# LEVEL II SCOUR ANALYSIS FOR BRIDGE 7 (SALITH00080007) on TOWN HIGHWAY 8, crossing the MIDDLEBURY RIVER, SALISBURY, VERMONT

U.S. Geological Survey
Open-File Report 98-257

Prepared in cooperation with
VERMONT AGENCY OF TRANSPORTATION
and

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

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# LEVEL II SCOUR ANALYSIS FOR BRIDGE 7 (SALITH00080007) on TOWN HIGHWAY 8, crossing the MIDDLEBURY RIVER, SALISBURY, VERMONT

By ERICK M. BOEHMLER AND LAURA MEDALIE

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FEDERAL HIGHWAY ADMINISTRATION

**Pembroke, New Hampshire**

**1998**

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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# CONTENTS



### FIGURES



### TABLES

## CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| | **Length** | |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | **Slope** | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |
| | **Area** | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | **Volume** | |
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| | **Velocity and Flow** | |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| cubic foot per second per square mile [$(ft^3/s)/mi^2$] | 0.01093 | cubic meter per second per square kilometer [$(m^3/s)/km^2$] |

## OTHER ABBREVIATIONS

| | | | |
|---|---|---|---|
| BF | bank full | LWW | left wingwall |
| cfs | cubic feet per second | MC | main channel |
| $D_{50}$ | median diameter of bed material | RAB | right abutment |
| DS | downstream | RABUT | face of right abutment |
| elev. | elevation | RB | right bank |
| f/p | flood plain | ROB | right overbank |
| $ft^2$ | square feet | RWW | right wingwall |
| ft/ft | feet per foot | TH | town highway |
| JCT | junction | UB | under bridge |
| LAB | left abutment | US | upstream |
| LABUT | face of left abutment | USGS | United States Geological Survey |
| LB | left bank | VTAOT | Vermont Agency of Transportation |
| LOB | left overbank | WSPRO | water-surface profile model |

In this report, the words “right” and “left” refer to directions that would be reported by an observer facing downstream.

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929-- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

In the appendices, the above abbreviations may be combined. For example, USLB would represent upstream left bank.

# LEVEL II SCOUR ANALYSIS FOR BRIDGE 7 (SALITH00080007) ON TOWN HIGHWAY 8, CROSSING THE MIDDLEBURY RIVER, SALISBURY, VERMONT

***By* Erick M. Boehmler and Laura Medalie**

## INTRODUCTION AND SUMMARY OF RESULTS

This report provides the results of a detailed Level II analysis of scour potential at structure SALITH00080007 on Town Highway 8 crossing the Middlebury River, Salisbury, 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 Champlain section of the Saint Lawrence Valley physiographic province in west-central Vermont. However, most of the watershed is situated in the Green Mountain section of the New England province. The 62.4-$mi^2$ drainage area is in a predominantly rural and forested basin. In the vicinity of the study site, the surface cover is pasture upstream of the bridge. There are row-crops on the downstream right overbank and forest on the downstream left overbank.

In the study area, the Middlebury River has an meandering channel with a slope of approximately 0.0009 ft/ft, an average channel top width of 84 feet and an average bank height of 7 feet. The channel bed material ranges from sand to cobbles with a median grain size ($D_{50}$) of 0.974 mm (0.00319 ft). The geomorphic assessment at the time of the Level I and Level II site visit on June 17, 1996, indicated that the reach was laterally unstable. The meandering configuration of the channel, cut-banks with block failure of the bank material, and the fine size of the bed and bank material suggest the potential for lateral movement of the channel is significant at this site.

The Town Highway 8 crossing of the Middlebury River is a 60-ft-long, two-lane bridge consisting of one 57-foot steel-beam span (Vermont Agency of Transportation, written communication, December 15, 1995). The opening length of the structure parallel to the bridge face is 54.2 feet. The bridge is supported by vertical, concrete abutments with sloping wingwalls and embankments. The channel is skewed approximately 25 degrees to the opening while the opening-skew-to-roadway is 10 degrees.

A scour hole, 4 feet deeper than the mean thalweg depth, was observed along the left bank side of the channel upstream of the site during the Level I assessment. Bedrock is exposed along the left bank upstream adjacent to the scour hole. The scour protection measures at this site were type-1 (less than 12 inches diameter) and type-2 (less than 36 inches diameter) stone fill. Type-1 stone fill was noted on the upstream left bank, and the upstream and downstream right wingwalls. Type-2 stone fill was found on the upstream left wingwall, the left abutment, and the downstream right bank. Additional details describing conditions at the site are included in the Level II Summary and appendices D and E.

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

Contraction scour for all modelled flows ranged from 5.7 to 13.5 feet. The worst-case contraction scour occurred at the 100-year discharge. Abutment scour ranged from 8.3 to 18.8 feet. The worst-case abutment scour occurred at the 500-year discharge. Additional information on scour depths and depths to armoring are included in the section titled “Scour Results”. Scoured-streambed elevations, based on the calculated scour depths, are presented in tables 1 and 2. A cross-section of the scour computed at the 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.

Plymouth, VT. Quadrangle, 1:24,000, 1966
Photoinspected 1983

NORTH

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

***Structure Number*** SALITH00080007 ***Stream*** Middlebury River

***County*** Addison ***Road*** TH 8 ***District*** 5

## Description of Bridge

***Bridge length*** 60 ***ft*** ***Bridge width*** 24.9 ***ft*** ***Max span length*** 57 ***ft***

***Alignment of bridge to road (on curve or straight)*** Slight curve

***Abutment type*** Vertical, concrete ***Embankment type*** Sloping

***Stone fill on abutment?*** Yes ***Date of inspection*** 6/17/96

***Description of stone fill*** Type-2 was noted on the upstream left wingwall and the upstream end of the left abutment and type-1 was noted at the upstream end of the upstream right wingwall and along the entire downstream right wingwall.

The abutments and wingwalls are concrete.

Yes 25

***Is bridge skewed to flood flow according to*** Yes ***survey?*** ***Angle***

There is a severe channel bend in the upstream reach. The scour hole has developed in the location where the flow impacts the bedrock exposure on the upstream left bank.

***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*** | 6/17/96 | 0 | 0 |
| ***Level II*** | 6/17/96 | 0 | 0 |

***Potential for debris*** Moderate. There are a few trees on the banks of this meandering, laterally unstable channel.

***Describe any features near or at the bridge that may affect flow (include observation date)*** None evident on 6/17/96.

### Description of the Geomorphic Setting

***General topography*** The channel is located in a wide flood plain with mild to moderately sloping valley walls on both sides.

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

***Date of inspection*** 6/17/96

***DS left:*** Moderately sloping channel bank to an irregular overbank.

***DS right:*** Moderately sloping channel bank to an irregular flood plain.

***US left:*** Moderately sloping channel bank and valley wall.

***US right:*** Moderately sloping channel bank to an irregular flood plain.

### Description of the Channel

***Average top width*** 84 ft ***Average depth*** 7 ft

***Predominant bed material*** Sand ***Bank material*** Silt / Clay / Sand

Perennial, meandering, and wider at bends with semi-alluvial channel boundaries and narrow bars.

6/17/96

***Vegetative co*** Trees, shrubs, and brush.

***DS left:*** Trees, shrubs, and brush.

***DS right:*** Trees, shrubs, and brush.

***US left:*** Grass and brush with a few trees and shrubs.

***US right:*** No

***Do banks appear stable?*** ***If not, describe location and type of instability and date of observation.*** The channel meanders and there is fine size bank and bed material through the reach. There was block failure of bank material at cut-banks evident upstream of this site at the time of the assessment.

None evident on 6/17/96.

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

## Hydrology

***Drainage area*** 62.4 ***mi²***

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

| *Physiographic province/section* | *Percent of drainage area* |
|---|---|
| Saint Lawrence Valley / Champlain | 5 |
| New England / Green Mountain | 95 |

***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*** -- ***mi²***

***Is there a lake/p[illegible]*** No

-

### Calculated Discharges

***Q100*** 7,000 ***ft³/s*** ***Q500*** 9,800 ***ft³/s***

The 100- and 500-year discharges were selected based on flood frequency estimates available in the VTAOT database for bridge 11 in Middlebury immediately downstream of this site over the Middlebury River with a drainage area of 62.8 square miles. The values from the VTAOT database were central in a range defined by several empirical equations (Benson, 1962; FHWA, 1983; Johnson and Tasker, 1974; Potter, 1957a&b; Talbot, 1887), which were extrapolated to the 500-year event.

## Description of the Water-Surface Profile Model (WSPRO) Analysis

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

***Datum tie between USGS survey and VTAOT plans*** Subtract 12.1 feet from the USGS arbitrary survey datum to obtain the VTAOT plans' datum.

***Description of reference marks used to determine USGS datum.*** RM1 is a VTAOT metallic disk set in the top of the concrete upstream left wingwall (elev. 510.84 feet, arbitrary survey datum). RM2 is a nail in the second power pole to the right from the bridge (elev. 502.56 feet, arbitrary survey datum). RM3 is a chiseled X on top of the downstream end of the right abutment (elev. 508.38 feet, arbitrary survey datum).

### Cross-Sections Used in WSPRO Analysis

| [1]*Cross-section* | *Section Reference Distance (SRD) in feet* | [2]*Cross-section development* | *Comments* |
|---|---|---|---|
| EXITX | -88 | 1 | Exit section |
| FULLV | 0 | 5 | Downstream Full-valley section (BRIDG channel and EXITX overbank) |
| BRIDG | 0 | 1 | Bridge section |
| RDWAY | 15 | 1 | Road Grade section |
| APPRO | 80 | 1 | Approach section |

[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 0.037 to 0.057, and overbank “n” values ranged from 0.042 to 0.075.

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 0.00088 ft/ft, which was estimated from the topographic map (U.S. Geological Survey, 1943).

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

## Bridge Hydraulics Summary

***Average bridge embankment elevation*** 509.8 ***ft***
***Average low steel elevation*** 506.2 ***ft***

***100-year discharge*** 7,000 ***$ft^3$/s***
***Water-surface elevation in bridge opening*** 505.1 ***ft***
***Road overtopping?*** Yes ***Discharge over road*** 2090 ***$ft^3$/s***
***Area of flow in bridge opening*** 734 ***$ft^2$***
***Average velocity in bridge opening*** 6.7 ***ft/s***
***Maximum WSPRO tube velocity at bridge*** 8.2 ***ft/s***

***Water-surface elevation at Approach section with bridge*** 506.1
***Water-surface elevation at Approach section without bridge*** 505.1
***Amount of backwater caused by bridge*** 1.0 ***ft***

***500-year discharge*** 9,800 ***$ft^3$/s***
***Water-surface elevation in bridge opening*** 506.5 ***ft***
***Road overtopping?*** Yes ***Discharge over road*** 5,500 ***$ft^3$/s***
***Area of flow in bridge opening*** 784 ***$ft^2$***
***Average velocity in bridge opening*** 5.5 ***ft/s***
***Maximum WSPRO tube velocity at bridge*** 7.9 ***ft/s***

***Water-surface elevation at Approach section with bridge*** 507.3
***Water-surface elevation at Approach section without bridge*** 506.3
***Amount of backwater caused by bridge*** 1.0 ***ft***

***Incipient overtopping discharge*** 4,250 ***$ft^3$/s***
***Water-surface elevation in bridge opening*** 503.0 ***ft***
***Area of flow in bridge opening*** 621 ***$ft^2$***
***Average velocity in bridge opening*** 6.8 ***ft/s***
***Maximum WSPRO tube velocity at bridge*** 8.3 ***ft/s***

***Water-surface elevation at Approach section with bridge*** 504.0
***Water-surface elevation at Approach section without bridge*** 503.5
***Amount of backwater caused by bridge*** 0.5 ***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 Davis, 1995). Scour depths were calculated assuming an infinite depth of erosive material and a homogeneous particle-size distribution. However, bedrock was exposed at the surface along the left bank side of the channel and may limit the depth of scour at this site. The results of the scour analyses for the 100- and 500-year discharges are presented in tables 1 and 2 and the 100-year scour depths are shown graphically in figure 8. The scour depths for the 500-year event were less than those for the 100-year event and thus do not appear in figure 8.

