6377. 1.00 ****** 0.62 6.28
TYPE PPCD FLOW C P/A LSEL BLEN XLAB XRAB
1. **** 2. 0.480 0.000 495.62 ****** ****** ******

XSID:CODE SRD FLEN HF VHD EQL ERR Q WSEL
RDWAY:RG 15. ****** ****** ****** ****** 496.76

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

FIRST USER DEFINED TABLE.

XSID:CODE SRDL LEW AREA VHD HF EQL CRWS Q WSEL
SRD FLEN REW K ALPH HO ERR FR# VEL
USDAM:XS 492.22 0.52 487.26 503.99 ****** 0.25 493.15 492.90
XSEC1:XS ****** 0.28 487.78 503.61 0.50 0.00 0.07 493.66 493.59
EXITX:XS ****** 0.34 488.45 504.28 0.19 0.01 0.10 494.08 493.98
FULLY:FV ****** 0.36 488.59 504.42 0.08 0.00 0.11 494.17 494.06
BRIDG:BR 493.28 0.62 488.62 496.15 ****** 0.61 496.76 496.15
RDWAY:RG ****** 496.81 514.98 ****** 0.01 496.90 496.77
APPRO:AS 492.97 0.11 489.16 503.77 0.08 0.87 0.01 496.78 496.77

SECOND USER DEFINED TABLE.

XSID:CODE CRWS FR# YMIN YMAX HF HO VHD EQL WSEL
USDAM:XS 492.22 0.52 487.26 503.99 ****** 0.25 493.15 492.90
XSEC1:XS ****** 0.28 487.78 503.61 0.50 0.00 0.07 493.66 493.59
EXITX:XS ****** 0.34 488.45 504.28 0.19 0.01 0.10 494.08 493.98
FULLY:FV ****** 0.36 488.59 504.42 0.08 0.00 0.11 494.17 494.06
BRIDG:BR 493.28 0.62 488.62 496.15 ****** 0.61 496.76 496.15
RDWAY:RG ****** 496.81 514.98 ****** 0.01 496.90 496.77
APPRO:AS 492.97 0.11 489.16 503.77 0.08 0.87 0.01 496.78 496.77
APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION
Appendix C. Bed material particle-size distribution for a pebble count in the channel approach of structure ARLITH00010004, in Arlington, Vermont.
APPENDIX D:

HISTORICAL DATA FORM
According to the structural inspection report dated 7/21/94, the structure is a single span rolled beam bridge. The curtain wall at the left abutment has some minor cracking and scaling. The stem of the left abutment has some cracking with leakage at the fascia lines. The wingwalls of both abutments are in good condition with only minor cracking and scaling. The curtain wall at the right abutment has some leakage at the top and some cracking and heavy scaling at the bottom. The stem of the right abutment has some hairline vertical cracking. There has been additional fill and stone fill placed along the edge of the channel at the upstream left wingwall. The channel takes a slight turn into and out of (continued on page 34)
Bridge Hydrologic Data

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

Terrain character: _________________________________________________________________

Stream character & type:

Streambed material: _______________________________________________________________

Discharge Data (cfs):  

<table>
<thead>
<tr>
<th>Q2.33</th>
<th>Q10</th>
<th>Q25</th>
<th>Q50</th>
<th>Q100</th>
<th>Q500</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-immediatly upstream of the site)

Water Surface Elevation Estimates for Existing Structure:

<table>
<thead>
<tr>
<th>Peak discharge frequency</th>
<th>Q2.33</th>
<th>Q10</th>
<th>Q25</th>
<th>Q50</th>
<th>Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water surface elevation (ft)</td>
<td></td>
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<tr>
<td>Velocity (ft / sec)</td>
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</tbody>
</table>

Long term stream bed changes:

Are the roadway overtopped below the Q100? (Yes, No, Unknown): ______  Frequency: _______

Relief Elevation (ft): ___________  Discharge over roadway at Q100 (ft³/sec): _______

Are there other structures nearby? (Yes, No, Unknown): ______  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:
the structure. There is some minor debris in the channel. There are laid up stone retaining walls from an earlier structure left in place in front of the abutments. A memo in the inspection folder notes that a new subfooting at the east abutment was poured on 9/26/91.

