LEVEL II SCOUR ANALYSIS FOR
BRIDGE 28 (BRIDTH00440028) on
TOWN HIGHWAY 44, crossing
PLYMOUTH BROOK,
BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-188

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION
LEVEL II SCOUR ANALYSIS FOR BRIDGE 28 (BRIDTH00440028) on TOWN HIGHWAY 44, crossing PLYMOUTH BROOK, BRIDGEWATER, VERMONT

By SCOTT A. OLSON and JOSEPH D. AYOTTE

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Pembroke, New Hampshire
1996
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### CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

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<th>By</th>
<th>To obtain</th>
</tr>
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<tbody>
<tr>
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</tr>
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<td>millimeter (mm)</td>
</tr>
<tr>
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<td>0.3048</td>
<td>meter (m)</td>
</tr>
<tr>
<td>mile (mi)</td>
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<td>kilometer (km)</td>
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<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>
<td>square mile (mi²)</td>
<td>2.590</td>
<td>square kilometer (km²)</td>
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<tr>
<td><strong>Volume</strong></td>
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<td></td>
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<tr>
<td>cubic foot (ft³)</td>
<td>0.02832</td>
<td>cubic meter (m³)</td>
</tr>
<tr>
<td><strong>Velocity and Flow</strong></td>
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<td></td>
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<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>
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<tr>
<td>cubic foot per second per square mile</td>
<td>0.01093</td>
<td>cubic meter per second per km²</td>
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### OTHER ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<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.
INTRODUCTION

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00440028 on town highway 44 crossing Plymouth Brook, Bridgewater, Vermont (figures 1–8). A Level II study is a basic engineering analysis of the site, including a quantitative analysis of stream stability and scour (U.S. Department of Transportation, 1993). A Level I study is included in Appendix E of this report. A Level I study provides a qualitative geomorphic characterization of the study site. Information on the bridge available from VTAOT files was compiled prior to conducting Level I and Level II analyses and can be found in Appendix D.

The site is in the Green Mountain physiographic division of central Vermont in the town of Bridgewater. The 11.3-m$^2$ drainage area is a predominantly rural basin. In the vicinity of the study site, the left and right banks are pasture.

In the study area, Plymouth Brook has an incised channel with a slope of approximately 0.0054 ft/ft, an average channel top width of 42 ft and an average channel depth of 3 ft. The predominant channel bed material is gravel ($D_{50}$ is 62.3 mm or 0.204 ft). The geomorphic assessment at the time of the Level I and Level II site visit on November 9, 1994, indicated that the reach was stable.
The town highway 44 crossing of Plymouth Brook is a 34-ft-long bridge consisting of one 31-foot concrete span (Vermont Agency of Transportation, written communication, August 24, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. The channel is skewed approximately 10 degrees to the opening while the opening-skew-to-roadway is 5 degrees.

Type-2 (less than 36 inches) stone fill protects the upstream left and right wingwalls. Type-1 (less than 12 inches) stone fill protects the road approaches. Additional details describing conditions at the site are included in the Level II Summary and Appendices D and E.

Scour depths and rock rip-rap sizes were computed using the general guidelines described in Hydraulic Engineering Circular 18 (Richardson and others, 1993). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. The scour analysis results are presented in tables 1 and 2 and a graph of the scour depths is presented in figure 8.
Figure 1. Location of study area on USGS 1:24,000 scale map.
Figure 2. Location of study area on Vermont Agency of Transportation town highway map.
## LEVEL II SUMMARY

<table>
<thead>
<tr>
<th>Structure Number</th>
<th>Stream</th>
<th>County</th>
<th>Road</th>
<th>District</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRIDTH00440028</td>
<td>Plymouth Brook</td>
<td>Windsor</td>
<td>TH044</td>
<td>04</td>
</tr>
</tbody>
</table>