Contraction scour for each modeled discharge was computed by use of the Laursen live-bed contraction scour equation (Richardson and Davis, 1995, p. 30, equation 17). Results from this contraction scour analysis are shown in tables 1 and 2 and figure 8. At this site, the incipient motion velocity was very close to the critical velocity. Therefore, contraction scour also was computed by use of the Laursen clear-water contraction scour equation (Richardson and Davis, 1995, p. 32, equation 20). Results from this analysis are provided in appendix F.

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

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

## Scour Results

| *Contraction scour:* | *100-yr discharge* | *500-yr discharge* | *Incipient overtopping discharge* |
|---|---|---|---|
| | *(Scour depths in feet)* | | |
| ***Main channel*** | | | |
| *Live-bed scour* | 13.5 | 5.7 | 11.7 |
| *Clear-water scour* | -- | -- | -- |
| *Depth to armoring* | N/A | N/A | N/A |
| ***Left overbank*** | -- | -- | -- |
| ***Right overbank*** | -- | -- | -- |

| *Local scour:* | *100-yr discharge* | *500-yr discharge* | *Incipient overtopping discharge* |
|---|---|---|---|
| ***Abutment scour*** | | | |
| *Left abutment* | 16.0 | 18.8 | 13.4 |
| *Right abutment* | 11.2 | 12.7 | 8.3 |
| ***Pier scour*** | | | |
| *Pier 1* | -- | -- | -- |
| *Pier 2* | -- | -- | -- |
| *Pier 3* | -- | -- | -- |

## Riprap Sizing

| | *100-yr discharge* | *500-yr discharge* | *Incipient overtopping discharge* |
|---|---|---|---|
| | | *($D_{50}$ in feet)* | |
| ***Abutments:*** | | | |
| *Left abutment* | 1.1 | 0.8 | 1.1 |
| *Right abutment* | 1.1 | 0.8 | 1.1 |
| ***Piers:*** | | | |
| *Pier 1* | -- | -- | -- |
| *Pier 2* | -- | -- | -- |

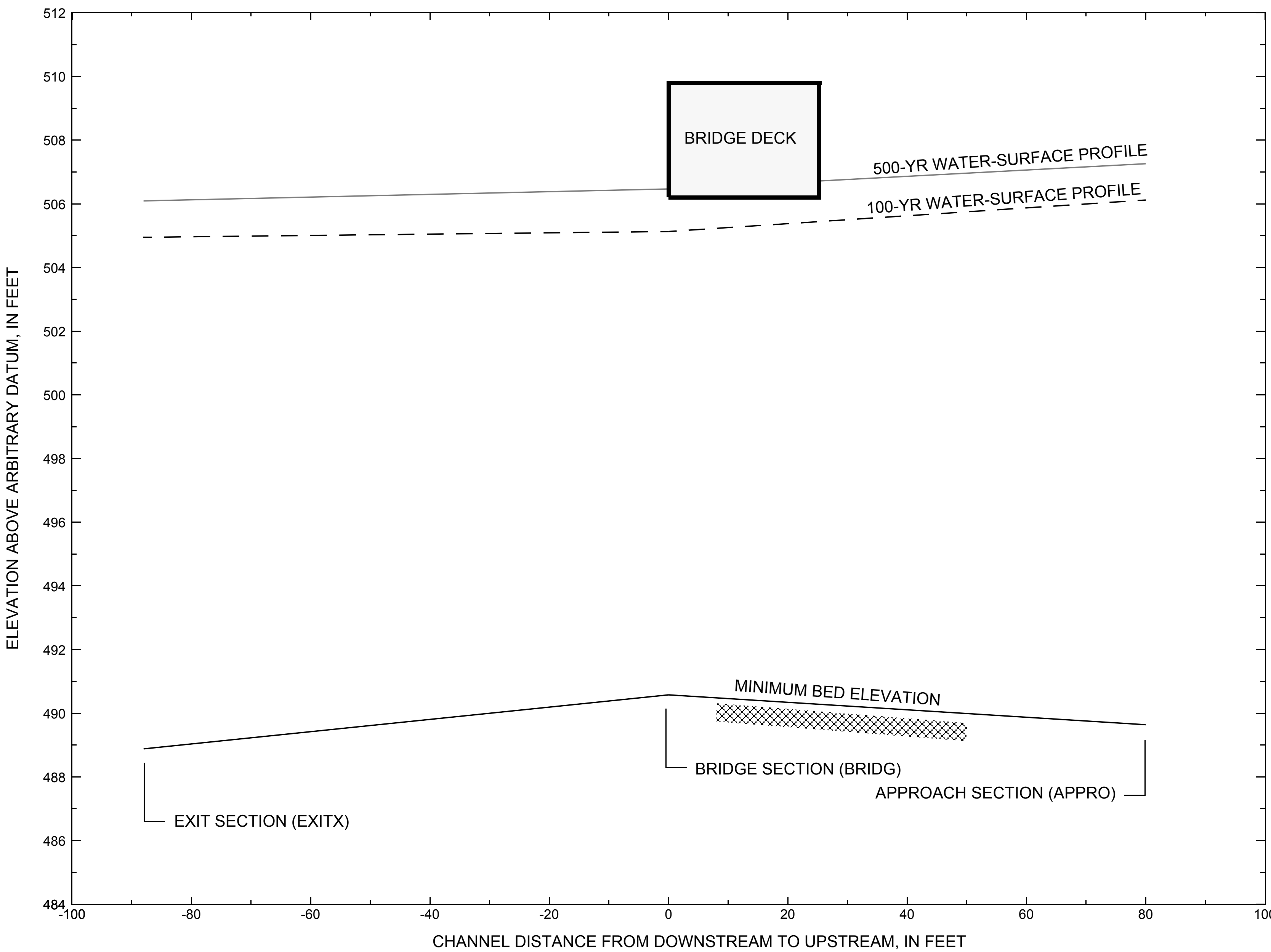



Figure 7. Water-surface profiles for the 100- and 500-year discharges at structure SALITH00080007 on Town Highway 8, crossing the Middlebury River, Salisbury, Vermont.

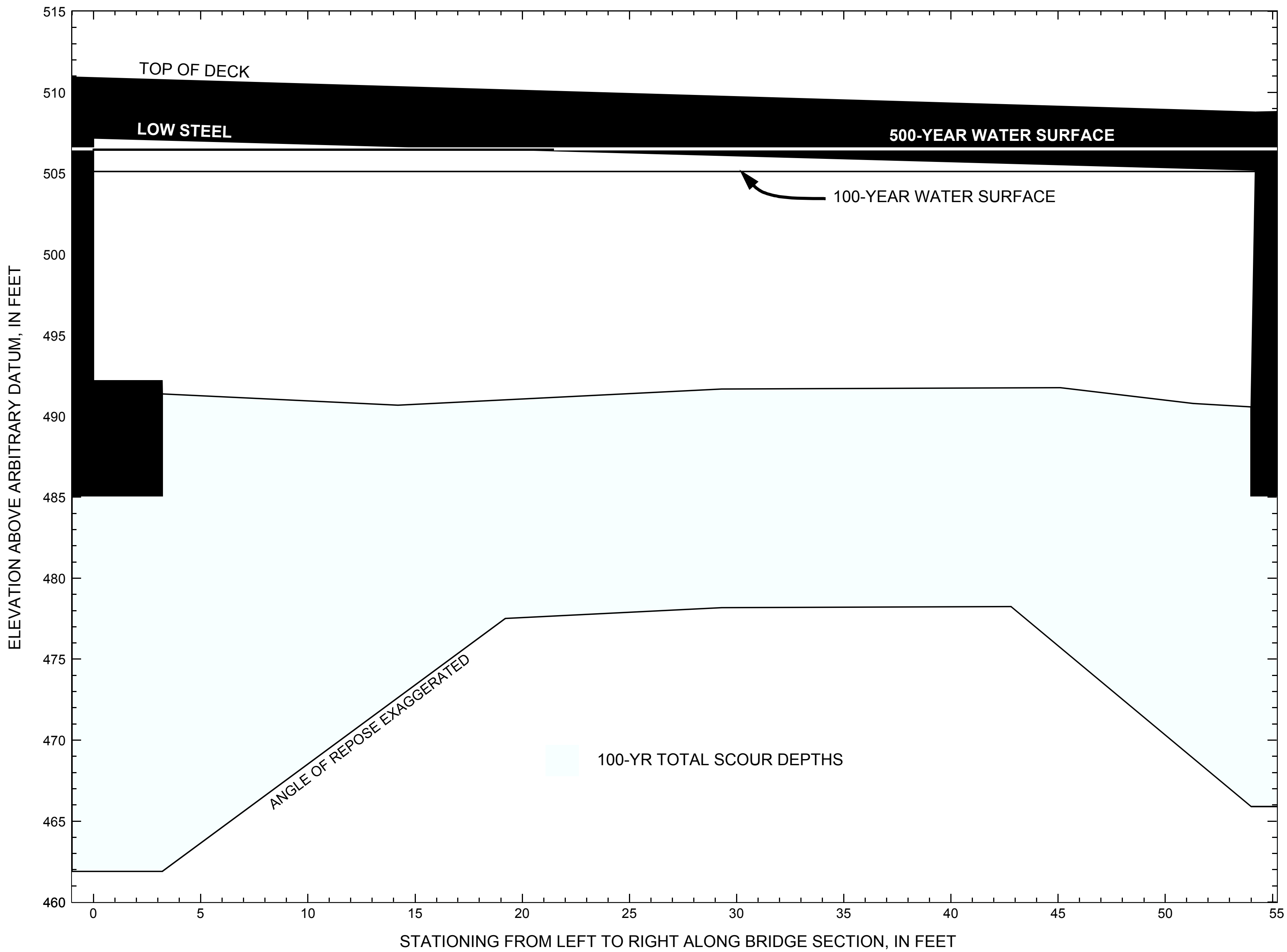



Figure 8. Scour elevations for the 100-year discharge at structure SALITH00080007 on Town Highway 8, crossing the Middlebury River, Salisbury, Vermont.

**Table 1.** Remaining footing/pile depth at abutments for the 100-year discharge at structure SALITH00080007 on Town Highway 8, crossing the Middlebury River, Salisbury, Vermont.

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

| Description | Station[1] | VTAOT bridge seat elevation (feet) | Surveyed minimum low-chord elevation[2] (feet) | Bottom of footing/pile elevation[2] (feet) | Channel elevation at abutment/ pier[2] (feet) | Contraction scour depth (feet) | Abutment scour depth (feet) | Pier scour depth (feet) | Depth of total scour (feet) | Elevation of scour[2] (feet) | Remaining footing/pile depth (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100-year discharge is 7,000 cubic-feet per second | | | | | | | | | | | |
| Left abutment | 0.0 | 494.9 | 507.2 | 485.1 | 491.4 | 13.5 | 16.0 | -- | 29.5 | 461.9 | -23.2 |
| Right abutment | 54.2 | 492.7 | 505.2 | 485.1 | 490.6 | 13.5 | 11.2 | -- | 24.7 | 465.9 | -19.2 |

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 SALITH00080007 on Town Highway 8, crossing the Middlebury River, Salisbury, Vermont.