USGS Watershed Data

Watershed Hydrographic Data

<table>
<thead>
<tr>
<th>Drainage area (DA)</th>
<th>12.06 mi²</th>
<th>Lake and pond area</th>
<th>0.08 mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed storage (ST)</td>
<td>0.7 %</td>
<td>Bridge site elevation</td>
<td>720 ft</td>
</tr>
<tr>
<td>Headwater elevation</td>
<td>1481 ft</td>
<td>Main channel length</td>
<td>6.56 mi</td>
</tr>
<tr>
<td>10% channel length elevation</td>
<td>740 ft</td>
<td>85% channel length elevation</td>
<td>930 ft</td>
</tr>
<tr>
<td>Main channel slope (S)</td>
<td>21.7 ft / mi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Watershed Precipitation Data

| Average site precipitation | _________ in | Average headwater precipitation | _________ in |
| Maximum 2yr-24hr precipitation event (I24,2) | _________ in |
| Average seasonal snowfall (Sn) | _________ ft |
Bridge Plan Data

Are plans available? Y* If no, type ctrl-n pl Date issued for construction (MM / YYY): -/-
Project Number SA#29 Minimum channel bed elevation: -
Low superstructure elevation: USLAB ___ DSLAB ___ USRAB ___ DSRAB ___
Benchmark location description: B.M. #7, paint spot on corner of downstream right abutment, elev. 178.07

Reference Point (MSL, Arbitrary, Other): Unknown Datum (NAD27, NAD83, Other): -
Foundation Type: ____ (1-Spreadfooting; 2-Pile; 3-Gravity; 4-Unknown)
If 1: Footing Thickness _____ Footing bottom elevation: ______
If 2: Pile Type: _____ (1-Wood; 2-Steel or metal; 3-Concrete) Approximate pile driven length: ______
If 3: Footing bottom elevation: ______
Is boring information available? N If no, type ctrl-n bi Number of borings taken: _____
Foundation Material Type: ______ (1-regolith, 2-bedrock, 3-unknown)
Briefly describe material at foundation bottom elevation or around piles:

Comments:
*Not sure whether these plans correspond with Arlington Bridge 4.
According to Project No - 70 - 30 (T.H. #1) PWA-6114 (Record Plans) 1935,
Sheet 6 shows road over unnamed brook, with the following information:
Concrete bridge S.A. #29; constructed 1931; clear span 44'; roadway width 20'; concrete sidewalk 4'
The sketch also shows a barn very close (within several feet) to the upstream right bank and roadway.
# Cross-sectional Data

Is cross-sectional data available? **N**

If no, type `ctrl-n xs`

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

Comments:

<table>
<thead>
<tr>
<th>Station</th>
<th>Feature</th>
<th>Low cord elevation</th>
<th>Bed elevation</th>
<th>Low cord to bed length</th>
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</thead>
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Source *(FEMA, VTAOT, Other)*? _________

Comments:

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<tr>
<th>Station</th>
<th>Feature</th>
<th>Low cord elevation</th>
<th>Bed elevation</th>
<th>Low cord to bed length</th>
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<th>Station</th>
<th>Feature</th>
<th>Low cord elevation</th>
<th>Bed elevation</th>
<th>Low cord to bed length</th>
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36
APPENDIX E:

LEVEL I DATA FORM
U. S. Geological Survey
Bridge Field Data Collection and Processing Form

Structure Number ARLITH00010004

A. General Location Descriptive
1. Data collected by (First Initial, Full last name) M IVANOFF Date (MM/DD/YY) 07 / 30 / 1996
2. Highway District Number 01
   County BENNINGTON 003
   Waterway (I - 6) WARM BROOK
   Route Number FAS114
   Descriptive comments:
   LOCATED 0.9 MILES EAST OF JUNCTION WITH US 7 SOUTH.

