Application of the BRIdge Stream Tube Model for Alluvial River Simulations (BRI-STARS) at Bridge 101-17-5096A, State Road 101 Over the St. Joseph River at Saint Joe, Indiana

By DAVID C. VOELKER

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per foot (ft/ft)	1.000	meter per meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

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Abstract

The BRIdge Stream Tube Model for Alluvial River Simulations (BRI-STARS) at bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Indiana, was applied as part of a bridge-scour study. BRI-STARS, developed by Colorado State University for the Federal Highway Administration, is designed to determine potential degradation or aggradation of the streambed by simulating sediment transport during a design flow event.

Channel cross sections were surveyed to describe the stream reach being studied, and hydrographs representing 100-year and 500-year floods were developed. The 100-year-flood discharge at the site is 11,900 cubic feet per second, and the 500-year-flood discharge is 15,100 cubic feet per second.

Maximum scour occurred at or near the peak of the simulated flood hydrographs. Simulated scour depths at the peak of the 100-year-flood hydrograph ranged from 3.47 to 4.25 feet at the bridge piers, 23.04 to 39.16 feet at the abutments, and from 0 scour to an aggradation of 3.33 feet for general contraction scour. Simulated scour depths at the peak of the 500-year-flood hydrograph ranged from 3.71 to 4.58 feet at the piers, 26.37 to 43.84 feet at the abutments, and from 0 scour to an aggradation of 3.80 feet for general contraction scour. Maximum contraction scour over the entire flood hydrograph was 0.78 feet for the 500-year flood and 1.00 foot for the 100-year flood, using data from samples collected with the BMH-53 piston sampler. Use of the clam-bucket sample data showed no contraction scour for either flood hydrograph.

Pier scour was calculated in BRI-STARS with the Colorado State University equation, abutment scour was predicted with Froehlich's live-bed equation, and contraction scour was determined with Laursen's contraction-scour equations.

INTRODUCTION

Susceptibility of bridge piers to streambed scouring is a major concern in evaluating bridge safety. One of the most common causes of bridge failure stems from flooding and the subsequent scouring of streambed materials from around bridge foundations. Following the collapse of several bridges throughout the United States, the Transportation Research Board of the National Research Council began efforts to study scour at bridges and issued Technical Advisory 5140.20 (U.S. Federal Highway Administration, 1988) to address the scour issue. The Technical Advisory states that every bridge over a waterway should be assessed as to its vulnerability to damage from scour to determine the prudent measures needed for ensuring a secure bridge structure (U.S. Federal Highway Administration, 1991).

Background

Several types of scour can be evaluated at a bridge site, including total, general, contraction, and local scour. Total scour is composed of general scour, contraction scour, and local (pier or abutment) scour. General scour is the long-term degradation or lowering of the streambed. Contraction scour occurs at a channel constriction and is the result of increased flow velocity as a result of the decreased flow area. Local (or pier or abutment) scour is caused by disturbances of flow in the vicinity of piers and abutments (Southard, 1993).

The BRIdge Stream Tube Model for Alluvial River Simulations (BRI-STARS) (Molinas, 1994) was developed for use as a tool in the assessment of bridge scour. The U.S. Geological Survey, in cooperation with the Indiana Department of Transportation (INDOT), applied the BRI-STARS model at a bridge crossing in Indiana.

Purpose and Scope

This report describes the application of the BRI-STARS computer model at one bridge crossing in Indiana. The results of the computer simulations are tabulated in this report and were compared to previous scour analyses done at the site by Miller and Wilson (1996). Input files used in the BRI-STARS simulations are included in the appendixes.

DESCRIPTION OF THE BRIDGE STREAM TUBE MODEL FOR ALLUVIAL RIVER SIMULATIONS (BRI-STARS)

The BRI-STARS model, developed by Colorado State University (CSU) for the Federal Highway Administration (FHA), provides simulations of alluvial scour or deposition under various flow conditions. The model consists of three major components: (1) step-backwater computations, (2) streamtube computations, and (3) sediment-routing computations. The model simulates scour resulting from highway encroachments and was developed to simulate long-term variations in river streambeds for which sediment and hydraulic data are limited (Molinas and Santoro, 1989).

Data requirements for the BRI-STARS model include several input components. These requirements include a combination of measurements and information collected at the bridge site and/or information generated with analytical methods.