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

| Description | Station[1] | VTAOT bridge seat elevation (feet) | Surveyed minimum low-chord elevation[2] (feet) | Bottom of footing/pile elevation[2] (feet) | Channel elevation at abutment/ pier[2] (feet) | Contraction scour depth (feet) | Abutment scour depth (feet) | Pier scour depth (feet) | Depth of total scour (feet) | Elevation of scour[2] (feet) | Remaining footing/pile depth (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 500-year discharge is 9,800 cubic-feet per second | | | | | | | | | | | |
| Left abutment | 0.0 | 494.9 | 507.2 | 485.1 | 491.4 | 5.7 | 18.8 | -- | 24.5 | 466.9 | -18.2 |
| Right abutment | 54.2 | 492.7 | 505.2 | 485.1 | 490.6 | 5.7 | 12.7 | -- | 18.4 | 472.2 | -12.9 |

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

# SELECTED REFERENCES

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M. A., 1962, Factors Influencing the Occurrence of Floods in a Humid Region of Diverse Terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Brown, S.A. and Clyde, E.S., 1989, Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11, Publication FHWA-IP-89-016, 156 p.

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

Federal Highway Administration, 1993, Stream Stability and Scour at Highway Bridges: Participant Workbook: Federal Highway Administration Report FHWA-HI-91-011.

Froehlich, D.C., 1989, Local scour at bridge abutments *in* Ports, M.A., ed., Hydraulic Engineering--Proceedings of the 1989 National Conference on Hydraulic Engineering: New York, American Society of Civil Engineers, p. 13-18.

Hayes, D.C.,1993, Site selection and collection of bridge-scour data in Delaware, Maryland, and Virginia: U.S. Geological Survey Water-Resources Investigation Report 93-4017, 23 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: U.S. Geological Survey, Bulletin 17B of the Hydrology Subcommittee, 190 p.

Johnson, C.G. and Tasker, G.D.,1974, Progress report on flood magnitude and frequency of Vermont streams: U.S. Geological Survey Open-File Report 74-130, 37 p.

Lagasse, P.F., Schall, J.D., Johnson, F., Richardson, E.V., Chang, F., 1995, Stream Stability at Highway Structures: Federal Highway Administration Hydraulic Engineering Circular No. 20, Publication FHWA-IP-90-014, 144 p.

Laursen, E.M., 1960, Scour at bridge crossings: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 86, no. HY2, p. 39-53.

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

Potter, W. D., 1957b, Peak rates of runoff in the New England Hill and Lowland area, Bureau of Public Roads

Richardson, E.V. and Davis, S.R., 1995, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular No. 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment: Federal Highway Administration Publication FHWA-HI-90-016.

Ritter, D.F., 1984, Process Geomorphology: W.C. Brown Co., Debuque, Iowa, 603 p.

Shearman, J.O., 1990, User's manual for WSPRO--a computer model for water surface profile computations: Federal Highway Administration Publication FHWA-IP-89-027, 187 p.

Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model; research report: Federal Highway Administration Publication FHWA-RD-86-108, 112 p.

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

U.S. Department of Transportation, 1993, Stream stability and scour at highway bridges, Participant Workbook: Federal Highway Administration Publication FHWA HI-91-011.

U.S. Geological Survey, 1943, Cornwall, Vermont 7.5 Minute Series quadrangle map: U.S. Geological Survey Topographic Maps; Photoinspected 1983; Contour interval, 20 feet; Scale 1:24,000.

U.S. Geological Survey, 1944, East Middlebury, Vermont 7.5 Minute Series Quadrangle Map: U.S. Geological Survey p Topographic Maps; Photorevised, 1972; Contour Interval, 20 feet, Scale, 1:24,000.

# APPENDIX A:

# WSPRO INPUT FILE

# WSPRO INPUT FILE

```
T1        U.S. Geological Survey WSPRO Input File sali007.wsp
T2        Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
T3        Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
*
J3         6 29 30 552 553 551 5 16 17 13 3 * 15 14 23 21 11 12 4 7 3
*
Q           7000.0   9800.0    4250.0
SK          0.00088  0.00088   0.00088
*
XS   EXITX    -88
GR         -243.3, 525.66   -132.7, 513.35    -90.3, 507.72    -39.5, 501.23
GR          -11.2, 500.48      0.0, 492.80      3.7, 490.25     12.7, 488.88
GR           22.6, 489.50     31.8, 491.04     47.9, 490.15     52.0, 489.73
GR           62.3, 492.88     67.9, 498.02     78.8, 500.27    360.4, 502.45
GR          650.8, 504.60    659.3, 506.04    776.6, 507.17    885.9, 507.21
*           368.9, 503.92    387.0, 504.57
*
N           0.075        0.057        0.050
SA                 -11.2         78.8
*
XS   FULLV      0
GR         -243.3, 525.66   -132.7, 513.35    -90.3, 507.72    -39.5, 501.23
GR          -11.2, 500.48      0.0, 492.20      3.2, 492.19      3.2, 491.38
GR           14.2, 490.68     29.3, 491.68     45.1, 491.76     51.3, 490.79
GR           54.0, 490.58     62.3, 492.88     67.9, 498.02     78.8, 500.27
GR          360.4, 502.45    650.8, 504.60    659.3, 506.04    776.6, 507.17
GR          885.9, 507.21
*
N           0.075        0.057        0.045
SA                 -11.2         78.8
*
*             SRD     LSEL    XSSKEW
BR   BRIDG      0    506.19      10.0
GR            0.0, 507.18      0.0, 492.20      3.2, 492.19      3.2, 491.38
GR           14.2, 490.68     29.3, 491.68     45.1, 491.76     51.3, 490.79
GR           54.0, 490.58     54.2, 505.20      0.0, 507.18
*
*         BRTYPE  BRWDTH    EMBSS   EMBELV   WWANGL
CD           4      29.5      1.8    509.8     42.5
N           0.037
*
*             SRD    EMBWID   IPAVE
XR   RDWAY     15      24.9     2
GR         -314.2, 528.12   -150.0, 517.85      0.0, 510.90     55.2, 508.77
GR           89.8, 507.55    210.0, 504.42    280.2, 503.94    347.7, 504.23
GR          400.2, 504.57    650.8, 506.70    776.6, 507.17    885.9, 507.21
*
AS   APPRO     80
GR          -70.4, 512.33    -39.5, 502.18    -10.5, 496.70      0.0, 492.71
GR           16.8, 489.72     32.9, 489.85     37.1, 490.09     40.6, 489.64
GR           50.3, 492.73     67.2, 500.04    147.1, 501.08    246.1, 501.32
GR          510.0, 501.81    578.0, 504.60    650.8, 506.70    776.6, 507.20
GR          885.9, 507.21
*           309.9, 503.30
*
N           0.042       0.057        0.047
SA                 -10.5       67.2
```

```
*
HP 1 BRIDG 505.13 1 505.13
HP 2 BRIDG 505.13 * * 4908
HP 2 RDWAY 505.79 * * 2092
HP 1 APPRO 506.12 1 506.12
HP 2 APPRO 506.12 * * 7000
*
HP 1 BRIDG 506.47 1 506.47
HP 2 BRIDG 506.47 * * 4302
HP 2 RDWAY 506.77 * * 5498
HP 1 APPRO 507.26 1 507.26
HP 2 APPRO 507.26 * * 9800
*
HP 1 BRIDG 503.02 1 503.02
HP 2 BRIDG 503.02 * * 4250
HP 1 APPRO 503.97 1 503.97
HP 2 APPRO 503.97 * * 4250
*
EX
ER
```

# APPENDIX B:

# **WSPRO OUTPUT FILE**

# WSPRO OUTPUT FILE

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

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      734    127845     53     82                        15447
   505.13           734    127845     53     82  1.00      0     54    15447

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       505.13     0.0    54.2   734.0  127845.    4908.   6.69

X STA.         0.0        5.4        8.4       11.0       13.3       15.6
  A(I)            70.5       40.9       36.6       33.4       31.4
  V(I)            3.48       6.00       6.70       7.35       7.82

X STA.        15.6       17.8       19.9       22.1       24.3       26.5
  A(I)            31.3       29.9       29.8       30.2       29.8
  V(I)            7.84       8.20       8.24       8.13       8.22

X STA.        26.5       28.7       31.1       33.3       35.7       38.1
  A(I)            29.8       30.5       30.4       31.4       31.0
  V(I)            8.23       8.04       8.08       7.82       7.92

X STA.        38.1       40.6       43.2       45.9       49.0       54.2
  A(I)            33.4       34.4       36.0       41.6       71.8
  V(I)            7.35       7.14       6.81       5.90       3.42

    VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      15.

         WSEL     LEW     REW    AREA        K        Q    VEL
       505.79   157.4   543.7   424.7   14976.    2092.   4.93

X STA.       157.4      206.0      221.3      234.5      245.9      256.7
  A(I)            30.8       21.2       19.7       17.9       17.9
  V(I)            3.40       4.94       5.30       5.84       5.83

X STA.       256.7      266.6      275.9      284.8      294.2      303.8
  A(I)            17.1       16.6       16.4       16.9       17.0
  V(I)            6.11       6.30       6.38       6.20       6.15

X STA.       303.8      313.7      324.3      335.5      347.4      360.8
  A(I)            17.2       17.9       18.3       18.9       20.3
  V(I)            6.08       5.86       5.73       5.52       5.15

X STA.       360.8      375.3      392.7      413.2      442.5      543.7
  A(I)            20.8       23.0       24.5       28.8       43.6
  V(I)            5.04       4.55       4.27       3.63       2.40

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      217     23019     41     42                         2840
             2     1067    156012     78     81                        22449
             3     2372    195976    563    564                        27610
   506.12          3656    375007    682    686  1.25    -50    631    42970

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

         WSEL     LEW     REW    AREA        K        Q    VEL
       506.12   -51.5   630.7  3656.4  375007.    7000.   1.91

X STA.       -51.5      -14.2       -0.4        8.5       16.1       23.0
  A(I)           183.7      147.7      125.9      119.5      112.1
  V(I)            1.91       2.37       2.78       2.93       3.12

X STA.        23.0       30.0       37.2       44.4       54.4       81.1
  A(I)           114.8      116.3      115.6      136.2      196.1
  V(I)            3.05       3.01       3.03       2.57       1.79

X STA.        81.1      115.0      153.5      195.5      238.6      283.7
  A(I)           192.8      200.5      209.0      209.7      215.3
  V(I)            1.82       1.75       1.67       1.67       1.63

X STA.       283.7      330.4      379.4      429.8      486.8      630.7
  A(I)           219.1      225.0      227.1      251.4      338.5
  V(I)            1.60       1.56       1.54       1.39       1.03
```

```
     U.S. Geological Survey WSPRO Input File sali007.wsp
     Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
     Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
        *** RUN DATE & TIME: 11-24-97  11:29

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

  WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
          1      784    111994     19    117                        28463
506.47           784    111994     19    117  1.00      0     54    28463

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

      WSEL     LEW     REW    AREA        K        Q    VEL
    506.47     0.0    54.2   783.8  111994.    4302.   5.49

X STA.        0.0        4.5        7.0        9.1       11.0       12.9
  A(I)           64.9       36.4       31.8       30.3       28.2
  V(I)           3.32       5.92       6.76       7.10       7.62

X STA.       12.9       14.7       16.4       18.3       20.3       22.8
  A(I)           28.2       27.3       28.0       30.9       36.8
  V(I)           7.63       7.87       7.69       6.96       5.85

X STA.       22.8       25.3       28.0       30.8       33.6       36.4
  A(I)           38.2       38.7       39.2       39.2       40.3
  V(I)           5.64       5.56       5.49       5.48       5.33

X STA.       36.4       39.4       42.4       45.7       49.0       54.2
  A(I)           40.4       42.2       43.8       46.9       72.2
  V(I)           5.32       5.09       4.91       4.59       2.98

 VELOCITY DISTRIBUTION:  ISEQ =  4;  SECID = RDWAY;  SRD =      15.