3. Mile marker 000950
   Town ARLINGTON 01375
   Hydrologic Unit Code: 2020003

B. Bridge Deck Observations
4. Surface cover... LBUS 5 RBUS 4 LBDS 5 RBDS 5 Overall 5
   (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 1 UB 1 DS 1 (1- pool; 2- riffle)
6. Bridge structure type 1 (1- single span; 2- multiple span; 3- single arch; 4- multiple arch; 5- cylindrical culvert; 6- box culvert; or 7- other)
7. Bridge length 49 (feet) Span length 44 (feet) Bridge width 27.6 (feet)
8. Road approach to bridge:
   8. LB 2 RB 1 (0 even, 1- lower, 2- higher)
   9. Embankment slope (run / rise in feet / foot):
      US left -- US right --
10. Channel approach to bridge (BF):
    15. Angle of approach: 10
    16. Bridge skew: 0
   17. Channel impact zone 1:
      Exist? Y (Y or N)
      Range? 15 feet UB (US, UB, DS) to 60 feet DS
   18. Channel impact zone 2:
      Exist? N (Y or N)
      Range? feet ___(US, UB, DS) to ___ feet ___
      Impact Severity: 0- none to very slight; 1- Slight; 2- Moderate; 3- Severe

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

Qa/Qc Check by: EW Date: 10/1/96
Computerized by: EW Date: 10/1/96
Reviewed by: SAO Date: 2/7/97
18. Bridge Type: **1a**

1a- Vertical abutments with wingwalls
1b- Vertical abutments without wingwalls

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

3- Spill through abutments

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

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

**#4:** Right over-bank is cut grass with some residential homes.

**#5:** Left bank includes shrub and brush and marsh upstream. Beyond 100 feet left of the left edge of water the surface cover is forest.

---

### C. Upstream Channel Assessment

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>23. Bank protection type: LB 2 RB 0</td>
<td>31. Bank protection condition: LB 2 RB —</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</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.):

**Beaver dam is 250 feet upstream.**

**Left bank protection extends from 24 feet upstream to 5 feet upstream.**
33. Point/Side bar present? __ (Y or N, if N type ctrl-n pb) 34. Mid-bar distance: ------- 35. Mid-bar width: -------
36. Point bar extent: ______ feet _____ (US, UB) to ______ feet _____ (US, UB, DS) positioned ______%LB to ______%RB
37. Material: ______
38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):

NO POINT BARS

39. Is a cut-bank present? __ (Y or if N type ctrl-n cb) 40. Where? ______ (LB or RB)
41. Mid-bank distance: ______
42. Cut bank extent: ______ feet _____ (US, UB) to ______ feet _____ (US, UB, DS)
43. Bank damage: ______ (1- eroded and/or creep; 2- slip failure; 3- block failure)
44. Cut bank comments (eg. additional cut banks, protection condition, etc.):

NO CUT BANKS

45. Is channel scour present? __ (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.):

Thalweg is 1.5 feet.

49. Are there major confluences? __ (Y or if N type ctrl-n mc) 50. How many? ______
51. Confluence 1: Distance ______ 52. Enters on ______ (LB or RB) 53. Type ______ (1- perennial; 2- ephemeral)
   Confluence 2: Distance ______ Enters on ______ (LB or RB) Type ______ (1- perennial; 2- ephemeral)
54. Confluence comments (eg. confluence name):

NO MAJOR CONFLUENCES
Beaver dam has created many seeps along the left bank.

D. Under Bridge Channel Assessment

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

<table>
<thead>
<tr>
<th>56. Height (BF)</th>
<th>57 Angle (BF)</th>
<th>61. Material (BF)</th>
<th>62. Erosion (BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB 15.5 ______</td>
<td>RB 1.5 ______</td>
<td>LB 2 ______</td>
<td>RB 7 ______</td>
</tr>
<tr>
<td>58. Bank width (BF)</td>
<td>59. Channel width (Amb)</td>
<td>60. Thalweg depth (Amb)</td>
<td>90.0</td>
</tr>
<tr>
<td>NO POINT BARS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.):

3421
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. Debris and Ice Comments:

2

Beaver dam is upstream with some dead trees in pond area.