### Description of Bridge

<table>
<thead>
<tr>
<th>Bridge length</th>
<th>Bridge width</th>
<th>Max span length</th>
<th>Alignment of bridge to road (on curve or straight)</th>
<th>Abutment type</th>
<th>Embankment type</th>
<th>Date of inspection</th>
<th>Description of stone fill</th>
<th>Brief description of piers/abutments</th>
<th>Is bridge skewed to flood flow according to Level I survey?</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 ft</td>
<td>20 ft</td>
<td>31 ft</td>
<td>straight</td>
<td>vertical</td>
<td>sloping</td>
<td>11/09/94</td>
<td>Type-2, in good condition, along the bases of the US wingwalls. Type-1 protection on road approaches.</td>
<td>Abutments are vertical and concrete. The footing is exposed on the left abutment.</td>
<td>Y</td>
<td>10</td>
</tr>
</tbody>
</table>

- Is bridge skewed to flood flow according to Level I survey? Y 10

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

<table>
<thead>
<tr>
<th>Date of inspection</th>
<th>Percent of channel blocked horizontally</th>
<th>Percent of channel blocked vertically</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level I</td>
<td>11/09/94</td>
<td>-</td>
</tr>
<tr>
<td>Level II</td>
<td>Low</td>
<td>-</td>
</tr>
</tbody>
</table>

### Potential for debris:

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

---

7
Description of the Geomorphic Setting

**General topography**
At the bridge site, Plymouth Brook has entered the valley of Broad Brook. Upstream of the site, Plymouth Brook is a steep gradient upland stream.

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

**Date of inspection** 11/09/94

| DS left: | wide flood plain |
| DS right: | wide flood plain |
| US left: | bank is at the foot of a moderately steep hillside |
| US right: | wide flood plain |

**Description of the Channel**

| Average top width | 42 |
| Predominant bed material | gravel |
| Average depth | 3 |
| Bank material | silt/clay |
| Predominant bed material | probably incised channel with relatively wide floodplains compared to the channel |

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

| DS left: | pasture |
| DS right: | pasture |
| US left: | pasture |
| US right: | Y |

**Do banks appear stable?**

11/09/94--There is no fluvial erosion evident on either the upstream or downstream banks.

11/09/94--none

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

**Drainage area** 11.3 mi²

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

<table>
<thead>
<tr>
<th>Physiographic province</th>
<th>Percent of drainage area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Mountain Prov.</td>
<td>100</td>
</tr>
</tbody>
</table>

**Is drainage area considered rural or urban?** Rural

Describe any significant urbanization:

None. Area is mostly forested high-elevation headwater drainage.

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

**USGS gage description**

**USGS gage number**

**Gage drainage area** 3070 mi²

**Is there a lake/pond that will significantly affect hydrology/hydraulics?** No

**Calculated Discharges**

<table>
<thead>
<tr>
<th>Q100</th>
<th>Q500</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft³/s</td>
<td>ft³/s</td>
</tr>
<tr>
<td>3070</td>
<td>3990</td>
</tr>
</tbody>
</table>

The Q100 and Q500 discharges based upon a direct cubic feet per second per square mile of drainage relationship with discharges estimated for nearby (1500 feet) Bridgewater bridge 027 and compared with several different empirical methods (Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887; FEMA, 1980). Bridge 027 discharges had been based upon an area relationship [(13.9/26.9) to the 0.7 power] with bridge 57 on Broad Brook which had flood frequency estimates available in the VTAOT database (VTAOT, written communication, May 1995).
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  
Not applicable.

Description of reference marks used to determine USGS datum.  
RM1 is a chiseled ‘X’ at the downstream left corner of the bridge deck (elev. 999.45 ft, arbitrary datum).  RM2 is a chiseled ‘X’ at the upstream right corner of the bridge deck (elev. 1000.13 ft, arbitrary datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Section Reference Distance (SRD) in feet</th>
<th>Cross-section development</th>
<th>Comments</th>
</tr>
</thead>
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<tr>
<td>EXITX</td>
<td>-51</td>
<td>1</td>
<td>Exit section</td>
</tr>
<tr>
<td>FULLV</td>
<td>0</td>
<td>2</td>
<td>Downstream Full-valley section (Templated from EXITX)</td>
</tr>
<tr>
<td>BRIDG</td>
<td>0</td>
<td>1</td>
<td>Bridge section</td>
</tr>
<tr>
<td>RDWAY</td>
<td>9</td>
<td>1</td>
<td>Road Grade section</td>
</tr>
<tr>
<td>APPRO</td>
<td>50</td>
<td>2</td>
<td>Modelled Approach section (Templated from SURVA)</td>
</tr>
<tr>
<td>SURVA</td>
<td>71</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 analysis reported herein reflects 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, Jr. and Schneider (1989). Final adjustments to the values were made during the modelling of the reach. Channel “n” values for the reach ranged from 0.035 to 0.037, and overbank “n” values ranged from 0.030 to 0.032.