      WSEL     LEW     REW    AREA        K        Q    VEL
    506.77   119.8   669.5   878.6   39763.    5498.   6.26

X STA.      119.8      190.6      210.8      226.9      241.3      254.9
  A(I)           65.3       42.6       38.9       36.2       35.4
  V(I)           4.21       6.45       7.06       7.59       7.77

X STA.      254.9      267.5      279.6      291.5      303.8      316.8
  A(I)           34.0       33.8       33.4       33.7       35.2
  V(I)           8.10       8.13       8.22       8.15       7.81

X STA.      316.8      330.0      344.0      359.3      375.3      393.2
  A(I)           34.9       36.3       38.4       38.6       41.3
  V(I)           7.88       7.57       7.16       7.12       6.66

X STA.      393.2      413.6      437.7      468.6      511.1      669.5
  A(I)           44.3       47.8       53.9       61.1       93.4
  V(I)           6.20       5.75       5.10       4.50       2.94

 CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

  WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
          1      266     30506     44     46                         3693
          2     1156    178182     78     81                        25300
          3     3076    235666    819    819                        33836
507.26          4498    444354    941    945  1.39    -54    886    47375

 VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

      WSEL     LEW     REW    AREA        K        Q    VEL
    507.26   -55.0   885.9  4498.1  444354.    9800.   2.18

X STA.      -55.0      -16.2       -2.0        7.8       15.7       23.0
  A(I)          208.6      160.4      147.6      132.5      127.3
  V(I)           2.35       3.06       3.32       3.70       3.85

X STA.       23.0       30.5       37.9       45.9       57.4       84.7
  A(I)          130.4      128.4      136.7      159.1      215.3
  V(I)           3.76       3.82       3.58       3.08       2.28

X STA.       84.7      115.7      150.8      189.2      229.3      270.8
  A(I)          210.6      223.6      235.1      241.9      245.9
  V(I)           2.33       2.19       2.08       2.03       1.99

X STA.      270.8      315.9      363.9      418.7      480.6      885.9
  A(I)          264.3      276.7      310.8      344.1      599.0
  V(I)           1.85       1.77       1.58       1.42       0.82
```

```
        U.S. Geological Survey WSPRO Input File sali007.wsp
        Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
        Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
           *** RUN DATE & TIME: 11-24-97  11:29

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

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      621    100353     53     77                         12036
   503.02           621    100353     53     77  1.00      0     54    12036

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

         WSEL     LEW     REW    AREA        K        Q    VEL
       503.02     0.0    54.2   621.4  100353.    4250.   6.84

X STA.         0.0         5.3         8.2        10.8        13.1        15.3
  A(I)            57.8        34.7        30.3        27.8        27.1
  V(I)            3.67        6.12        7.01        7.63        7.85

X STA.        15.3        17.5        19.7        21.9        24.2        26.4
  A(I)            26.5        25.9        25.7        26.0        25.6
  V(I)            8.03        8.22        8.27        8.18        8.29

X STA.        26.4        28.7        31.1        33.4        35.8        38.3
  A(I)            26.3        26.0        26.3        26.6        27.3
  V(I)            8.08        8.16        8.08        7.98        7.77

X STA.        38.3        40.8        43.4        46.2        49.3        54.2
  A(I)            28.1        28.7        31.9        35.0        57.8
  V(I)            7.55        7.40        6.66        6.08        3.68

    CROSS-SECTION PROPERTIES:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

     WSEL  SA#     AREA         K   TOPW   WETP  ALPH    LEW    REW      QCR
             1      136     11905     34     35                          1538
             2      900    117478     78     81                         17390
             3     1238     72287    495    495                         11108
   503.97          2275    201670    608    611  1.47    -44    563    20567

    VELOCITY DISTRIBUTION:  ISEQ =  5;  SECID = APPRO;  SRD =      80.

         WSEL     LEW     REW    AREA        K        Q    VEL
       503.97   -44.9   562.6  2274.8  201670.    4250.   1.87

X STA.       -44.9       -12.7        -1.8         5.1        10.8        15.9
  A(I)           120.4        93.3        79.0        72.7        70.1
  V(I)            1.76        2.28        2.69        2.92        3.03

X STA.        15.9        20.6        25.5        30.3        35.1        40.0
  A(I)            67.0        68.9        67.6        67.8        69.6
  V(I)            3.17        3.09        3.14        3.13        3.05

X STA.        40.0        45.4        52.4        73.0       112.9       164.3
  A(I)            72.5        82.2       128.1       143.1       156.0
  V(I)            2.93        2.58        1.66        1.48        1.36

X STA.       164.3       222.9       289.0       358.7       436.1       562.6
  A(I)           162.6       174.2       174.7       183.2       221.6
  V(I)            1.31        1.22        1.22        1.16        0.96
```

```
        U.S. Geological Survey WSPRO Input File sali007.wsp
        Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
        Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
           *** RUN DATE & TIME: 11-24-97  11:29

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

EXITX:XS   ******    -68     2718  0.17 *****  505.12  497.61    7000  504.95
       -87 ******    653   235738  1.68 ***** *******    0.30    2.58

FULLV:FV       88    -68     2724  0.15  0.08  505.20 *******    7000  505.05
         0     88    653   238077  1.49  0.00    0.00    0.28    2.57
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       80    -48     3009  0.11  0.06  505.26 *******    7000  505.14
        80     80    597   289062  1.33  0.00    0.00    0.22    2.33
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
          WS1,WSSD,WS3,RGMIN =   506.71       0.00     504.47     503.94

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

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

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

BRIDG:BR       88      0      734  0.92  0.15  506.05  497.78    4908  505.13
         0     88     54   127865  1.32  0.77   -0.01    0.36    6.69

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   4.  0.871 ******  506.19 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      15.    55.  0.02  0.07  506.16    0.00   2092.  505.79

            Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****
   RT:   2092.   386.   158.   543.   1.8   1.1   5.5   4.9   1.5   3.1

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

APPRO:AS       51    -50     3655  0.07  0.09  506.19  498.72    7000  506.12
        80     82    631   374834  1.25  0.05   -0.01    0.16    1.92

      M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
     0.916  0.772   85921.    26.    80. ********

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL   WSEL
   EXITX:XS     -88.   -69.   653.   7000.  235738.    2718.    2.58  504.95
   FULLV:FV       0.   -69.   653.   7000.  238077.    2724.    2.57  505.05
   BRIDG:BR       0.     0.    54.   4908.  127865.     734.    6.69  505.13
   RDWAY:RG      15.*******     0.   2092.       0.*********    2.00  505.79
   APPRO:AS      80.   -51.   631.   7000.  374834.    3655.    1.92  506.12

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      26.    80.   85921.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    497.61    0.30  488.88  525.66************  0.17  505.12  504.95
   FULLV:FV  ********    0.28  490.58  525.66  0.08  0.00  0.15  505.20  505.05
   BRIDG:BR    497.78    0.36  490.58  507.18  0.15  0.77  0.92  506.05  505.13
   RDWAY:RG  ****************  503.94  528.12  0.02******  0.07  506.16  505.79
   APPRO:AS    498.72    0.16  489.64  512.33  0.09  0.05  0.07  506.19  506.12
```

# WSPRO OUTPUT FILE (continued)

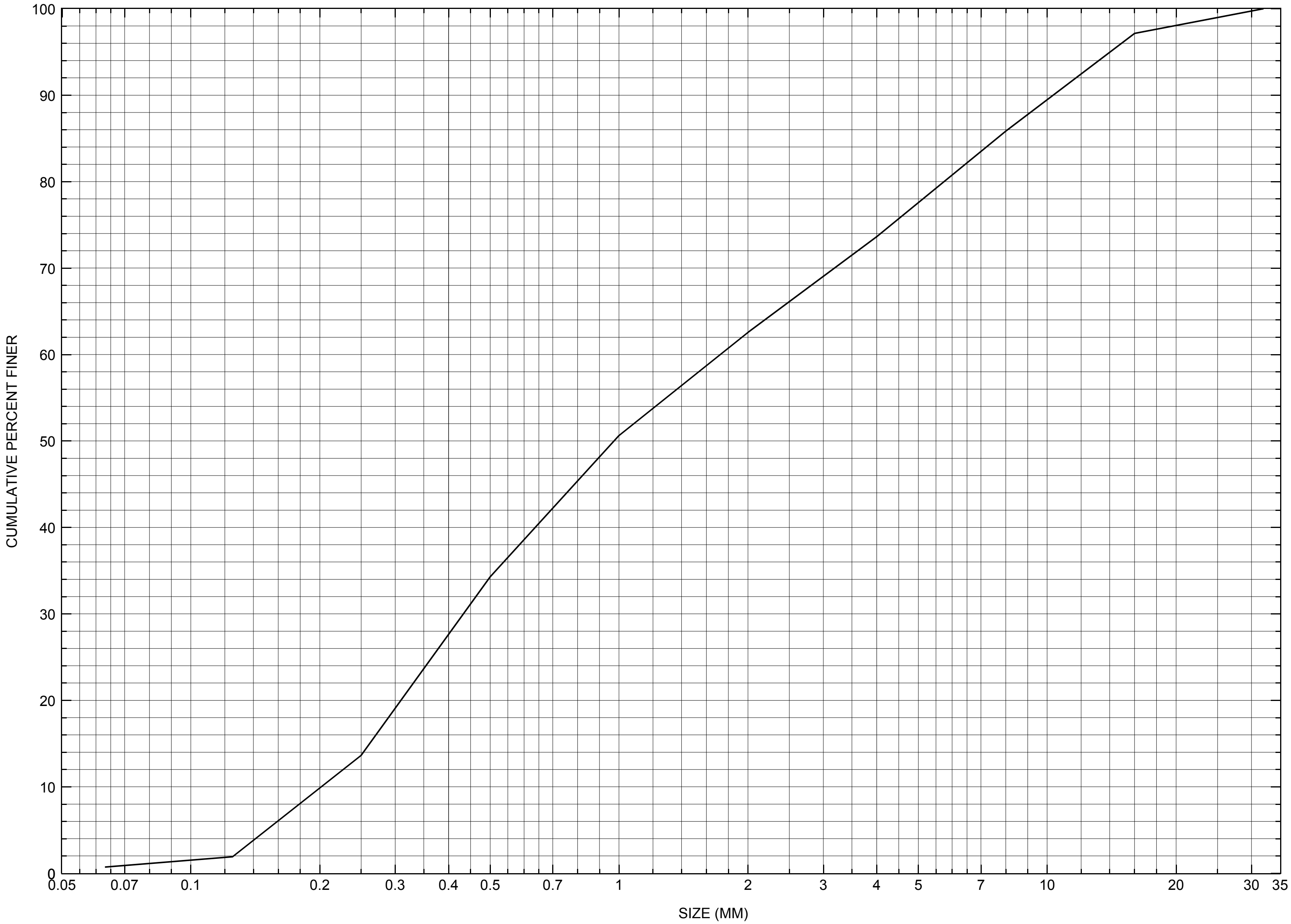
```
        U.S. Geological Survey WSPRO Input File sali007.wsp
        Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
        Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
           *** RUN DATE & TIME: 11-24-97  11:29

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

EXITX:XS   ******    -77     3548  0.18 *****  506.27  499.50    9800  506.09
       -87 ******    664   330402  1.49 ***** *******    0.27    2.76

FULLV:FV       88    -77     3555  0.16  0.08  506.34 *******    9800  506.19
         0     88    674   339107  1.33  0.00    0.00    0.26    2.76
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       80    -51     3758  0.13  0.06  506.40 *******    9800  506.27
        80     80    636   389225  1.24  0.00    0.00    0.22    2.61
         <<<<<THE ABOVE RESULTS REFLECT “NORMAL” (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   509.33       0.00     505.45     503.94

