LEVEL II SCOUR ANALYSIS FOR BRIDGE 42 (BRIDTH00040042) on TOWN HIGHWAY 4, crossing DAILEY HOLLOW BROOK, BRIDGEWATER, VERMONT

U.S. Geological Survey
Open-File Report 96-243

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION
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<table>
<thead>
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<th>By</th>
<th>To obtain</th>
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<td>inch (in.)</td>
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<td>millimeter (mm)</td>
</tr>
<tr>
<td>foot (ft)</td>
<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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<td><strong>Slope</strong></td>
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</tr>
<tr>
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<td>meter per kilometer (m/km)</td>
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<td><strong>Area</strong></td>
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<td></td>
</tr>
<tr>
<td>square mile (mi²)</td>
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<td>square kilometer (km²)</td>
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<td><strong>Volume</strong></td>
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<td></td>
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<td>cubic foot (ft³)</td>
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<td>cubic meter (m³)</td>
</tr>
<tr>
<td><strong>Velocity and Flow</strong></td>
<td></td>
<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>
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<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>second per square kilometer [(m³/s)/km²]</td>
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### Other Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</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 42 (BRIDTH00040042) ON TOWN HIGHWAY 4, CROSSING DAILEY HOLLOW BROOK, BRIDGEWATER, VERMONT

By Scott A. Olson and Matthew A. Weber

INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure BRIDTH00040042 on town highway 4 crossing Dailey Hollow 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 2.20-mi² drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the overbanks are covered by shrubs and trees except for the upstream right overbank where there is a house. Dailey Hollow Brook enters Dailey Hollow Branch at the downstream face of the bridge.

In the study area, Dailey Hollow Brook has an incised, sinuous channel with a slope of approximately 0.035 ft/ft. The channel top width and channel depth upstream of the bridge is 19 ft and 3 ft, respectively. Downstream of the bridge and the confluence the channel top width and channel depth is 39 ft and 2 ft respectively. The predominant channel bed material is cobble and gravel \( (D_{50} \text{ is } 64.7 \text{ mm or } 0.212 \text{ ft}) \). The geomorphic assessment at the time of the Level I and Level II site visit on November 1, 1994, indicated that the reach was stable.

The town highway 4 crossing of Dailey Hollow Brook is a 25-ft-long, one-lane bridge consisting of one 23-foot concrete span (Vermont Agency of Transportation, written communication, August 25, 1994). The bridge is supported by vertical, concrete abutments with wingwalls. Type-2 stone fill (less than 36 inches) exists along all four wingwalls, the downstream right road approach, and the channel banks in the immediate vicinity of the bridge. The channel is skewed approximately 20 degrees to the opening; the opening-skew-to-roadway is also 20 degrees. 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). 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 modelled flows was 0.0 ft. Abutment scour ranged from 3.9 to 5.4 ft. with the worst-case abutment scour occurring 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, 1993, p. 48). Many factors, including historical performance during flood events, the geomorphic assessment, scour protection measures, and the results of the hydraulic analyses, must be considered to properly assess the validity of abutment scour results. Therefore, scour depths adopted by VTAOT may differ from the computed values documented herein, based on the consideration of additional contributing factors and experienced engineering judgement.
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>BRIDTH00040042</th>
<th>Stream</th>
<th>Dailey Hollow Brook</th>
</tr>
</thead>
<tbody>
<tr>
<td>County</td>
<td>Windsor</td>
<td>Road</td>
<td>TH04</td>
</tr>
<tr>
<td>District</td>
<td>04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Description of Bridge

- **Bridge length:** 25 ft
- **Bridge width:** 17.4 ft
- **Max span length:** 23 ft
- **Alignment of bridge to road (on curve or straight):** straight
- **Abutment type:** vertical
- **Embankment type:** sloping on left
- **Stone fill on abutment?:** no
- **Date of inspection:** 11/01/94

Type-2 stone protects the wingwalls and the channel banks in the vicinity of the bridge. The downstream right road embankment is also protected with type-2 stone. The abutments and wingwalls are concrete.

| Debris accumulation on bridge at time of Level I or Level II site visit: |
|-----------------------------|-----------------------------|
| Date of inspection | Percent of channel blocked horizontally | Percent of channel blocked vertically |
| Level I               | 11/01/94                    | -              | -              |
| **Level II** | Moderate with the banks upstream often undercut with many trees |

Potential for debris

November 1, 1994. Dailey Hollow Brook empties into Dailey Hollow Branch immediately downstream of the bridge. Both streams are roughly the same size.
Description of the Geomorphic Setting

**General topography**
The bridge is in a steep narrow valley with moderate relief.

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

**Date of inspection** 11/01/94

- **DS left:** Steep high bank. A gravel road parallels the left bank.
- **DS right:** Moderately sloping bank.
- **US left:** Steep high bank. A gravel road parallels the left bank.
- **US right:** High river bank with a flat narrow overbank to a steep valley wall.