Cross-section information is used by the model to determine the extent of the channel shape and slope. The cross-section information was collected in field surveys and includes measurements of the bridge opening, exit, and approach sections. Several cross sections upstream and downstream from the bridge opening also were surveyed. Analysis of the data indicated that the length of the channel reach being modeled needed to be extended for the model to transport sediment appropriately; additional cross sections were propagated in the upstream and downstream channel, using geometry from surveyed cross sections and surveyed river slope in the study reach to adjust the bed elevations in the propagated cross sections.

Roughness coefficients, Manning's *n* values, were input for each surveyed ground point in the cross section. The *n* values were selected from previous studies information, photographs, reference materials such as Arcement and Schneider (1989) and Barnes (1987), and with the field surveyor's judgment.

Input for local energy losses was determined by running the model to examine water-surface elevations throughout the study reach. Adjustments of the local energy losses were used to calibrate the water-surface elevations with those computed by the Water Surface PROfile (WSPRO) computation program (Shearman, 1990) used in the study by Miller and Wilson (1996) at the site.

The BRI-STARS user's manual indicates that calculated scour generally is not sensitive to the number of stream tubes simulated in the model (Molinas, 1994, p.79). Three stream tubes were selected for the final model to represent conditions similar to those in the approach and exit cross sections. Those sections consist of two overbank flood plains plus the main channel.

DESCRIPTION OF STUDY SITE

Bridge 101-17-5096A, State Road 101 bridge over the St. Joseph River at Saint Joe, Ind., is approximately 145 mi northeast of Indianapolis in

De Kalb County (fig. 1). The site has a drainage area of 663 mi^2 and is located in a rural area surrounded by woodlands and farmland. The St. Joseph River Basin is characterized by rolling terrain, and the general channel slope is 0.00023 ft/ft. The channel is relatively straight as it approaches the bridge and meanders gently downstream from the bridge.

The slope of the thalweg in the surveyed section of the study reach is 0.0014 ft/ft and was used to propagate the additional cross sections upstream and downstream from those surveyed. In the study area, the flood plain is approximately 0.5 mi wide, and the banks are wooded and stable. The bed material is sand and gravel with an armouring cobble layer in parts of the channel (Miller and Wilson, 1996).

The bridge was built in 1963 and consists of four spans, supported by three concrete and steel piers, and sloping concrete spill-through abutments. The bridge is 282 ft long and 31 ft wide. The piers are 2 ft wide and are on spread footings approximately 10 to 20 ft below the surveyed bed elevations. The abutments and piers are minimally skewed (less than 5 degrees) to the flow, while the bridge deck is skewed 22 degrees to the flow.

BRIDGE-SCOUR ANALYSIS

The channel was surveyed along a 1,845-ft reach from 1,563 ft upstream to 282 ft downstream from the bridge. Following an initial analysis of the model simulation, the modeler determined that the simulations required extension of the study reach in the upstream and downstream directions. The reach was extended because no suspended-sediment or sediment-transport data were available for the study reach, and the model had to "build" its own sediment-inflow hydrograph. The study area was extended an additional 3,600 ft by propagating additional cross sections 1,600 ft farther upstream and 2,000 ft farther downstream from the surveyed cross sections. The propagated cross sections were determined using the most upstream- and downstream-surveyed cross sections and applying the stream slope to determine new elevations. The total study reach included in the model was 5,445 ft (fig. 2). Extending the study reach created the time and distance required for the model to pick up and transport adequate sediment through the bridge opening.

The model makes the assumption that the cross sections are defined perpendicular to the flow, and there is no mechanism in the model to adjust the cross sections for skew. This assumption affected the cross section that describes the bridge opening because of the skew angle (22 degrees) of the bridge relative to the flow. To correct for skew, the cross-section data describing the bridge opening were adjusted by the cosine of the angle of skew (22 degrees), which resulted in a 0.927 correction factor. Application of the correction factor resulted in a bridge opening perpendicular to flow of 261 ft, as compared with the actual bridge length of 282 ft. The adjusted-length cross section was input into the model as the bridge cross-section data. All other cross sections were surveyed perpendicular to flow in the main channel.