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.
 ===220 FLOW CLASS 1 (4) SOLUTION INDICATES POSSIBLE PRESSURE FLOW.
           WS3,WSIU,WS1,LSEL =   506.47     507.04     507.26     506.19

 ===245 ATTEMPTING FLOW CLASS 2 (5) SOLUTION.
 ===250 INSUFFICIENT HEAD FOR PRESSURE FLOW.
                        YU/Z,WSIU,WS = 1.05     506.95     507.05

 ===270 REJECTED FLOW CLASS 2 (5) SOLUTION.
 ===265 ROAD OVERFLOW APPEARS EXCESSIVE.
                 QRD,QRDMAX,RATIO =    5498.      5405.    1.02

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

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

BRIDG:BR       88      0      784  0.62  0.31  507.09  497.24    4302  506.47
         0     88     54   111977  1.32  0.52    0.00    0.29    5.49

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   4.  0.870 ******  506.19 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      15.    55.  0.03  0.10  507.34    0.00   5498.  506.77

             Q   WLEN    LEW    REW  DMAX  DAVG  VMAX  VAVG  HAVG  CAVG
   LT:      0. ****** ****** ****** ***** ***** ***** ***** ***** *****
   RT:   5498.   551.   120.   671.   2.8   1.6   6.9   6.2   2.2   3.1

===140 AT SECID “APPRO”:  END OF CROSS SECTION EXTENDED VERTICALLY.
                             WSEL,YLT,YRT =   507.26      512.3      507.2

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

APPRO:AS       51    -54     4499  0.10  0.22  507.36  502.45    9800  507.26
        80     86    886   444519  1.39  0.05    0.00    0.21    2.18

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.921  0.903   43040.    63.   117. ********

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q        K     AREA     VEL    WSEL
   EXITX:XS     -88.   -78.   664.   9800.  330402.    3548.    2.76  506.09
   FULLV:FV      0.    -78.   674.   9800.  339107.    3555.    2.76  506.19
   BRIDG:BR      0.     0.     54.   4302.  111977.     784.    5.49  506.47
   RDWAY:RG      15.*******    0.    5498.       0.       0.    2.00  506.77
   APPRO:AS      80.   -55.   886.   9800.  444519.    4499.    2.18  507.26

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS      63.   117.   43040.

 SECOND USER DEFINED TABLE.

    XSID:CODE     CRWS      FR#    YMIN    YMAX     HF    HO   VHD      EGL    WSEL
   EXITX:XS     499.50     0.27  488.88  525.66************  0.18  506.27  506.09
   FULLV:FV   ********     0.26  490.58  525.66  0.08  0.00  0.16  506.34  506.19
   BRIDG:BR     497.24     0.29  490.58  507.18  0.31  0.52  0.62  507.09  506.47
   RDWAY:RG   ***************  503.94  528.12  0.03******  0.10  507.34  506.77
   APPRO:AS     502.45     0.21  489.64  512.33  0.22  0.05  0.10  507.36  507.26
```

# WSPRO OUTPUT FILE (continued)

```
        U.S. Geological Survey WSPRO Input File sali007.wsp
        Hydraulic analysis for structure SALITH00080007   Date: 27-JUN-97
        Town Highway 8 Crossing the Middlebury River, Salisbury, VT       EMB
           *** RUN DATE & TIME: 11-24-97  11:29

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

EXITX:XS   ******    -54     1631  0.17 *****  503.43  495.60    4250  503.26
       -87 ******    469   143167  1.63 ***** *******    0.33    2.61

FULLV:FV       88    -55     1615  0.17  0.08  503.52 *******    4250  503.35
         0     88    482   136614  1.56  0.00    0.01    0.33    2.63
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

APPRO:AS       80    -42     1969  0.11  0.06  503.57 *******    4250  503.46
        80     80    550   169354  1.55  0.00   -0.01    0.26    2.16
         <<<<<THE ABOVE RESULTS REFLECT "NORMAL" (UNCONSTRICTED) FLOW>>>>>

 ===215 FLOW CLASS 1 SOLUTION INDICATES POSSIBLE ROAD OVERFLOW.
           WS1,WSSD,WS3,RGMIN =   503.97       0.00     503.02     503.94

 ===260 ATTEMPTING FLOW CLASS 4 SOLUTION.

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

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

BRIDG:BR       88      0      621  0.89  0.12  503.91  497.19    4250  503.02
         0     88     54   100364  1.23  0.36    0.00    0.39    6.84

     TYPE PPCD FLOW      C    P/A    LSEL   BLEN   XLAB   XRAB
       4. ****   4.  0.903 ******  506.19 ****** ****** ******

    XSID:CODE    SRD   FLEN    HF   VHD     EGL     ERR       Q    WSEL
   RDWAY:RG      15.        <<<<<EMBANKMENT IS NOT OVERTOPPED>>>>>

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

APPRO:AS       51    -44     2277  0.08  0.07  504.05  496.55    4250  503.97
        80     72    563   201893  1.47  0.07    0.00    0.21    1.87

       M(G)   M(K)       KQ   XLKQ   XRKQ    OTEL
      0.909  0.543   92159.     9.    64. ********

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

  FIRST USER DEFINED TABLE.

    XSID:CODE    SRD    LEW    REW       Q         K      AREA     VEL    WSEL
   EXITX:XS     -88.   -55.   469.   4250.  143167.     1631.    2.61  503.26
   FULLV:FV       0.   -56.   482.   4250.  136614.     1615.    2.63  503.35
   BRIDG:BR       0.     0.    54.   4250.  100364.      621.    6.84  503.02
   RDWAY:RG      15.**************      0.        0.        0.    2.00********
   APPRO:AS      80.   -45.   563.   4250.  201893.     2277.    1.87  503.97

    XSID:CODE   XLKQ   XRKQ       KQ
   APPRO:AS       9.    64.   92159.

 SECOND USER DEFINED TABLE.

    XSID:CODE    CRWS     FR#    YMIN    YMAX    HF    HO   VHD      EGL    WSEL
   EXITX:XS    495.60    0.33  488.88  525.66************  0.17  503.43  503.26
   FULLV:FV   ********   0.33  490.58  525.66  0.08  0.00  0.17  503.52  503.35
   BRIDG:BR    497.19    0.39  490.58  507.18  0.12  0.36  0.89  503.91  503.02
   RDWAY:RG   ***************  503.94  528.12  0.02******  0.08  504.03********
   APPRO:AS    496.55    0.21  489.64  512.33  0.07  0.07  0.08  504.05  503.97
  ER