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 0.0054 ft/ft which was estimated from an analysis of surveyed thalweg points, edge of water points, and the topographic map (U.S. Geological Survey, 1966).

The surveyed approach section (SURVA) was moved along the approach channel slope (0.012 ft/ft) to establish the modelled approach section (APPRO), one bridge length upstream of the upstream face as recommended by Shearman and others (1986). This approach also provides a consistent method for determining scour variables.
Bridge Hydraulics Summary

Average bridge embankment elevation  999.8 ft
Average low steel elevation  996.8 ft

100-year discharge  3070 ft³/s
Water-surface elevation in bridge opening  997.1 ft
Road overtopping?  Y  Discharge over road  80 ft³/s
Area of flow in bridge opening  278 ft²
Average velocity in bridge opening  10.8 ft/s
Maximum WSPRO tube velocity at bridge  12.8 ft/s

Water-surface elevation at Approach section with bridge  999.9 ft
Water-surface elevation at Approach section without bridge  994.7 ft
Amount of backwater caused by bridge  5.2 ft

500-year discharge  3990 ft³/s
Water-surface elevation in bridge opening  997.1 ft
Road overtopping?  Y  Discharge over road  772 ft³/s
Area of flow in bridge opening  278 ft²
Average velocity in bridge opening  11.6 ft/s
Maximum WSPRO tube velocity at bridge  13.8 ft/s

Water-surface elevation at Approach section with bridge  1000.7 ft
Water-surface elevation at Approach section without bridge  995.4 ft
Amount of backwater caused by bridge  5.3 ft

Incipient overtopping discharge  2857 ft³/s
Water-surface elevation in bridge opening  997.1 ft
Area of flow in bridge opening  278 ft²
Average velocity in bridge opening  10.3 ft/s
Maximum WSPRO tube velocity at bridge  12.2 ft/s

Water-surface elevation at Approach section with bridge  999.5 ft
Water-surface elevation at Approach section without bridge  994.4 ft
Amount of backwater caused by bridge  5.1 ft
Scour Analysis Summary

Special Conditions or Assumptions Made in Scour Analysis

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

The 100-year, 500-year and incipient road-overflow 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). Therefore, contraction scour for the 100-year, 500-year and incipient road-overflow discharges 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, 1993, p. 35, equation 18) for the three events were also computed and can be found in appendix F.

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

Scour at the right abutment was computed by use of the HIRE equation (Richardson and others, 1993, p. 50, equation 25) because the HIRE equation is recommended when the length to depth ratio of the embankment blocking flow exceeds 25. The variables used by the HIRE abutment-scour equation are defined the same as those defined for the Froehlich abutment-scour equation.
### Scour Results

**Contraction scour:**

<table>
<thead>
<tr>
<th></th>
<th>100-yr discharge</th>
<th>500-yr 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>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Clear-water scour</td>
<td>1.4</td>
<td>2.1</td>
<td>0.9</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>15.0</td>
<td>15.8</td>
<td>14.6</td>
</tr>
<tr>
<td>Left abutment</td>
<td>9.2</td>
<td>9.3</td>
<td>8.3</td>
</tr>
<tr>
<td>Right abutment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pier scour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 3</td>
<td></td>
<td></td>
<td></td>
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</table>