Development of Flood Hydrographs

Discharge-frequency curves (discharge plotted against drainage area) published by the Indiana Department of Natural Resources (IDNR) (1993) were used to determine the 10-, 25-, 50-, and 100-year peak discharges (Miller and Wilson 1996). The 500-year peak discharge was extrapolated from the 10-, 25-, 50-, and 100-year peak discharges by use of linear regression. The linear regression involved log-transformed discharges and Pearson Type III plotting positions for zero-skew as listed in "Guidelines for Determining Flood Flow Frequency" (U.S. Geological Survey, 1982). With these methods, Miller and Wilson (1996) determined the 100-year peak discharge at bridge 101-17-5096A to be 11,900 ft^3/s and the 500-year peak discharge to be 15,100 ft^3/s.

These discharges provided the magnitude of the peak discharge; however, the model simulates conditions during a flood, and simulated flood hydrographs had to be developed. Water-surface elevations used in the model were estimated to develop the 100- and 500-year-flood hydrographs (fig. 3). Because the site is ungaged, records from USGS gaging stations upstream and downstream from the site were used to roughly estimate the shape and duration of the 100- and 500-year-flood

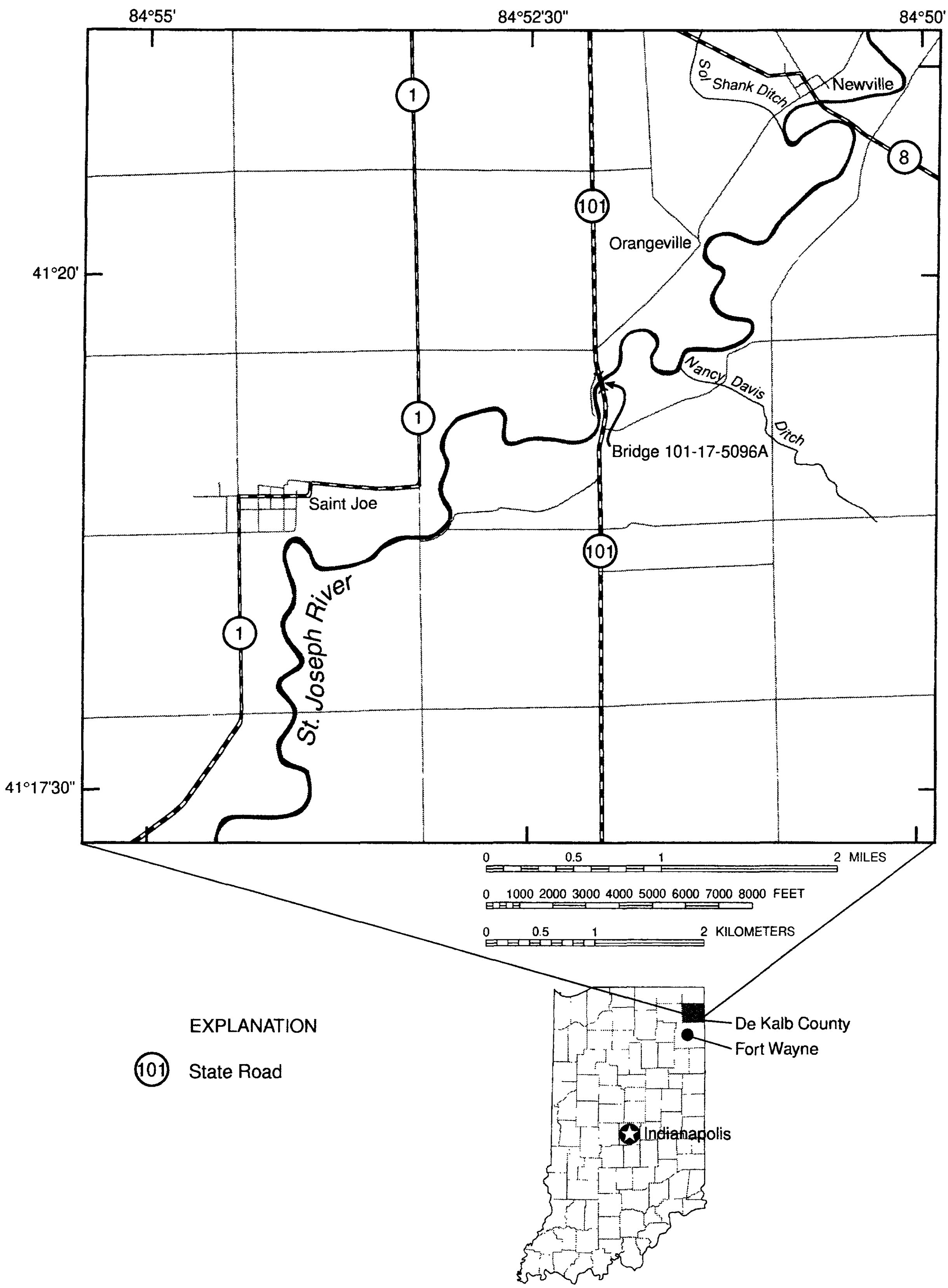

Figure 1. Location of bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Indiana.