---

### Abutments

<table>
<thead>
<tr>
<th>Abutments</th>
<th>71. Attack (BF)</th>
<th>72. Slope (Qmax)</th>
<th>73. Toe loc. (BF)</th>
<th>74. Scour Condition</th>
<th>75. Scour depth</th>
<th>76. Exposure depth</th>
<th>77. Material</th>
<th>78. Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABUT</td>
<td>10</td>
<td>90</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>7.0</td>
<td>90.0</td>
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<tr>
<td>RABUT</td>
<td>1</td>
<td>0</td>
<td>90</td>
<td>2</td>
<td>2</td>
<td>41.5</td>
<td></td>
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</tbody>
</table>

**Pushed:** LB or RB  **Toe Location (Loc.):** 0- even, 1- set back, 2- protrudes

**Scour cond.:** 0- not evident; 1- evident (comment); 2- footing exposed; 3- undermined footing; 4- piling exposed; 5- settled; 6- failed

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

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

0

3.0

1

Left abutment footing begins 5 feet under bridge from upstream bridge face and extends to 0 feet downstream. The old stone abutment protruding into channel extends from 8 feet under bridge to 8 feet downstream.

Right abutment footing and old stone abutment extends from 15 feet under bridge from upstream bridge face to 13 feet downstream.

---

### Wingwalls

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<tbody>
<tr>
<td>USRWW:</td>
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<tr>
<td>DSLWW:</td>
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<tr>
<td>DSRWW:</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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<tbody>
<tr>
<td>Type</td>
<td>-</td>
<td>0</td>
<td>Y</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Condition</td>
<td>Y</td>
<td>-</td>
<td>1</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Extent</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
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</tr>
</tbody>
</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.):

- 
- 
- 
- 
5 1 5 1 1

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>
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</thead>
<tbody>
<tr>
<td>w1</td>
<td>w2</td>
<td>w3</td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td>8.5</td>
</tr>
<tr>
<td>Pier 2</td>
<td>4.0</td>
<td>5.0</td>
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<tr>
<td>Pier 3</td>
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<tr>
<td>Pier 4</td>
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Level 1 Pier Descr.

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<tr>
<th>1</th>
<th>2</th>
<th>3</th>
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</table>

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

<table>
<thead>
<tr>
<th>Bank protection type (Qmax):</th>
<th>LB</th>
<th>RB</th>
<th>Bank protection condition:</th>
<th>LB</th>
<th>RB</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRD - Section ref. dist. to US face</td>
<td></td>
<td></td>
<td>Bed and bank Material:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bed and bank Material:</td>
<td>0- organics; 1- silt / clay, &lt; 1/16mm; 2- sand, 1/16 - 2mm; 3- gravel, 2 - 64mm; 4- cobble, 64 - 256mm; 5- boulder, &gt; 256mm; 6- bedrock; 7- manmade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank Erosion:</td>
<td>0- not evident; 1- light fluvial; 2- moderate fluvial; 3- heavy fluvial / mass wasting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank protection types:</td>
<td>0- absent; 1- &lt; 12 inches; 2- &lt; 36 inches; 3- &lt; 48 inches; 4- &lt; 60 inches; 5- wall / artificial levee</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank protection conditions:</td>
<td>1- good; 2- slumped; 3- eroded; 4- failed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

- 
- 
- 
- 
- 
- 
- 

NO PIERS

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):

1 1
Point/Side bar present? (Y or N. if N type ctrl-n pb) Mid-bar distance: ______ Mid-bar width: ______
Point bar extent: ______ feet (US, UB, DS) to ______ feet (US, UB, DS) positioned ______ %LB to ______ %RB
Material: ______
Point or side bar comments (Circle Point or Side; note additional bars, material variation, status, etc.):

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

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

Are there major confluences? (Y or if N type ctrl-n mc) How many? ______
Confluence 1: Distance ______ Enters on ______ (LB or RB) Type ______ (1- perennial; 2- ephemeral)
Confluence 2: Distance ______ Enters on ______ (LB or RB) Type ______ (1- perennial; 2- ephemeral)
Confluence comments (eg. confluence name):