**Description of the Channel**

<table>
<thead>
<tr>
<th>Average top width</th>
<th>19 (US)</th>
<th>Predominant bed material</th>
<th>cobble / gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average depth</td>
<td>3.2 (US)</td>
<td>Bank material</td>
<td>High gradient,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>slightly sinuous stream with no flood plains.</td>
</tr>
</tbody>
</table>

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

- **DS left:** Forested.
- **DS right:** Immediate banks have significant woody vegetation; grass on overbanks.
- **US left:** Forested.
- **US right:** Immediate bank is grass; forested beyond.

**Do banks appear stable?**

- **Y**

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

11/01/94--None.
### Hydrology

**Drainage area**  
2.20 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  
None.

**Describe any significant urbanization:**

---

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

**USGS gage description**

**USGS gage number**

**Gage drainage area**  
No

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

---

**Calculated Discharges**

<table>
<thead>
<tr>
<th>Q100</th>
<th>805 ft³/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q500</td>
<td>1,060 ft³/s</td>
</tr>
</tbody>
</table>

Q100 and Q500 for Bridgewater bridge #42 were based on a drainage area relationship with Bridgewater bridge #30 which is on Dailey Hollow Branch. The Q100 for bridge #30 was taken from VTAOT files. The Q500 for bridge #30 was determined by a weighted average of numerous extrapolated empirical methods which were applicable to a stream with it’s size drainage in this region (Potter, 1957a&b; Johnson and Tasker, 1974; FHWA, 1983; Talbot, 1887; FEMA, 1980).
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 1355 feet to the study’s arbitrary datum to obtain VTAOT plans’ datum (NAD27).

Description of reference marks used to determine USGS datum. RM1 is the center of a bronze disk on top of the downstream end of the right abutment (elev. 99.62 ft, arbitrary survey datum). RM2 is a chiseled X on the upstream end of the left abutment (elev. 99.23 ft, arbitrary survey datum).

Cross-Sections Used in WSPRO Analysis

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Section Reference Distance (SRD) in feet</th>
<th>2Cross-section development</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>EXITX</td>
<td>-45</td>
<td>1</td>
<td>Surveyed exit section downstream of the confluence of a Dailey Hollow Brook and Dailey Hollow Branch (this section modelled with the combined discharge).</td>
</tr>
<tr>
<td>EXIT2</td>
<td>-20</td>
<td>2</td>
<td>Exit section (templated from EXITX)</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>55</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 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 0.055 to 0.075, and overbank “n” values ranged from 0.055 to 0.105.

Since the confluence of Dailey Hollow Brook and Dailey Hollow Branch was at the immediate downstream face of the bridge, the exit section (EXITX) was surveyed just downstream of the confluence. Normal depth at the exit section (EXITX) was assumed and used as the starting water surface for the model. 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 0.0221 ft/ft which was determined from surveyed thalweg points downstream of the confluence.

The discharges used in the normal depth computations were 1,780 ft³/s (100-year) and 2,260 ft³/s (500-year), which are the estimated combined flow of the Dailey Hollow Brook and Dailey Hollow Branch. Both streams are assumed to peak at the same time since each has similar basin characteristics including drainage area. The 100-year discharge of Dailey Hollow Branch is from the VTAOT database (written communication, May 1995). The 500-year discharge for Dailey Hollow Branch was based on a drainage area relationship (2.2/2.5) with the study site.