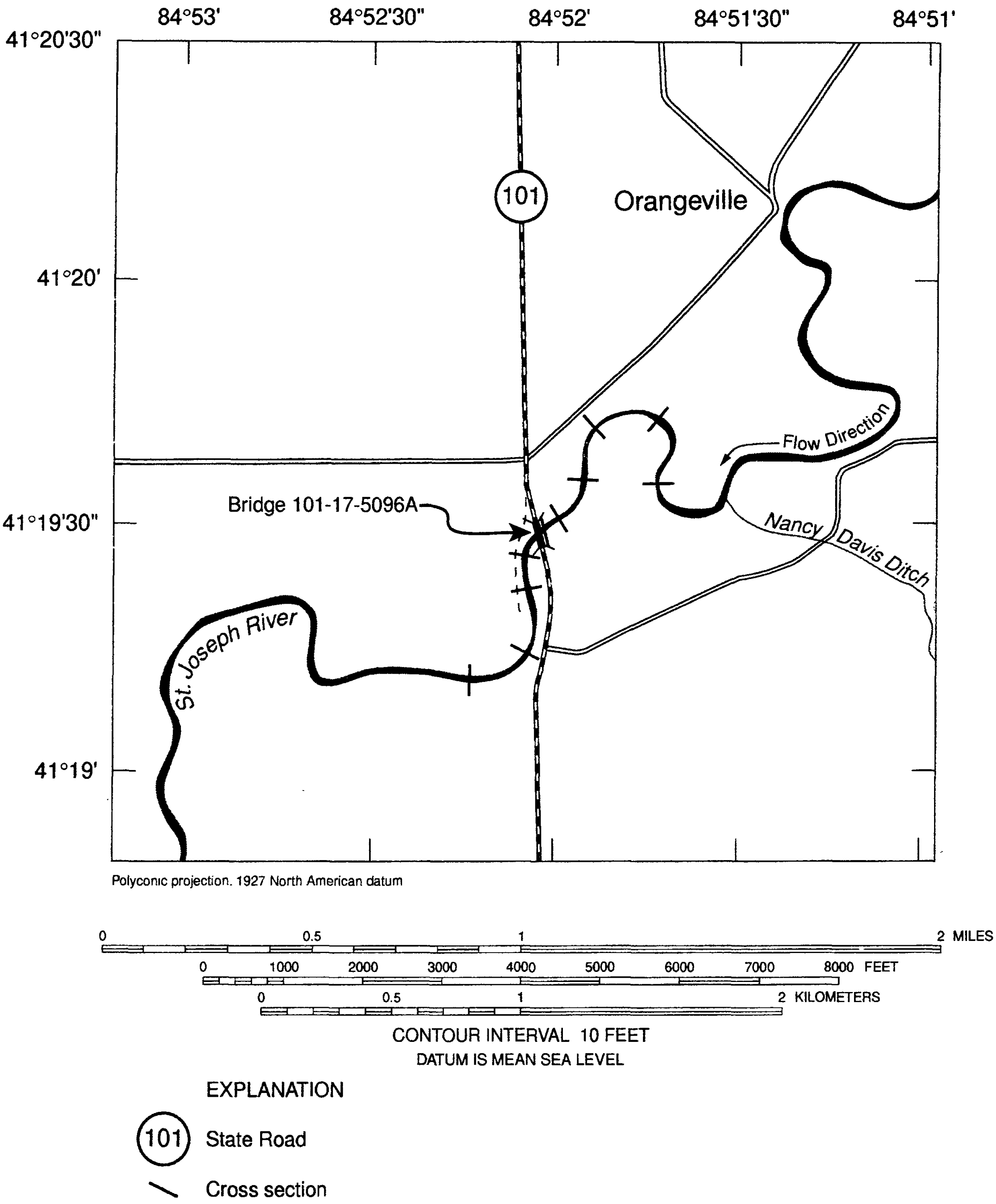

Figure 2. Cross-section locations for the study reach at bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Indiana.