### Rock Riprap Sizing

**Incipient overtopping**

<table>
<thead>
<tr>
<th></th>
<th>100-yr discharge</th>
<th>500-yr discharge</th>
<th>$D_{50}$ in feet</th>
<th>discharge</th>
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<tr>
<td><strong>Abutments:</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Left abutment</td>
<td>2.3</td>
<td>2.7</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Right abutment</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Piers:</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00440028 on town highway 44, crossing Plymouth Brook, Bridgewater, Vermont.
Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00440028 on town highway 44, crossing Plymouth Brook, Bridgewater, Vermont.
Table 1. Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00440028 on Town Highway 44, crossing Plymouth Brook, Bridgewater, 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>996.46</td>
<td>--</td>
<td>989.4</td>
<td>1.4</td>
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<td>16.4</td>
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<tr>
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<td>--</td>
<td>997.06</td>
<td>--</td>
<td>986.9</td>
<td>1.4</td>
<td>9.2</td>
<td>--</td>
<td>10.6</td>
<td>976.3</td>
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</table>

100-yr. discharge is 3,070 cubic-feet per second

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

Table 2. Remaining footing/pile depth at abutments for the 500-year discharge at structure BRIDTH00440028 on Town Highway 44, crossing Plymouth Brook, Bridgewater, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

<table>
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<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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<tbody>
<tr>
<td>Left abutment</td>
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<td>996.46</td>
<td>--</td>
<td>989.4</td>
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500-yr. discharge is 3,990 cubic-feet per second

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


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


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


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


APPENDIX A:

WS PRO INPUT FILE
WS PRO INPUT FILE

T1 U.S. GEOLOGICAL SURVEY WS PRO INPUT FILE brid028.wsp
T2 CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
T3 HYDRAULIC ANALYSIS OF BRID028 SAO

J1 * * 0.002
J3 6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3

Q 3070 3990 2857
WS 994.6 995.3 994.5
SK 0.0054 0.0054 0.0054

XS EXITSX -51
GR -81.8, 994.85 -7.6, 994.21 0.0, 990.46 12.1, 986.80
GR 19.8, 986.08 25.6, 985.93 34.8, 986.76 41.9, 988.99
GR 47.9, 992.72 72.2, 994.10 104.6, 995.55 195.9, 996.01
GR 354.0, 999.64 484.2, 1000.65 543.6, 1016.91
N 0.031 0.037 0.032
SA -7.6 47.9

XS FULLV 0 * * * 0.0054

BR BRIDG 0 996.8 10
GR 0.0, 996.46 0.3, 989.39 3.6, 987.97 5.6, 987.21
GR 11.7, 986.46 19.2, 986.83 27.8, 986.87 27.8, 987.40
GR 27.9, 988.45 29.5, 988.51 29.5, 997.06 0.0, 996.46
N 0.035
CD 4 17.0 5.1 999.5 60.0 5.2

XR RDWAY 9 20.0 2
GR -127.1, 1005.36 -49.4, 1000.15 0.0, 999.51 30.5, 1000.10
GR 145.7, 999.46 251.2, 1001.06 384.1, 1004.91 470.7, 1010.03
GR 577.0, 1019.34

XT SURVA 71
GR -62.4, 1005.41 -49.9, 997.07 -13.7, 993.87 -6.9, 991.30
GR 0.0, 987.71 1.3, 987.37 9.2, 987.30 18.0, 987.38
GR 21.6, 987.78 24.2, 989.04 35.5, 991.10 40.8, 993.67
GR 66.2, 994.81 100.1, 997.28 269.7, 999.67 278.2, 1000.69
GR 316.7, 1000.69 324.4, 1003.68 346.2, 1004.38 361.3, 1013.93

AS APPRO 50
GT -0.25
N 0.030 0.037 0.032
SA -14. 40.8

HP 1 BRIDG 997.06 1 997.06
HP 2 BRIDG 997.06 * * 2991
HP 2 RDWAY 999.92 * * 80
HP 1 APPRO 999.92 1 999.92
HP 2 APPRO 999.92 * * 3070