F. Geomorphic Channel Assessment

Stage of reach evolution ______
1- Constructed
2- Stable
3- Aggraded
4- Degraded
5- Laterally unstable
6- Vertically and laterally unstable

Left bank protection consists of the old abutment which extends from the bridge face to 8 feet downstream.
Right bank protection consists of the old abutment which extends from bridge face to 13 feet downstream.
The confluence of Warm Brook and Fayville Branch is 526 feet downstream of bridge. A dam exists approxi-
108. Evolution comments (*Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors*):

- 
- 
- 

**NO POINT BARS**

Y
LB
60
12
DS
90
APPENDIX F:

SCOUR COMPUTATIONS
SCOUR COMPUTATIONS

Structure Number: ARL004TH00010004          Town:    ARLINGTON
Road Number:      TH1                        County:  BENNINGTON
Stream:  WARM BROOK

Initials SAO      Date:    1/14/97  Checked:

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 others, 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>2020</td>
<td>2730</td>
<td>900</td>
</tr>
<tr>
<td>Main Channel Area, ft²</td>
<td>150</td>
<td>155</td>
<td>127</td>
</tr>
<tr>
<td>Left overbank area, ft²</td>
<td>473</td>
<td>499</td>
<td>363</td>
</tr>
<tr>
<td>Right overbank area, ft²</td>
<td>1173</td>
<td>1302</td>
<td>634</td>
</tr>
<tr>
<td>Top width main channel, ft</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Top width L overbank, ft</td>
<td>89</td>
<td>91</td>
<td>83</td>
</tr>
<tr>
<td>Top width R overbank, ft</td>
<td>440</td>
<td>444</td>
<td>395</td>
</tr>
<tr>
<td>D50 of channel, ft</td>
<td>0.109</td>
<td>0.109</td>
<td>0.109</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>8.8</td>
<td>9.1</td>
<td>7.5</td>
</tr>
<tr>
<td>y₁, average depth, LOB, ft</td>
<td>5.3</td>
<td>5.5</td>
<td>4.4</td>
</tr>
<tr>
<td>y₁, average depth, ROB, ft</td>
<td>2.7</td>
<td>2.9</td>
<td>1.6</td>
</tr>
<tr>
<td>Total conveyance, approach</td>
<td>121054</td>
<td>138098</td>
<td>61152</td>
</tr>
<tr>
<td>Conveyance, main channel</td>
<td>18083</td>
<td>19117</td>
<td>13829</td>
</tr>
<tr>
<td>Conveyance, LOB</td>
<td>26582</td>
<td>28777</td>
<td>17940</td>
</tr>
<tr>
<td>Conveyance, ROB</td>
<td>76390</td>
<td>90204</td>
<td>29383</td>
</tr>
<tr>
<td>Percent discrepancy, conveyance</td>
<td>0.0008</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Qm, discharge, MC, cfs</td>
<td>301.7</td>
<td>377.9</td>
<td>203.5</td>
</tr>
<tr>
<td>Ql, discharge, LOB, cfs</td>
<td>443.6</td>
<td>568.9</td>
<td>264.0</td>
</tr>
<tr>
<td>Qr, discharge, ROB, cfs</td>
<td>1274.7</td>
<td>1783.2</td>
<td>432.4</td>
</tr>
<tr>
<td>Vm, mean velocity MC, ft/s</td>
<td>2.0</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Vl, mean velocity, LOB, ft/s</td>
<td>0.9</td>
<td>1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Vr, mean velocity, ROB, ft/s</td>
<td>1.1</td>
<td>1.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Vc-m, crit. velocity, MC, ft/s</td>
<td>7.7</td>
<td>7.7</td>
<td>7.5</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>
<td>ERR</td>
<td>ERR</td>
<td>ERR</td>
</tr>
</tbody>
</table>

Results

Live-bed(1) or Clear-Water(0) Contraction Scour?