The surveyed exit section was then used as a template and moved upstream in the model with a correction for the bed slope to a location one bridge length downstream of the bridge and the discharge was changed to only include the flows of Dailey Hollow Brook.
Bridge Hydraulics Summary

Average bridge embankment elevation

99.6 ft

Average low steel elevation

97.9 ft

100-year discharge

805 ft³/s

Water-surface elevation in bridge opening

90.7 ft

Road overtopping?  ________  Discharge over road  ________  -- ft³/s

Area of flow in bridge opening

106 ft²

Average velocity in bridge opening

7.6 ft/s

Maximum WSPRO tube velocity at bridge

9.5 ft/s

Water-surface elevation at Approach section with bridge

91.6 ft

Water-surface elevation at Approach section without bridge

91.8 ft

Amount of backwater caused by bridge

-- ft

500-year discharge

1,060 ft³/s

Water-surface elevation in bridge opening

91.5 ft

Road overtopping?  ________  Discharge over road  ________  -- ft³/s

Area of flow in bridge opening

121 ft²

Average velocity in bridge opening

8.8 ft/s

Maximum WSPRO tube velocity at bridge

11.1 ft/s

Water-surface elevation at Approach section with bridge

92.6 ft

Water-surface elevation at Approach section without bridge

92.7 ft

Amount of backwater caused by bridge

-- ft

Incipient overtopping discharge

-- ft³/s

Water-surface elevation in bridge opening

-- ft

Area of flow in bridge opening

-- ft²

Average velocity in bridge opening

-- ft/s

Maximum WSPRO tube velocity at bridge

-- ft/s

Water-surface elevation at Approach section with bridge

-- ft

Water-surface elevation at Approach section without bridge

-- ft

Amount of backwater caused by bridge

-- 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.

Contraction scour was computed by use of the live-bed contraction scour equation (Richardson and others, 1993, p. 33, equation 16,17). For contraction scour computations, the average depth in the contracted section (AREA/TOPWIDTH) is subtracted from the depth of flow computed by the scour equation (Y2) to determine the actual amount of scour.

Abutment scour was computed by use of the Froehlich equation (Richardson and others, 1993, p. 49, equation 24). 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>
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<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>0.0</td>
<td>0.0</td>
<td>--</td>
</tr>
<tr>
<td>Clear-water scour</td>
<td>1.0^−</td>
<td>2.3^−</td>
<td>−</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><strong>Abutment scour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left abutment</td>
<td>3.9^−</td>
<td>5.0^−</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pier scour</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td></td>
<td></td>
<td></td>
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<td>Pier 2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pier 3</td>
<td></td>
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<td></td>
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## Rock Riprap Sizing

<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><strong>Abutments:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left abutment</td>
<td>1.1</td>
<td>1.5</td>
<td>--</td>
</tr>
<tr>
<td>Right abutment</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Piers:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 1</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pier 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7. Water-surface profiles for the 100- and 500-yr discharges at structure BRIDTH00040042 on town highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.
Figure 8. Scour elevations for the 100-yr and 500-yr discharges at structure BRIDTH00040042 on town highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.
**Table 1.** Remaining footing/pile depth at abutments for the 100-year discharge at structure BRIDTH00040042 on Town Highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station</th>
<th>VTAOT plans' bridge seat 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>1452.4</td>
<td>97.66</td>
<td>81</td>
<td>85.4</td>
<td>0.0</td>
<td>4.3</td>
<td>--</td>
<td>4.3</td>
<td>81.1</td>
<td>0</td>
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<tr>
<td>Right abutment</td>
<td>20.8</td>
<td>1452.8</td>
<td>98.13</td>
<td>81</td>
<td>86.1</td>
<td>0.0</td>
<td>3.9</td>
<td>--</td>
<td>3.9</td>
<td>82.2</td>
<td>1</td>
</tr>
</tbody>
</table>

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

100-yr. discharge is 1,780 cubic-feet per second

**Table 2.** Remaining footing/pile depth at abutments for the 500-year discharge at structure BRIDTH00040042 on Town Highway 4, crossing Dailey Hollow Brook, Bridgewater, Vermont.
[VTAOT, Vermont Agency of Transportation; --, no data]

<table>
<thead>
<tr>
<th>Description</th>
<th>Station</th>
<th>VTAOT plans' bridge seat 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>1452.4</td>
<td>97.66</td>
<td>81</td>
<td>85.4</td>
<td>0.0</td>
<td>5.4</td>
<td>--</td>
<td>5.4</td>
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<td>86.1</td>
<td>0.0</td>
<td>5.0</td>
<td>--</td>
<td>5.0</td>
<td>81.1</td>
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</table>

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

500-yr. discharge is 2,260 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:

WS PRO INPUT FILE
### WSPRO INPUT FILE

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Data</th>
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<tr>
<td>1</td>
<td>U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp</td>
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</tr>
<tr>
<td>2</td>
<td>CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HYDRAULIC ANALYSIS OF BRID042 SAO</td>
<td></td>
</tr>
<tr>
<td>J3</td>
<td>6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3</td>
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<tr>
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<td>GR</td>
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<td>Q</td>
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</tr>
<tr>
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<td>HP 1</td>
<td>APPRO 91.61 1 91.61</td>
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</tr>
<tr>
<td>HP 1</td>
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<td>HP 2</td>
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<td>HP 2</td>
<td>APPRO 92.55 * * 1060</td>
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</table>
APPENDIX B:

WSPRO OUTPUT FILE
**U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp**  
CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca  
HYDRAULIC ANALYSIS OF BRIDTH00040042 SAO  
*** RUN DATE & TIME: 10-03-95 10:46  
CROSS SECTION PROPERTIES: ISEQ = 4; SECID = BRIDGE; SRD = 0.  
<table>
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<tr>
<th>WSEL</th>
<th>SA#</th>
<th>AREA</th>
<th>K</th>
<th>TOPW</th>
<th>WETP</th>
<th>ALPH</th>
<th>LEW</th>
<th>REW</th>
<th>QCR</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>19.29.</td>
<td>1399.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

VELOCITY DISTRIBUTION: ISEQ = 4; SECID = BRIDGE; SRD = 0.  
<table>
<thead>
<tr>
<th>WSEL</th>
<th>LEW</th>
<th>REW</th>
<th>AREA</th>
<th>K</th>
<th>Q</th>
<th>VEL</th>
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<td>90.67</td>
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<td>7.62</td>
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**CROSS SECTION PROPERTIES: ISEQ = 6; SECID = APPRO; SRD = 55.**  
<table>
<thead>
<tr>
<th>WSEL</th>
<th>SA#</th>
<th>AREA</th>
<th>K</th>
<th>TOPW</th>
<th>WETP</th>
<th>ALPH</th>
<th>LEW</th>
<th>REW</th>
<th>QCR</th>
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<td>2</td>
<td>78.3165.</td>
<td>23.26.</td>
<td>813.</td>
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VELOCITY DISTRIBUTION: ISEQ = 6; SECID = APPRO; SRD = 55.  
<table>
<thead>
<tr>
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<th>LEW</th>
<th>REW</th>
<th>AREA</th>
<th>K</th>
<th>Q</th>
<th>VEL</th>
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<tbody>
<tr>
<td>91.61</td>
<td>-1.4</td>
<td>21.3</td>
<td>77.6</td>
<td>3165.</td>
<td>805.</td>
<td>10.37</td>
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</table>

**WSPRO OUTPUT FILE**
U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH0040042 USING FILE brid042.dca
HYDRAULIC ANALYSIS OF BRID042    SAO
*** RUN DATE & TIME: 10-03-95 10:46
CROSS-SECTION PROPERTIES: ISEQ =  4;  SECID = BRIDG;  SRD =      0.
WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
 1     121.    8151.    19.    31.                       1714.
91.46          121.    8151.    19.    31.  1.00     0.    21.   1714.
VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = BRIDG;  SRD =      0.
WSEL     LEW     REW    AREA        K        Q    VEL
91.46    0.1    20.7    120.9    8151.    1060.   8.77
X STA.         0.1        2.2        3.4        4.4        5.4        6.2
A(I)              12.2        7.1        6.1        5.6        5.2
V(I)              4.35        7.43        8.67        9.39       10.15
X STA.          6.2        7.1        7.8        8.6        9.4       10.1
A(I)              5.1        4.9        4.8        4.8        4.8
V(I)              10.44       10.73       10.99       11.05       11.12
X STA.         10.1       10.9       11.7       12.5       13.3      14.2
A(I)              4.8        4.8        4.9        4.9        5.1
V(I)              11.03       11.13       10.72       10.71       10.45
X STA.         14.2       15.1       16.0       17.1      18.4      20.7
A(I)              5.2        5.6        6.0        7.1       11.8
V(I)              10.19       9.45        8.78        7.48       4.50
CROSS-SECTION PROPERTIES: ISEQ =  6;  SECID = APPRO;  SRD =      55.
WSEL  SA#     AREA        K   TOPW   WETP  ALPH    LEW    REW     QCR
VELOCITY DISTRIBUTION:  ISEQ =  6;  SECID = APPRO;  SRD =      55.
WSEL     LEW     REW    AREA        K        Q    VEL
92.55    -2.6     23.9    100.8    4430.    1060.  10.52
X STA.         -2.6        2.1        3.5        4.5        5.4       6.2
A(I)              8.9        6.1        4.9        4.7        4.3
V(I)              5.95        8.71       10.86       11.37       12.36
X STA.          6.2        6.9        7.6        8.2        8.8       9.4
A(I)              4.2        4.1        3.9        3.8        3.8
V(I)              12.51       12.85       13.70       13.88       13.91
X STA.         10.1       10.8       11.5       12.2       12.9
A(I)              3.9        4.0        4.0        4.2        4.3
V(I)              13.58       13.16       13.24       12.69       12.44
X STA.         12.9       13.7       14.6       15.5       16.9      23.9
A(I)              4.5        4.7        5.3        6.7       10.4
V(I)              11.69       11.23        9.99        7.86        5.09