HP 1 BRIDG 997.06 1 997.06
HP 2 BRIDG 997.06 * * 3223
HP 2 RDWAY 1000.63 * * 772
HP 1 APPRO 1000.74 1 1000.74
HP 2 APPRO 1000.74 * * 3990
APPENDIX B:

WS PRO OUTPUT FILE
**WSPRO OUTPUT FILE**

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH00440028 USING FILE brid028.dca
HYDRAULIC ANALYSIS OF BRIDTH00440028 SAO

*** RUN DATE & TIME: 09-15-95 13:38

CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.
WSEL SA# AREA K TOPW WETP ALPH LEW REM QCR
1 278. 2#178. 0. 75. 0. 0. 0. 0.
997.06 278. 2#178. 0. 75. 1.00 0. 30. 0.

VELOCITY DISTRIBUTION: ISEQ = 3; SECID = BRIDG; SRD = 0.
WSEL LNM REM AREA K Q VEL
997.06 0.0 29.5 277.6 2#178. 2991. 10.77
X STA. 0.0 3.3 5.0 6.5 7.9 9.2
A(I) 23.7 15.3 13.9 13.1 12.6
V(I) 6.32 9.76 10.75 11.42 11.88
X STA. 9.2 10.5 11.7 12.9 14.0 15.2
A(I) 12.4 11.8 11.9 11.8 11.7
V(I) 12.11 12.72 12.54 12.73 12.77
X STA. 15.2 16.4 17.6 18.8 20.0 21.2
A(I) 11.8 11.7 11.8 12.2 12.4
V(I) 12.70 12.74 12.63 12.25 12.08
X STA. 21.2 22.5 23.8 25.2 26.7 29.5
A(I) 12.4 13.0 13.6 15.2 25.3
V(I) 12.02 11.47 11.01 9.81 5.91

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = RDWAY; SRD = 9.
WSEL LNM REM AREA K Q VEL
999.92 -31.6 176.0 36.8 619. 80. 2.17
X STA. -31.6 -11.8 -6.0 -1.7 2.1 7.6
A(I) 2.6 1.7 1.6 1.5 1.8
V(I) 1.56 2.36 2.55 2.73 2.29
X STA. 7.6 98.0 107.7 114.7 120.4 125.0
A(I) 5.2 2.2 1.9 1.7 1.5
V(I) 0.77 1.85 2.12 2.34 2.58
X STA. 125.0 129.2 132.9 136.4 139.6 142.6
A(I) 1.5 1.4 1.4 1.3 1.3
V(I) 2.67 2.85 2.90 3.01 3.05
X STA. 142.6 145.6 148.6 152.5 157.7 176.0
A(I) 1.3 1.3 1.5 1.7 2.5
V(I) 2.99 3.00 2.68 2.41 1.57

VELOCITY DISTRIBUTION: ISEQ = 5; SECID = APPRO; SRD = 50.
WSEL LNM REM AREA K Q VEL
999.92 -54.5 273.9 1334.5 18434. 3070. 2.29
X STA. -54.5 -30.8 -18.6 -9.0 -3.1 1.0
A(I) 82.5 64.7 64.2 54.9 48.5
V(I) 1.86 2.37 2.39 2.80 3.16
X STA. 1.0 4.5 7.8 11.2 14.5 17.8
A(I) 44.6 42.9 43.3 42.7 42.6
V(I) 3.44 3.58 3.55 3.60 3.61
X STA. 17.8 21.2 25.3 30.0 35.5 44.7
A(I) 43.0 47.8 49.0 52.1 66.6
V(I) 3.57 3.21 3.13 2.95 2.30
X STA. 44.7 57.4 72.8 97.8 145.8 273.9
A(I) 76.5 83.1 99.2 124.2 171.1
V(I) 2.01 1.85 1.55 1.24 0.90
### CROSS-SECTION PROPERTIES: ISEQ = 3; SECID = BRIDG; SRD = 0.

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

---

### EXITX:XS

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### FULLX:FW

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

---

125 FR# EXCEEDS FNTS TEST AT SECID "APPRO": TRIALS CONTINUED.

FNTS TEST, FR#, WSEL, CRWS = 0.80 | 0.94 | 994.65 | 993.86

---

110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.