<table>
<thead>
<tr>
<th></th>
<th>Main Channel</th>
<th>Left Overbank</th>
<th>Right Overbank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
ARMORING

<table>
<thead>
<tr>
<th>D90</th>
<th>0.299</th>
<th>0.299</th>
<th>0.299</th>
</tr>
</thead>
<tbody>
<tr>
<td>D95</td>
<td>0.959</td>
<td>0.959</td>
<td>0.959</td>
</tr>
<tr>
<td>Critical grain size, Dc, ft</td>
<td>0.2584</td>
<td>0.3788</td>
<td>0.1692</td>
</tr>
<tr>
<td>Decimal-percent coarser than Dc</td>
<td>0.133</td>
<td>0.0814</td>
<td>0.273</td>
</tr>
<tr>
<td>Depth to armoring, ft</td>
<td>5.05</td>
<td>12.82</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Clear Water Contraction Scour in MAIN CHANNEL

\[ y_2 = \left( \frac{Q_2^2}{131D_m^{2/3}W_2^2} \right)^{3/7} \] Converted to English Units
\[ y_s = y_2 - y_{bridge} \]
(Richardson and others, 1995, p. 32, eq. 20, 20a)

<table>
<thead>
<tr>
<th>Approach Section</th>
<th>Q100</th>
<th>Q500</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main channel Area, ft²</td>
<td>150</td>
<td>155</td>
<td>127</td>
</tr>
<tr>
<td>Main channel width, ft</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>y1, main channel depth, ft</td>
<td>8.82</td>
<td>9.12</td>
<td>7.47</td>
</tr>
</tbody>
</table>

Bridge Section

| (Q) total discharge, cfs | 2020 | 2730 | 900 |
| (Q) discharge thru bridge, cfs | 1112 | 1335 | 900 |
| Main channel conveyance | 6377 | 6726 | 6377 |
| Total conveyance | 6377 | 6726 | 6377 |
| Q2, bridge MC discharge, cfs | 1112 | 1335 | 900 |
| Main channel area, ft² | 141 | 140 | 141 |
| Main channel width (skewed), ft | 41.7 | 41.7 | 41.7 |
| Cum. width of piers in MC, ft | 0.0 | 0.0 | 0.0 |
| W, adjusted width, ft | 41.7 | 41.7 | 41.7 |
| y_bridge (avg. depth at br.), ft | 3.38 | 3.36 | 3.38 |
| Dm, median (1.25*D50), ft | 0.13625 | 0.13625 | 0.13625 |
| y2, depth in contraction, ft | 3.65 | 4.27 | 3.04 |
| ys, scour depth (y2-y_bridge), ft | 0.27 | 0.91 | -0.34 |

Pressure Flow Scour (contraction scour for orifice flow conditions)

\[ H_b + Y_s = C_q * g_b r / V_c \]
\[ C_q = 1 / C_f * C_c \]
\[ C_f = 1.5 * F_r ^ {0.43} \] (<=1)
\[ C_c = \sqrt{0.10(\frac{H_b}{(ya-w)-0.56})} + 0.79 \] (<=1)
(Richardson and others, 1995, p. 145-146)