 NORMAL  END  OF  WSPRO  EXECUTION.
```

# APPENDIX C:

# BED-MATERIAL PARTICLE-SIZE DISTRIBUTION




Appendix C. Bed material particle-size distribution for a sediment sample from the channel approach of structure SALITH00080007, in Salisbury, Vermont.

# APPENDIX D:

# HISTORICAL DATA FORM

United States Geological Survey
Bridge Historical Data Collection and Processing Form

# Structure Number SALITH00080007

## General Location Descriptive

Data collected by *(First Initial, Full last name)* L. Medalie

Date *(MM/DD/YY)* 12 / 15 / 95

Highway District Number *(I - 2; nn)* 05

County *(FIPS county code; I - 3; nnn)* 001

Town *(FIPS place code; I - 4; nnnnn)* 62575

Mile marker *(I - 11; nnn.nnn)* 000000

Waterway *(I - 6)* MIDDLEBURY RIVER

Road Name *(I - 7):* -

Route Number TH 8

Vicinity *(I - 9)* 0.85 MI TO JCT W CL3 TH7

Topographic Map Cornwall

Hydrologic Unit Code: 02010002

Latitude *(I - 16; nnnn.n)* 43572

Longitude *(i - 17; nnnnn.n)* 73079

## Select Federal Inventory Codes

FHWA Structure Number *(I - 8)* 10011700070117

Maintenance responsibility *(I - 21; nn)* 03

Maximum span length *(I - 48; nnnn)* 0057

Year built *(I - 27; YYYY)* 1972

Structure length *(I - 49; nnnnnn)* 000060

Average daily traffic, ADT *(I - 29; nnnnnn)* 000100

Deck Width *(I - 52; nn.n)* 249

Year of ADT *(I - 30; YY)* 92

Channel & Protection *(I - 61; n)* 6

Opening skew to Roadway *(I - 34; nn)* 10

Waterway adequacy *(I - 71; n)* 7

Operational status *(I - 41; X)* A

Underwater Inspection Frequency *(I - 92B; XYY)* N

Structure type *(I - 43; nnn)* 302

Year Reconstructed *(I - 106)* 0000

Approach span structure type *(I - 44; nnn)* 000

Clear span (*nnn.n ft*) 55.6

Number of spans *(I - 45; nnn)* 001

Vertical clearance from streambed (*nnn.n ft*) 15.6

Number of approach spans *(I - 46; nnnn)* 0000

Waterway of full opening (*nnn.n ft*$^2$) 860

Comments:

**According to the structural inspection report dated 12/8/94, this structure is a single span steel-beam bridge. The abutment walls, wingwalls, backwalls, and footings are concrete. The concrete has alligator cracks with some leaks overall. Some stone fill is evident around the ends of the wingwalls and a few boulders are evident in front of each abutment. The report indicates the channel has scoured down 1 to 2 feet at the right abutment and 2 to 3 feet at the left abutment. The channel makes a bend of nearly 90 degrees immediately upstream of the bridge. The left abutment footing is exposed.**

## Bridge Hydrologic Data

Is there hydrologic data available? Y if No, type ctrl-n h    VTAOT Drainage area ($mi^2$): 62.5

Terrain character: Flat to mountainous

Stream character & type:

Streambed material: Silty-sand with some gravel

Discharge Data (*cfs*): $Q_{2.33}$ ____ $Q_{10}$ ____ $Q_{25}$ ____

$Q_{50}$ ____ $Q_{100}$ ____ $Q_{500}$ ____

Record flood date (*MM / DD / YY*): ___ / ___ / ___    Water surface elevation (*ft*): ____

Estimated Discharge (*cfs*): ____    Velocity at Q ____ (*ft/s*): ____

Ice conditions (*Heavy, Moderate, Light*) : Moderate    Debris (*Heavy, Moderate, Light*): Moderate

The stage increases to maximum highwater elevation (*Rapidly, Not 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: N/A

Watershed storage area (*in percent*): - %

The watershed storage area is: - (*1-mainly at the headwaters; 2- uniformly distributed; 3-immediatly upstream oi the site*)

Water Surface Elevation Estimates for Existing Structure:

| Peak discharge frequency | $Q_{2.33}$ | $Q_{10}$ | $Q_{25}$ | $Q_{50}$ | $Q_{100}$ |
|---|---|---|---|---|---|
| Water surface elevation (*ft*) | - | - | - | - | - |
| Velocity (*ft / sec*) | - | - | - | - | - |

Long term stream bed changes: -

Is the roadway overtopped below the $Q_{100}$? (*Yes, No, Unknown*): U    Frequency: -

Relief Elevation (*ft*): -    Discharge over roadway at $Q_{100}$ ($ft^3/sec$): -

Are there other structures nearby? (*Yes, No, Unknown*): N  *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 ($ft^2$): -

Downstream distance (*miles*): - Town: - Year Built: -

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

Clear span (*ft*): - Clear Height (*ft*): - Full Waterway ($ft^2$): -

Comments:

**According to a hydraulic data assessment, the stream velocity at the design stage is 9 feet per second (fps). The Q25 is the design discharge of 6000 cfs. The ordinary high water elevation is 486.9 feet while the design high water elevation is 491.4 feet. There is a vertical clearance of 1.2 feet at the design stage to the low bridge seat. A check discharge equal to 1.2 times the design discharge (7000 cfs) resulted in a water surface elevation of 492.5 feet. The allowable water surface elevation is 492.7 feet, which is limited by the low bridge seat.**

## USGS Watershed Data

Watershed Hydrographic Data

Drainage area *(DA)* **62.43** $mi^2$

Lake/pond/swamp area **0.396** $mi^2$

Watershed storage *(ST)* **0.63** %

Bridge site elevation **360** ft

Headwater elevation **3234** ft

Main channel length **14.43** mi

10% channel length elevation **360** ft

85% channel length elevation **1700** ft

Main channel slope *(S)* **123.81** ft / mi

Watershed Precipitation Data

Average site precipitation - in

Average headwater precipitation - in

Maximum 2yr-24hr precipitation event *(I24,2)* **2.39** in

Average seasonal snowfall *(Sn)* **6.25** ft

## Bridge Plan Data

Are plans available? Y *If no, type ctrl-n pl* Date issued for construction *(MM / YYYY):* - / -

Project Number TF 6627 Minimum channel bed elevation: 477.0

Low superstructure elevation: USLAB 495.02 DSLAB 494.9 USRAB 492.78 DSRAB 492.66

Benchmark location description:

**BM #2 is a spike in the root of a 36” diameter elm tree with an assumed elevation of 500 feet. The tree is located approximately 80 feet in a downstream direction from the bridge and approximately 100 feet up the left bank from the Middlebury River.**

Reference Point (*MSL, Arbitrary, Other*): Arbitrary Datum (*NAD27, NAD83, Other*): -

Foundation Type: 1 (*1-Spreadfooting; 2-Pile; 3- Gravity; 4-Unknown*)

If 1: Footing Thickness 2 - 3* Footing bottom elevation: 473.0

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: 3 (*1-regolith, 2-bedrock, 3-unknown*)

Briefly describe material at foundation bottom elevation or around piles:

**NO FOUNDATION MATERIAL INFORMATION IS AVAILABLE.**

Comments:

*** The footing of the left abutment is 2 feet thick while that of the right abutment is 3 feet thick.**

**The low superstructure elevations shown above are the bridge seat elevations from the plans. Footing bottom elevations on both the right and left sides are 473.0 feet. The wingwall-abutment top corner elevation is 495.58 feet on the US left, 498.44 feet on the DS left, 496.34 feet on the US right, and 496.2 feet on the DS right.**

## Cross-sectional Data

Is cross-sectional data available? **Y** *If no, type ctrl-n xs*

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

Comments: **This cross section is the downstream face. The low chord elevation is from the surveyed data completed for this site on 6/17/96. The low chord to bed length data is from the sketch attached to a bridge inspection report dated 12/8/94. The sketch was done on 11/25/92.**

| Station | 0 | 3.1 | 19.8 | 33.4 | 49.2 | 52.5 | 55.6 | - | - | - | - |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature | RAB | - | - | - | - | - | LAB | - | - | - | - |
| Low chord elevation | 505.2 | - | - | - | - | - | 507.2 | - | - | - | - |
| Bed elevation | 491.7 | - | - | - | - | - | 492.6 | - | - | - | - |
| Low chord - bed length | 13.5 | 13.5 | 14.0 | 15.5 | 15.5 | 14.6 | 14.6 | - | - | - | - |

| Station | - | - | - | - | - | - | - | - | - | - | - |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature | - | - | - | - | - | - | - | - | - | - | - |
| Low cord elevation | - | - | - | - | - | - | - | - | - | - | - |
| Bed elevation | - | - | - | - | - | - | - | - | - | - | - |
| Low chord - bed length | - | - | - | - | - | - | - | - | - | - | - |

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

Comments: -

| Station | - | - | - | - | - | - | - | - | - | - | - |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature | - | - | - | - | - | - | - | - | - | - | - |
| Low chord elevation | - | - | - | - | - | - | - | - | - | - | - |
| Bed elevation | - | - | - | - | - | - | - | - | - | - | - |
| Low chord - bed length | - | - | - | - | - | - | - | - | - | - | - |

| Station | - | - | - | - | - | - | - | - | - | - | - |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature | - | - | - | - | - | - | - | - | - | - | - |
| Low cord elevation | - | - | - | - | - | - | - | - | - | - | - |
| Bed elevation | - | - | - | - | - | - | - | - | - | - | - |
| Low chord - bed length | - | - | - | - | - | - | - | - | - | - | - |

APPENDIX E:

# LEVEL I DATA FORM

U. S. Geological Survey
Bridge Field Data Collection and Processing Form

Qa/Qc Check by: **MS** Date: **07/02/97**
Computerized by: **MS** Date: **07/03/97**
Reviewd by: **EMB** Date: **8/29/97**

Structure Number **SALITH00080007**

## A. General Location Descriptive

1. Data collected by *(First Initial, Full last name)* **L. MEDALIE** Date *(MM/DD/YY)* **06** / **17** / 19**96**

2. Highway District Number **05** Mile marker **000000**
County **Addison (001)** Town **Salisbury (62575)**
Waterway *(I - 6)* **Middlebury River** Road Name **Blake Roy Road**
Route Number **TH 8** Hydrologic Unit Code: **02010002**

3. Descriptive comments:
**This structure is located 0.85 mile from the junction of Town Highway 7 with Town Highway 8.**

## B. Bridge Deck Observations

4. Surface cover... LBUS **4** RBUS **4** LBDS **6** RBDS **3** Overall **4**
*(2b us,ds,lb,rb: **1**- Urban; **2**- Suburban; **3**- Row crops; **4**- Pasture; **5**- Shrub- and brushland; **6**- Forest; **7**- Wetland)*

5. Ambient water surface... US **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 **60** *(feet)* Span length **57** *(feet)* Bridge width **24.9** *(feet)*

### Road approach to bridge:

8. LB **2** RB **1** *( **0** even, **1**- lower, **2**- higher)*

9. LB **2** RB **2** *( **1**- Paved, **2**- Not paved)*

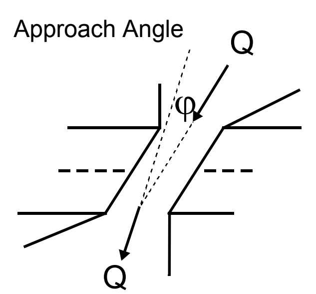
10. Embankment slope (*run / rise in feet / foot*):
US left **1.6:1** US right **2.0:1**

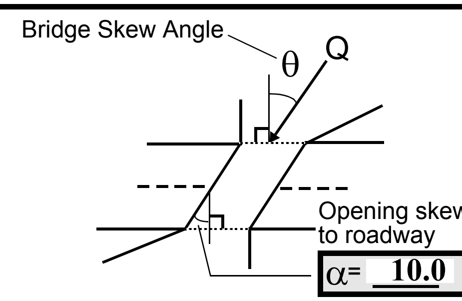
| | Protection | | 13.Erosion | 14.Severity |
|---|---|---|---|---|
| | 11.Type | 12.Cond. | | |
| LBUS | 0 | - | 0 | - |
| RBUS | 0 | - | 2 | 1 |
| RBDS | 1 | 1 | 0 | - |
| LBDS | 0 | - | 0 | - |

*Bank protection types: **0**- none; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*