WSPRO OUTPUT FILE (continued)
U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp
CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH00040042 USING FILE brid042.dca
HYDRAULIC ANALYSIS OF BRID042 SAO

*** RUN DATE & TIME: 10-03-95 10:46

XSID:CODE SRDL LEW AREA VHD HF EGL CRWS Q WSEL
SRD FLEN REN K ALPH HO ERR FR# VEL
EXIT:XS ****** -6. 193. 1.32 ****** 90.80 88.71 1780. 89.48
-45. ****** 37. 11969. 1.00 ****** 0.77 9.23
EXIT2:XS 25. -7. 210. 0.23 0.26 91.06 ****** 805. 90.83
-20. 37. 13506. 1.00 0.00 0.31 3.84
FULLV:FV 20. -6. 178. 0.32 0.09 91.19 ****** 805. 90.87
0. 20. 36. 10656. 1.00 0.04 0.39 4.51

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

---125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.
FNTEST,FR#,WSEL,CRWS = 0.80 0.91 91.84 91.59

---110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.
WSLIM1,WSLIM2,DELTAY = 90.37 106.85 0.50

---115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.
WSLIM1,WSLIM2,CRWS = 90.37 106.85 91.59

---135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.
"APPRO" KRATIO = 0.32

APPRO:AS 55. -2. 83. 1.46 0.97 93.31 91.59 805. 91.61
55. 55. 22. 3454. 1.00 1.14 0.01 0.91 9.69

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

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

XSID:CODE SRD LEW REW Q K AREA VEL WSEL
EXITX:XS -45. -6. 37. 1780. 11969. 193. 9.23 89.48
EXIT2:XS -20. -7. 37. 805. 13506. 210. 3.84 90.83
FULLV:FV 0. -6. 36. 805. 10656. 178. 4.51 90.87
BRIDG:BR 0. 0. 21. 805. 6728. 106. 7.63 90.67
RDWAY:RG 9. 0. 2. 0. 99.35 103.19

APPRO:AS 55. -1. 78. 1.67 1.20 93.28 91.59 805. 91.61
55. 20. 21. 3165. 1.00 0.51 0.00 0.99 10.37

M(G) M(K) EQ XLKQ XRKQ OTEL
0.130 0.000 3341. -1. 20. 89.18

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

FIRST USER DEFINED TABLE.

XSID:CODE SRD LEW AREA VHD HF EGL CRWS Q WSEL
EXITX:XS -45. -6. 37. 1780. 11969. 193. 9.23 89.48
EXIT2:XS -20. -7. 37. 805. 13506. 210. 3.84 90.83
FULLV:FV 0. -6. 36. 805. 10656. 178. 4.51 90.87
BRIDG:BR 0. 0. 21. 805. 6728. 106. 7.63 90.67
RDWAY:RG 9. "********** 0.********* 2.00********

APPRO:AS 55. -1. 21. 805. 3165. 78. 10.37 91.61

SECOND USER DEFINED TABLE.