WSL1M1, WSL1M2, DELTAY = 993.96 | 1013.68 | 0.50

---

24
---115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.
WSLIM1, WSLIM2, CRWS = 993.96 1013.68 993.86

APPRO: AS 50. -25. 323. 1.53 0.30 996.18 993.86 3070. 994.66
50. 50. 37327. 1.09 0.10 0.00 0.94 8.49 0.50
<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
WS3, WS1, WSEL = 994.23 997.79 997.91 996.80

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

---315 FR# EXCEEDS FNTEST AT SECID "FULLV": TRIALS CONTINUED.
FNTEST, FR#, WSEL = 0.80 1.04 995.35 994.26

---110 WSEL NOT FOUND AT SECID "FULLV": REDUCED DELTAY.
WSLIM1, WSLIM2, DELTAY = 994.49 1017.19 0.50

---115 WSEL NOT FOUND AT SECID "FULLV": USED WSMIN = CRWS.
WSLIM1, WSLIM2, CRWS = 994.49 1017.19 994.26

---140 AT SECID "FULLV": END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL, YLT, YRT = 995.26 995.13 1017.19

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
CREATED ON 29-AUG-95 FOR BRIDGE BRIDGET00440028 USING FILE brid028.dca
HYDRAULIC ANALYSIS OF BRIDGET00440028 SAO
*** RUN DATE & TIME: 09-15-95 13:38

---315 FR# EXCEEDS FNTEST AT SECID "FULLV": TRIALS CONTINUED.
FNTEST, FR#, WSEL, CRWS = 0.80 1.04 995.35 994.26

---110 WSEL NOT FOUND AT SECID "FULLV": REDUCED DELTAY.
WSLIM1, WSLIM2, DELTAY = 994.49 1017.19 0.50

---115 WSEL NOT FOUND AT SECID "FULLV": USED WSMIN = CRWS.
WSLIM1, WSLIM2, CRWS = 994.49 1017.19 994.26

---140 AT SECID "FULLV": END OF CROSS SECTION EXTENDED VERTICALLY.
WSEL, YLT, YRT = 995.26 995.13 1017.19

WSPRO OUTPUT FILE (continued)
<<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

---125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS =  0.80    0.99     995.43     995.15

---110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY =  994.76    1013.68    0.50

---115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS =   994.76    1013.68     995.15

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

---215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
WS1,WSSD,WS3,RGMIN =  1000.46       0.00     995.57     999.46

---260 ATTEMPTING FLOW CLASS 4 SOLUTION.

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
WS3,WSIU,WS1,LSEL =   995.34     999.97    1000.06     996.80

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

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

FIRST USER DEFINED TABLE.

SECOND USER DEFINED TABLE.
WSPRO OUTPUT FILE (continued)

U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid028.wsp
CREATED ON 29-AUG-95 FOR BRIDGE BRIDTH0440028 USING FILE brid028.dca
HYDRAULIC ANALYSIS OF BRID028 SAD

*** RUN DATE & TIME: 09-20-96 11:53

---125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS = 0.80 0.92 994.39 993.57

---110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 993.71 1013.68 0.50

---115 WSEL NOT FOUND AT SECID "APPRO": USED WS MIN = CRWS.
WSLIM1,WSLIM2,CRWS = 993.71 1013.68 993.57

APPRO:AS 50 -22 301 1.49 0.31 995.90 993.57 2857 994.40
50 50 63 34185 1.06 0.11 0.00 0.92 9.50

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

---220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
WS3,WSIU,WS1,LSEL = 993.90 997.30 997.44 996.80

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

---250 FIRST USER DEFINED TABLE.

---255 SECOND USER DEFINED TABLE.
APPENDIX C:

BED-MATERIAL PARTICAL-SIZE DISTRIBUTION
Appendix C. Bed material particle-size distributions for three pebble count transects at the approach cross-section for structure BRIDTH00440028, in Bridgewater, Vermont.
APPENDIX D:

HISTORICAL DATA FORM