*Erosion: **0** - none; **1**- channel erosion; **2**- road wash; **3**- both; **4**- other*
*Erosion Severity: **0** - none; **1**- slight; **2**- moderate; **3**- severe*

### Channel approach to bridge (BF):

15. Angle of approach: **0** 16. Bridge skew: **25**




17. Channel impact zone 1: Exist? **Y** *(Y or N)*
Where? **LB** *(LB, RB)* Severity **3**
Range? **60** feet **US** *(US, UB, DS)* to **125** feet **US**

Channel impact zone 2: Exist? **N** *(Y or N)*
Where? **-** *(LB, RB)* Severity **-**
Range? **-** feet **-** *(US, UB, DS)* to **-** feet **-**

*Impact Severity: **0**- none to very slight; **1**- Slight; **2**- Moderate; **3**- Severe*

18. Bridge Type: **4**

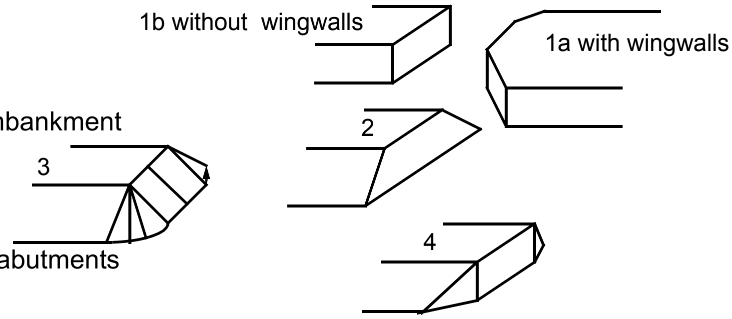
1a- Vertical abutments with wingwalls

1b- Vertical abutments without wingwalls

2- Vertical abutments and wingwalls, sloping embankment
Wingwalls parallel 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.)

**The bridge dimensions shown on the previous page are those obtained from the VTAOT database. The measured bridge length, span length, and bridge width were 59 feet, 58 feet, and 24.7 feet respectively.**
**The dense grass coverage helps to stabilize all the road approach embankments. There is road wash located just behind the upstream right wingwall. The DS right bank protection, indicated later in this assessment, is at the end of the DS right wingwall, midway up the slope between the top and bottom of the bank.**

## C. Upstream Channel Assessment

| 20. SRD | 21. Bank height (BF) LB | 21. Bank height (BF) RB | 22. Bank angle (BF) LB | 22. Bank angle (BF) RB | 26. % Veg. cover (BF) LB | 26. % Veg. cover (BF) RB | 27. Bank material (BF) LB | 27. Bank material (BF) RB | 28. Bank erosion (BF) LB | 28. Bank erosion (BF) RB |
|---|---|---|---|---|---|---|---|---|---|---|
| **30.0** | **4.0** | | | **7.5** | **1** | **2** | **126** | **254** | **2** | **2** |

23. Bank width **15.0**   24. Channel width **25.0**   25. Thalweg depth **77.5**   29. Bed Material **234**

30 .Bank protection type: LB **1** RB **1**   31. Bank protection condition: LB **1** RB **1**

*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.):

**Both the left bank and the right bank are covered with mostly grass and weeds.**
**The bed material grades from sand on the right side to cobbles and gravel on the left side of the channel. Bedrock is exposed at the surface along the left bank in the channel from 50 feet to 130 feet upstream.**
**The right bank protection consists of small pieces of stone where the river bends sharply, about 50 feet upstream of the bridge. The left bank protection extends from under the bridge to 55 feet US.**

33. Point/Side bar present? **Y** (Y or N. if N type ctrl-n pb) 34. Mid-bar distance: **60** 35. Mid-bar width: **10**

36. Point bar extent: **50** feet **US** (US, UB) to **60** feet **US** (US, UB, DS) positioned **80** %LB to **90** %RB

37. Material: **23**

38. Point or side bar comments (Circle Point or Side; Note additional bars, material variation, status, etc.):

**The point bar is present along the right bank at the sharp bend in the river just upstream. There is a second bar along the right bank located from 5 feet US to 40 feet US. Its mid-bar distance is 30 feet where the width is 8 feet. The bar is composed of sand and it is positioned 93% LB to 100% RB.**

39. Is a cut-bank present? **Y** (Y or if N type ctrl-n cb) 40. Where? **LB** (LB or RB)

41. Mid-bank distance: **105** 42. Cut bank extent: **50** feet **US** (US, UB) to **120** feet **US** (US, UB, DS)

43. Bank damage: **3** ( 1- eroded and/or creep; 2- slip failure; 3- block failure)

44. Cut bank comments (eg. additional cut banks, protection condition, etc.):

**This cut bank area is stabilized by the exposed bedrock.**

45. Is channel scour present? **Y** (Y or if N type ctrl-n cs) 46. Mid-scour distance: **85**

47. Scour dimensions: Length **80** Width **50** Depth : **4** Position **10** %LB to **50** %RB

48. Scour comments (eg. additional scour areas, local scouring process, etc.):

**There is another scour hole on the right bank that is located between the point bars along the right bank. The length is 15 feet, the width is 5 feet, and the depth is 2.5 feet. The average thalweg depth is 3 feet.**

49. Are there major confluences? **Y** (Y or if N type ctrl-n mc) 50. How many? **1**

51. Confluence 1: Distance **-** 52. Enters on **LB** (LB or RB) 53. Type **1** ( 1- perennial; 2- ephemeral)

Confluence 2: Distance **-** Enters on **-** (LB or RB) Type **-** ( 1- perennial; 2- ephemeral)

54. Confluence comments (eg. confluence name):

**The distance upstream to this confluence was not measured. The name of the tributary is Halnon Brook.**

## D. Under Bridge Channel Assessment

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

| 56. Height (BF) LB | RB | 57 Angle (BF) LB | RB | 61. Material (BF) LB | RB | 62. Erosion (BF) LB | RB |
|---|---|---|---|---|---|---|---|
| 51.5 | | 3.0 | | 2 | 7 | 7 | - |

58. Bank width (BF) **-** 59. Channel width **-** 60. Thalweg depth **90.0** 63. Bed Material **-**

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

*Bank Erosion: 0- not evident; 1- light fluvial; 2- moderate fluvial; 3- heavy fluvial / mass wasting*

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

**234**

**The bed material grades from fine to coarse material from the right to the left.**

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? 1___ *(Y or N)* Ice Blockage Potential Y____ *( 1- Low; 2- Moderate; 3- High)*

70. Debris and Ice Comments:

**1**

**The debris accumulation is essentially grass or weed stalks deposited on the island during high water.**
**The debris potential is low because there are few trees located near the banks.**
**There are gouges in the bark of several trees along the banks suggesting ice build-up may be significant along the reach.**

| Abutments | 71. Attack ∠(BF) | 72. Slope ∠ (Qmax) | 73. Toe loc. (BF) | 74. Scour Condition | 75. Scour depth | 76. Exposure depth | 77. Material | 78. Length |
|---|---|---|---|---|---|---|---|---|
| LABUT | | 0 | 90 | 2 | 2 | - | 2.5 | 90.0 |
| RABUT | 1 | 0 | 90 | | | 2 | 1 | 53.5 |

*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.):

**-**

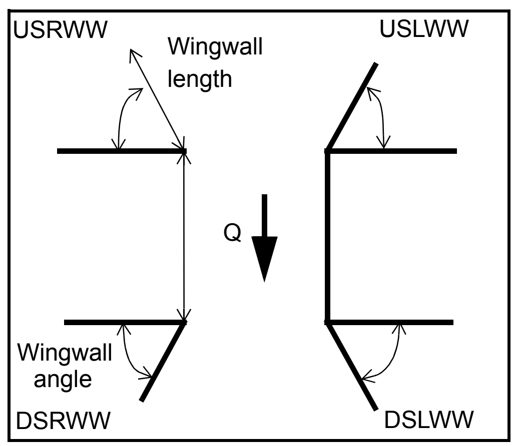
**-**

**1**

**Along the right abutment, the streambed is about one foot below the water surface up to about 2 to 3 feet from the wall. At the upstream wingwall, the depth is 2.5 feet. At the DS end of the right abutment, the top of the footing can be detected with a range pole approximately 3 to 4 inches below the streambed surface.**

80. **Wingwalls**:

| | Exist? | Material? | Scour Condition? | Scour depth? | Exposure depth? | 81. Angle? | Length? |
|---|---|---|---|---|---|---|---|
| USLWW: | | | | | | 53.5 | |
| USRWW: | Y | | 1 | | 2 | 2.0 | |
| DSLWW: | 0 | | 2.5 | | Y | 27.5 | |
| DSRWW: | 1 | | 1 | | - | 31.5 | |




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

82. **Bank / Bridge Protection**:

| Location | USLWW | USRWW | LABUT | RABUT | LB | RB | DSLWW | DSRWW |
|---|---|---|---|---|---|---|---|---|
| Type | - | 2 | Y | - | 1 | 1 | 1 | - |
| Condition | Y | - | 1 | - | 1 | 2 | 2 | - |
| Extent | 1 | 0.5 | 0 | 2 | 1 | 2 | 0 | - |

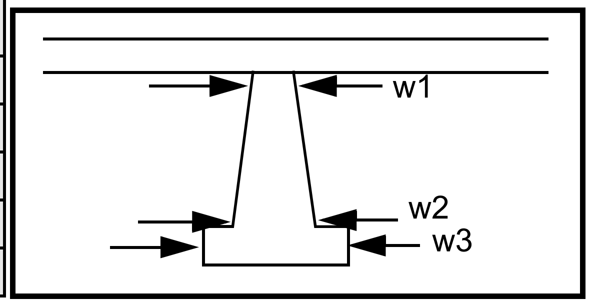
*Bank / Bridge protection types: 0- absent; 1- < 12 inches; 2- < 36 inches; 3- < 48 inches; 4- < 60 inches; 5- wall / artificial levee*
*Bank / Bridge protection conditions: 1- good; 2- slumped; 3- eroded; 4- failed*
*Protection extent: 1- entire base length; 2- US end; 3- DS end; 4- other*

83. Wingwall and protection comments (eg. undermined penetration, unusual scour processes, etc.):
**-**
**-**
**-**
**-**
**-**
**0**
**-**
**-**
**1**
**1**
**1**

## Piers:

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

| 85. Pier no. | width (w) feet | | | elevation (e) feet | | |
|---|---|---|---|---|---|---|
| | w1 | w2 | w3 | e@w1 | e@w2 | e@w3 |
| Pier 1 | | | | **30.0** | **24.0** | **55.0** |
| Pier 2 | | | | **16.0** | **45.0** | **21.0** |
| Pier 3 | | | **-** | **50.0** | **13.0** | **-** |
| Pier 4 | **-** | **-** | **-** | **-** | **-** | **-** |




| Level 1 Pier Descr. | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| 86. Location (BF) | **e foot-** | **but is** | **first 10** | **ment,** | *LFP, LTB, LB, MCL, MCM, MCR, RB, RTB, RFP* |
| 87. Type | **ing** | **cov-** | **feet** | **the** | ***1**- Solid pier, **2**- column, **3**- bent* |
| 88. Material | **of** | **ered** | **of** | **wing** | ***1**- Wood; **2**- concrete; **3**- metal; **4**- stone* |
| 89. Shape | **the** | **by** | **the** | **wall** | ***1**- Round; **2**- Square; **3**- Pointed* |
| 90. Inclined? | **US** | **0.5** | **DS** | **is** | *Y- yes; N- no* |
| 91. Attack ∠ (BF) | **right** | **to 1** | **left** | **con-** | |
| 92. Pushed | **wing** | **foot** | **wing** | **crete** | *LB or RB* |
| 93. Length (feet) | **-** | **-** | **-** | **-** | |
| 94. # of piles | **wall** | **of** | **wall** | **.** | |
| 95. Cross-members | **is** | **loose** | **from** | **Then** | ***0**- none; **1**- laterals; **2**- diagonals; **3**- both* |
| 96. Scour Condition | **not** | **sand.** | **the** | **the** | ***0**- not evident; **1**- evident (comment); **2**- footing exposed; **3**- piling exposed; **4**- undermined footing; **5**- settled; **6**- failed* |
| 97. Scour depth | **expo** | **For** | **left** | **wing** | |
| 98. Exposure depth | **sed** | **the** | **abut** | **wall** | |

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

**is a “laid-up” stone wall. The US left wingwall protection is located mostly at the center and the upstream end of the wingwall. However, the protection is very sparse at the corner of the upstream left wingwall and the upstream end of the left abutment.**

**N**

## E. Downstream Channel Assessment

100.

| SRD | Bank height (BF) LB | Bank height (BF) RB | Bank angle (BF) LB | Bank angle (BF) RB | % Veg. cover (BF) LB | % Veg. cover (BF) RB | Bank material (BF) LB | Bank material (BF) RB | Bank erosion (BF) LB | Bank erosion (BF) RB |
|---|---|---|---|---|---|---|---|---|---|---|
| - | - | | | - | - | - | - | - | - | - |

Bank width (BF) - Channel width - Thalweg depth - Bed Material -

Bank protection type (Qmax): LB - RB - Bank protection condition: LB - RB -

*SRD - Section ref. dist. to US face* *% Vegetation (Veg) cover: **1**- 0 to 25%; **2**- 26 to 50%; **3**- 51 to 75%; **4**- 76 to 100%*
*Bed and bank Material: **0**- organics; **1**- silt / clay, < 1/16mm; **2**- sand, 1/16 - 2mm; **3**- gravel, 2 - 64mm; **4**- cobble, 64 - 256mm; **5**- boulder, > 256mm; **6**- bedrock; **7**- manmade*