<table>
<thead>
<tr>
<th>Q100</th>
<th>Q500</th>
<th>OtherQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q, total, cfs</td>
<td>2020</td>
<td>2730</td>
</tr>
<tr>
<td>Q, thru bridge, cfs</td>
<td>1112</td>
<td>1335</td>
</tr>
<tr>
<td>Total Conveyance, bridge</td>
<td>6377</td>
<td>6726</td>
</tr>
<tr>
<td>Main channel (MC) conveyance, bridge</td>
<td>6377</td>
<td>6726</td>
</tr>
<tr>
<td>Q, thru bridge MC, cfs</td>
<td>1112</td>
<td>1335</td>
</tr>
<tr>
<td>Vc, critical velocity, ft/s</td>
<td>7.70</td>
<td>7.74</td>
</tr>
<tr>
<td>Vc, critical velocity, m/s</td>
<td>2.35</td>
<td>2.36</td>
</tr>
<tr>
<td>Main channel width (skewed), ft</td>
<td>41.7</td>
<td>41.7</td>
</tr>
<tr>
<td>Cum. width of piers in MC, ft</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>W, adjusted width, ft</td>
<td>41.7</td>
<td>41.7</td>
</tr>
<tr>
<td>qbr, unit discharge, ft²/s</td>
<td>26.7</td>
<td>32.0</td>
</tr>
<tr>
<td>qbr, unit discharge, m²/s</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Area of full opening, ft²</td>
<td>141.0</td>
<td>140.0</td>
</tr>
<tr>
<td>Hb, depth of full opening, ft</td>
<td>3.38</td>
<td>3.36</td>
</tr>
<tr>
<td>Hb, depth of full opening, m</td>
<td>1.03</td>
<td>1.02</td>
</tr>
<tr>
<td>Fr, Froude number, bridge MC</td>
<td>0.78</td>
<td>0.95</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Left Abutment</td>
<td>Right Abutment</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>---------------</td>
<td>----------------</td>
</tr>
<tr>
<td>(Qt), total discharge, cfs</td>
<td>2020</td>
<td>2020</td>
</tr>
<tr>
<td>a', abut. length blocking flow, ft</td>
<td>74.1</td>
<td>74.1</td>
</tr>
<tr>
<td>Ae, area of blocked flow ft^2</td>
<td>374.3</td>
<td>374.3</td>
</tr>
<tr>
<td>Qe, discharge blocked abut., cfs</td>
<td>340</td>
<td>340</td>
</tr>
<tr>
<td>Ve, (Qe/Ae), ft/s</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>ya, depth of f/p flow, ft</td>
<td>5.05</td>
<td>5.05</td>
</tr>
<tr>
<td>a'/ya</td>
<td>14.67</td>
<td>14.67</td>
</tr>
<tr>
<td>K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)</td>
<td>0.82</td>
<td>0.82</td>
</tr>
<tr>
<td>theta</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>K2</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Fr, froude number f/p flow</td>
<td>0.071</td>
<td>0.071</td>
</tr>
<tr>
<td>ys, scour depth, ft</td>
<td>10.82</td>
<td>10.82</td>
</tr>
<tr>
<td>HIRE equation (a'/ya &gt; 25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ys = 4<em>Fr^0.33</em>y1*K/0.55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Recipe for Abutment Scour:

**Froehlich's Abutment Scour**

\[
\text{Ys}/\text{Y1} = 2.27 \times K_1 \times K_2 \times (a'/\text{Y1})^{0.43} \times \text{Fr}_1^{0.61} + 1
\]

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

**Comparison of Chang and Laursen results (for unsubmerged orifice flow)**

\[
y_2, \text{from Laursen's equation, ft} = 3.64913 \times 4.268019 \times 3.044039
\]

**Abutment Scour**

\[
\text{Ve} = (\text{Qe}/\text{Ae}) \times \text{ft/s}
\]

\[
\text{ys, scour depth, ft} = 4 \times \text{Fr}^{0.33} \times \text{y1} \times K / 0.55
\]

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

Isbash Relationship
\[ D_{50} = y \cdot K \cdot Fr^2 / (S_s - 1) \] and
\[ D_{50} = y \cdot K \cdot (Fr^2)^{0.14} / (S_s - 1) \]
(Richardson and others, 1995, p112, eq. 81,82)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Q100</th>
<th>Q500</th>
<th>Qother</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fr, Froude Number</td>
<td>0.78</td>
<td>0.95</td>
<td>0.62</td>
</tr>
<tr>
<td>(Fr from the characteristic V and y in contracted section--mc, bridge section)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>y, depth of flow in bridge, ft</td>
<td>3.38</td>
<td>3.36</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Median Stone Diameter for riprap at: left abutment | right abutment, ft

| Fr<=0.8 (vertical abut.)  | 1.27 | ERR | 0.80    |
| Fr>0.8   (vertical abut.) | ERR  | 1.38| ERR     |
| Fr<=0.8 (spillthrough abut.) | 1.11 | ERR | 1.11   |
| Fr>0.8  (spillthrough abut.) | ERR | 1.22| ERR     |