XSID:CODE CRWS FR# YMIN YMAX HF HO VHD EGL WSEL
EXITX:XS 88.71 0.77 83.16 105.48 "********** 1.32 90.80 89.48
EXIT2:XS 0.31 84.12 106.44 0.26 0.00 0.23 91.06 90.83
FULLV:FV 0.39 84.89 107.21 0.09 0.04 0.32 91.19 90.87
BRIDG:BR 88.99 0.58 84.76 98.13 0.29 0.22 0.91 91.57 90.67
RDWAY:RG "********** 99.35 103.19 "***************
APPRO:AS 91.59 0.99 86.30 106.85 1.20 0.51 1.67 93.28 91.61

WSPRO OUTPUT FILE (continued)
U.S. GEOLOGICAL SURVEY WSPRO INPUT FILE brid042.wsp  
CREATED ON 03-OCT-95 FOR BRIDGE BRIDTH0040042 USING FILE brid042.dca  
HYDRAULIC ANALYSIS OF BRID042  
SAO  
*** RUN DATE & TIME: 10-03-95 10:46  

** EXITX:XS  ⎯ ⎯ ⎯ ⎯ -7.  229.  1.52  ⎯ ⎯ ⎯ 91.80  89.40  2260.  90.29  
   -45.  ⎯ ⎯ ⎯ 38.  15189.  1.00  ⎯ ⎯ ⎯ 0.78  9.88  
** EXIT2:XS  25.  -8.  254.  0.27  0.26  92.06  ⎯ ⎯ ⎯ 1060.  91.79  
   20.  40.  17513.  1.00  -0.01  0.32  4.17  
** FULLV:FV  20.  -7.  220.  0.36  0.09  92.19  ⎯ ⎯ ⎯ 1060.  91.83  
   0.  20.  14404.  1.00  0.05  0.38  4.82  

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

---125 FR# EXCEEDS FNTEST AT SECID "APPRO": TRIALS CONTINUED.  
FNTEST,FR#,WSEL,CRWS =  0.80  0.89  92.75  92.40  

---110 WSEL NOT FOUND AT SECID "APPRO": REDUCED DELTAY.  
WSLIM1,WSLIM2,DELTAY =  91.33  106.85  0.50  

---115 WSEL NOT FOUND AT SECID "APPRO": USED WSMIN = CRWS.  
WSLIM1,WSLIM2,CRWS =  91.33  106.85  92.40  

---135 CONVEYANCE RATIO OUTSIDE OF RECOMMENDED LIMITS.  
"APPRO" KRATIO =  0.33  

APPRO:AS  55.  -3.  106.  1.56  0.91  94.30  92.40  1060.  92.74  
55.  55.  24.  4724.  1.00  1.20  0.00  0.90  10.01  

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

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

** BRIDG:BR  20.  0.  121.  1.20  0.26  92.65  89.74  1060.  91.46  
0.  20.  8142.  1.00  0.33  0.00  0.62  8.77  

TYPE PPCF FLOW  C  P/A  LSEL  BLEN  XLAB  XRAB  
1. ****  1.  1.000  ******  97.90  ******  ******  ****  

** RDWAY:RG  9.  ******  *******  *****  0.******  2.00 ******  

APPRO:AS  55.  -3.  101.  1.72  1.03  94.27  92.40  1060.  92.55  
55.  24.  4437.  1.00  0.60  0.01  0.95  10.51  

M(G)  M(K)  EQ  XLKQ  XRKQ  OTEL  
0.241  0.000  4842.  -1.  20.  90.40  

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

FIRST USER DEFINED TABLE.  

** EXITX:XS  -45.  -7.  38.  2260.  15189.  229.  9.88  90.29  
** EXIT2:XS  -20.  -8.  40.  1060.  17513.  254.  4.17  91.79  
** FULLV:FV  0.  -7.  38.  1060.  14404.  220.  4.82  91.83  
** BRIDG:BR  0.  0.  21.  1060.  8142.  121.  8.77  91.46  
** RDWAY:RG  9.  ******  0.******  2.00 ******  
APPRO:AS  55.  -3.  24.  1060.  4437.  101.  10.51  92.55  

SECOND USER DEFINED TABLE.  

** EXITX:XS  89.40  0.78  83.16  105.48  1.52  91.80  90.29  
** EXIT2:XS  0.32  84.12  106.44  0.26  0.00  0.27  92.06  91.79  
** FULLV:FV  0.38  84.89  107.21  0.09  0.05  0.36  92.19  91.83  
** BRIDG:BR  89.74  0.62  84.76  98.13  0.26  0.33  1.20  92.65  91.46  
** RDWAY:RG  99.35  103.19  
APPRO:AS  92.40  0.95  86.30  106.85  1.03  0.60  1.72  94.27  92.55  

<<<< END OF WSPRO OUTPUT FILE >>>>>
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 BRIDTH00040042, in Bridgewater, Vermont.
APPENDIX D:

HISTORICAL DATA FORM