*Bank Erosion: **0**- not evident; **1**- light fluvial; **2**- moderate fluvial; **3**- heavy fluvial / mass wasting*
*Bank protection types: **0**- absent; **1**- < 12 inches; **2**- < 36 inches; **3**- < 48 inches; **4**- < 60 inches; **5**- wall / artificial levee*
*Bank protection conditions: **1**- good; **2**- slumped; **3**- eroded; **4**- failed*

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

-
-
-
-
-
-
-
-
-
-
-
-
-
-
-

101. Is a drop structure present? - (Y or N, if N type ctrl-n ds) 102. Distance: - feet

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

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

-
-
-
-
-
-

106. Point/Side bar present? _-_ (Y or N. if N type ctrl-n pb) Mid-bar distance: _-_ Mid-bar width: _-_

Point bar extent: _-_ 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? _N_ (Y or if N type ctrl-n cb) Where? _O_ (LB or RB) Mid-bank distance: _PIE_

Cut bank extent: _RS_ 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: _4_

Scour dimensions: Length _4_ Width _16_ Depth: _145_ Positioned _2_ %LB to _2_ %RB

Scour comments (eg. additional scour areas, local scouring process, etc.):

**234**
**0**
**2**
**-**

Are there major confluences? _1_ (Y or if N type ctrl-n mc) How many? _The_

Confluence 1: Distance _bed_ Enters on _mat_ (LB or RB) Type _erial_ ( **1**- perennial; **2**- ephemeral)

Confluence 2: Distance _grad_ Enters on _es_ (LB or RB) Type _fro_ ( **1**- perennial; **2**- ephemeral)

Confluence comments (eg. confluence name):

**m fine sand to bedrock from the right bank to the left bank side of the channel. The bedrock is exposed on the left side of the channel from 10 feet DS to 65 feet DS. The right bank protection extends from 43 feet DS to 67**

## F. Geomorphic Channel Assessment

107. Stage of reach evolution _fee_

**1**- Constructed
**2**- Stable
**3**- Aggraded
**4**- Degraded
**5**- Laterally unstable
**6**- Vertically and laterally unstable

108. Evolution comments *(Channel evolution not considering bridge effects; See HEC-20, Figure 1 for geomorphic descriptors)*:

**t DS, but it is not continuous. Although a considerable amount of material has been eroded, the left bank erosion is moderate because the bedrock prevents instability.**

**At approximately 100 feet downstream, the percent vegetation cover on both banks reduces to the range of 26 to 50%.**

## 109. G. Plan View Sketch

- N

| | | | |
|---|---|---|---|
| point bar pb | debris | flow Q | stone wall |
| cut-bank cb | rip rap or stone fill | cross-section | other wall |
| scour hole | | ambient channel | |

# APPENDIX F:

# SCOUR COMPUTATIONS

SCOUR COMPUTATIONS

Structure Number: SALITH00080007 Town: Middlebury
Road Number: TH 8 County: Addison
Stream: Middlebury River

Initials EMB Date: 7/25/97 Checked: RF 8/18/97

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

Critical Velocity of Bed Material (converted to English units)
Vc=11.21*y1^0.1667*D50^0.33 with Ss=2.65
(Richardson and others, 1995, p. 28, eq. 16)

Approach Section

| Characteristic | 100 yr | 500 yr | other Q |
|---|---|---|---|
| Total discharge, cfs | 7000 | 9800 | 4250 |
| Main Channel Area, ft2 | 1067 | 1156 | 900 |
| Left overbank area, ft2 | 217 | 266 | 136 |
| Right overbank area, ft2 | 2372 | 3076 | 1228 |
| Top width main channel, ft | 78 | 78 | 78 |
| Top width L overbank, ft | 41 | 44 | 34 |
| Top width R overbank, ft | 563 | 819 | 495 |
| D50 of channel, ft | 0.00319 | 0.00319 | 0.00319 |
| D50 left overbank, ft | -- | -- | -- |
| D50 right overbank, ft | -- | -- | -- |
| y1, average depth, MC, ft | 13.7 | 14.8 | 11.5 |
| y1, average depth, LOB, ft | 5.3 | 6.0 | 4.0 |
| y1, average depth, ROB, ft | 4.2 | 3.8 | 2.5 |
| Total conveyance, approach | 375007 | 444354 | 201670 |
| Conveyance, main channel | 156012 | 178182 | 117478 |
| Conveyance, LOB | 23019 | 30506 | 11905 |
| Conveyance, ROB | 195976 | 235666 | 72287 |
| Percent discrepancy, conveyance | 0.0000 | 0.0000 | 0.0000 |
| Qm, discharge, MC, cfs | 2912.2 | 3929.7 | 2475.7 |
| Ql, discharge, LOB, cfs | 429.7 | 672.8 | 250.9 |
| Qr, discharge, ROB, cfs | 3658.2 | 5197.5 | 1523.4 |
| Vm, mean velocity MC, ft/s | 2.7 | 3.4 | 2.8 |
| Vl, mean velocity, LOB, ft/s | 2.0 | 2.5 | 1.8 |
| Vr, mean velocity, ROB, ft/s | 1.5 | 1.7 | 1.2 |
| Vc-m, crit. velocity, MC, ft/s | 2.6 | 2.6 | 2.5 |
| Vc-l, crit. velocity, LOB, ft/s | ERR | ERR | ERR |
| Vc-r, crit. velocity, ROB, ft/s | ERR | ERR | ERR |

Results

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

| | | | |
|---|---|---|---|
| Main Channel | 1 | 1 | 1 |

Armoring
Dc=[(1.94*V^2)/(5.75*log(12.27*y/D90))^2]/[0.03*(165-62.4)]
Depth to Armoring=3*(1/Pc-1)

(Federal Highway Administration, 1993)

| Downstream bridge face property | 100-yr | 500-yr | Other Q |
|---|---|---|---|
| Q, discharge thru bridge MC, cfs | 4908 | 4302 | 4250 |
| Main channel area (DS), ft2 | 734 | 784 | 621 |
| Main channel width (normal), ft | 53.4 | 53.4 | 53.4 |
| Cum. width of piers, ft | 0.0 | 0.0 | 0.0 |
| Adj. main channel width, ft | 53.4 | 53.4 | 53.4 |
| D90, ft | 0.0000 | 0.0000 | 0.0000 |
| D95, ft | 0.0000 | 0.0000 | 0.0000 |
| Dc, critical grain size, ft | ERR | ERR | ERR |
| Pc, Decimal percent coarser than Dc | 0.000 | 0.000 | 0.000 |

Live-Bed Contraction Scour

Laursen's Live Bed Contraction Scour

y2/y1 = (Q2/Q1)^(6/7)*(W1/W2)^(k1)

ys=y2-y_bridge

(Richardson and others, 1995, p. 30, eq. 17 and 18)

| Characteristic | Approach 100 yr | 500 yr | Other Q | Bridge 100 yr | 500 yr | Other Q |
|---|---|---|---|---|---|---|
| Q1, discharge, cfs | 7000 | 9800 | 4250 | 4908 | 4302 | 4250 |
| Total conveyance | 375007 | 444354 | 201670 | 127845 | 111994 | 100353 |
| Main channel conveyance | 156012 | 178182 | 117478 | 127845 | 111994 | 100353 |
| Main channel discharge | 2912 | 3930 | 2476 | 4908 | 4302 | 4250 |
| Area - main channel, ft2 | 1067 | 1156 | 900 | 734 | 784 | 621 |
| (W1) channel width, ft | 78 | 78 | 78 | 53.4 | 53.4 | 53.4 |
| (Wp) cumulative pier width, ft | 0 | 0 | 0 | 0 | 0 | 0 |
| W1, adjusted bottom width(ft) | 78 | 78 | 78 | 53.4 | 53.4 | 53.4 |
| D50, ft | 0.00319 | 0.00319 | 0.00319 | | | |
| w, fall velocity, ft/s (p. 32) | 0.44 | 0.44 | 0.44 | | | |
| y, ave. depth flow, ft | 13.68 | 14.82 | 11.54 | 13.75 | 14.68 | 11.63 |
| S1, slope EGL | 0.00075 | 0.00075 | 0.000625 | | | |
| P, wetted perimeter, MC, ft | 81 | 81 | 81 | | | |
| R, hydraulic Radius, ft | 13.173 | 14.272 | 11.111 | | | |
| V*, shear velocity, ft/s | 0.564 | 0.587 | 0.473 | | | |
| V*/w | 1.282 | 1.334 | 1.075 | | | |
| Bed transport coeff., k1, (0.59 if V*/w<0.5; 0.64 if .5<V*/w<2; 0.69 if V*/w>2.0 p. 33) | | | | | | |
| k1 | 0.64 | 0.64 | 0.64 | | | |
| y2,depth in contraction, ft | 27.27 | 20.41 | 23.37 | | | |
| ys, scour depth, ft (y2-y_bridge) | 13.52 | 5.73 | 11.74 | | | |

Clear Water Contraction Scour in MAIN CHANNEL

y2 = (Q2^2/(131*Dm^(2/3)*W2^2))^(3/7)    Converted to English Units

ys=y2-y_bridge

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

| Bridge Section | Q100 | Q500 | Other Q |
|---|---|---|---|
| (Q) total discharge, cfs | 7000 | 9800 | 4250 |
| (Q) discharge thru bridge, cfs | 4908 | 4302 | 4250 |
| Main channel conveyance | 127845 | 111994 | 100353 |
| Total conveyance | 127845 | 111994 | 100353 |
| Q2, bridge MC discharge,cfs | 4908 | 4302 | 4250 |
| Main channel area, ft2 | 734 | 784 | 621 |
| Main channel width (normal), ft | 53.4 | 53.4 | 53.4 |
| Cum. width of piers in MC, ft | 0.0 | 0.0 | 0.0 |
| W, adjusted width, ft | 53.4 | 53.4 | 53.4 |
| y_bridge (avg. depth at br.), ft | 13.75 | 14.68 | 11.63 |
| Dm, median (1.25*D50), ft | 0.003988 | 0.003988 | 0.003988 |
| y2, depth in contraction,ft | 28.91 | 25.82 | 25.55 |
| ys, scour depth (y2-ybridge), ft | 15.16 | 11.14 | 13.92 |
| Depth to armoring, ft | N/A | N/A | N/A |

Abutment Scour

Froehlich's Abutment Scour
Ys/Y1 = 2.27*K1*K2*(a'/Y1)^0.43*Fr1^0.61+1
(Richardson and others, 1995, p. 48, eq. 28)

| | Left Abutment | | | Right Abutment | | |
|---|---|---|---|---|---|---|
| Characteristic | 100 yr Q | 500 yr Q | Other Q | 100 yr Q | 500 yr Q | Other Q |
| (Qt), total discharge, cfs | 7000 | 9800 | 4250 | 7000 | 9800 | 4250 |
| a', abut.length blocking flow, ft | 51.9 | 55.4 | 45.3 | 576.9 | 832.1 | 508.8 |
| Ae, area of blocked flow ft2 | 342.7 | 405.2 | 238.9 | 2068 | 3217.1 | 1334.8 |
| Qe, discharge blocked abut.,cfs | 731.5 | 1100 | 492.8 | -- | -- | 1685.6 |

(If using Qtotal_overbank to obtain Ve, leave Qe blank and enter Ve and Fr manually)

| | | | | | | |
|---|---|---|---|---|---|---|
| Ve, (Qe/Ae), ft/s | 2.13 | 2.71 | 2.06 | 1.55 | 1.72 | 1.26 |
| ya, depth of f/p flow, ft | 6.60 | 7.31 | 5.27 | 3.58 | 3.87 | 2.62 |

--Coeff., K1, for abut. type (1.0, verti.; 0.82, verti. w/ wingwall; 0.55, spillthru)

| | | | | | | |
|---|---|---|---|---|---|---|
| K1 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |

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

| | | | | | | |
|---|---|---|---|---|---|---|
| theta | 100 | 100 | 100 | 80 | 80 | 80 |
| K2 | 1.01 | 1.01 | 1.01 | 0.98 | 0.98 | 0.98 |
| Fr, froude number f/p flow | 0.146 | 0.177 | 0.158 | 0.132 | 0.154 | 0.137 |
| ys, scour depth, ft | 15.97 | 18.77 | 13.42 | 20.57 | 26.67 | 16.42 |

HIRE equation (a'/ya > 25)
ys = 4*Fr^0.33*y1*K/0.55
(Richardson and others, 1995, p. 49, eq. 29)

| | | | | | | |
|---|---|---|---|---|---|---|
| a'(abut length blocked, ft) | 51.9 | 55.4 | 45.3 | 576.9 | 832.1 | 508.8 |
| y1 (depth f/p flow, ft) | 6.60 | 7.31 | 5.27 | 3.58 | 3.87 | 2.62 |
| a'/y1 | 7.86 | 7.57 | 8.59 | 160.94 | 215.22 | 193.94 |
| Skew correction (p. 49, fig. 16) | 0.97 | 0.97 | 0.97 | 1.02 | 1.02 | 1.02 |
| Froude no. f/p flow | 0.15 | 0.18 | 0.16 | 0.13 | 0.15 | 0.14 |
| Ys w/ corr. factor K1/0.55: | | | | | | |
| vertical | ERR | ERR | ERR | 13.63 | 15.47 | 10.11 |
| vertical w/ ww's | ERR | ERR | ERR | 11.18 | 12.68 | 8.29 |
| spill-through | ERR | ERR | ERR | 7.50 | 8.51 | 5.56 |

Abutment riprap Sizing

Isbash Relationship
D50=y*K*Fr^2/(Ss-1) and D50=y*K*(Fr^2)^0.14/(Ss-1)
(Richardson and others, 1995, p112, eq. 81,82)

| Characteristic | Q100 | Q500 | Other Q | Q100 | Q500 | Other Q |
|---|---|---|---|---|---|---|
| Fr, Froude Number | 0.36 | 0.29 | 0.39 | 0.36 | 0.29 | 0.39 |
| y, depth of flow in bridge, ft | 13.75 | 14.68 | 11.63 | 13.75 | 14.68 | 11.63 |

| Median Stone Diameter for riprap at: | left abutment | | | right abutment, ft | | |
|---|---|---|---|---|---|---|
| Fr<=0.8 (vertical abut.) | 1.10 | 0.76 | 1.09 | 1.10 | 0.76 | 1.09 |
| Fr>0.8 (vertical abut.) | ERR | ERR | ERR | ERR | ERR | ERR |