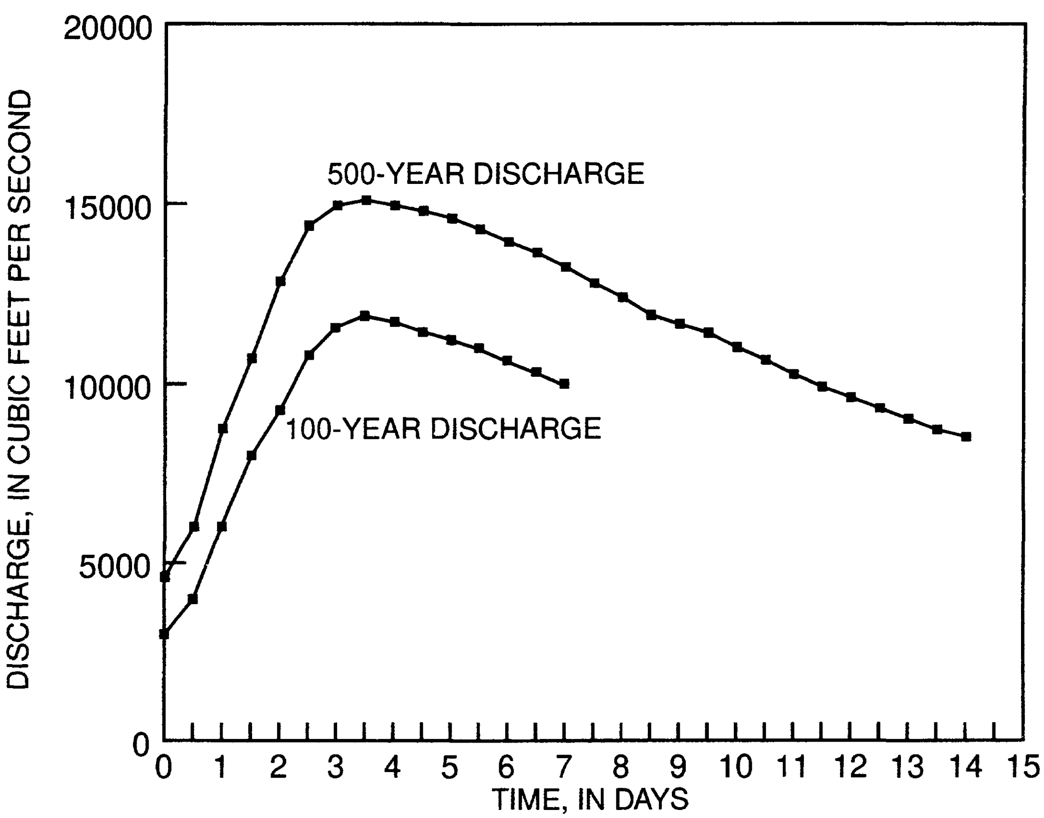

Figure 3. Simulated flood hydrographs for the 100- and 500-year floods for bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Indiana.

hydrographs at the site. The gaging stations used were the St. Joseph River near Newville (04178000) and the St. Joseph River near Fort Wayne (04180500). The drainage area is 663 mi^2 at the bridge site, 610 mi^2 at the St. Joseph River near Newville gaging station, and 1,060 mi^2 at the Fort Wayne gaging station.

To estimate the 100-year and 500-year flood hydrographs, the hydrographs of five historical floods from the St. Joseph River near Newville gaging station were plotted and analyzed for shape and duration. Discharges associated with those floods ranged from a mean daily flow of approximately 5,500 ft^3/s to about 9,500 ft^3/s. Because of the variability in the rises and recessions of these hydrographs, conservative rises and recessions (steeper rises and slower recessions) that might maximize potential scour conditions were used to estimate the 100- and 500-year-flood hydrographs shown in figure 3. Discretized hydrographs used by the BRI-STARS model were determined from the hydrographs, and historical IDNR flood profiles were used to assist with estimating water-surface elevations for the given discharges.

Sediment Transport

Scour of the streambed is affected by sediment availability and the transport capacity of the stream. The BRI-STARS model is designed to maximize the transport of sediment for a given discharge and calculated velocity. Sediment availability does not appear to be of importance in these simulations because of the quantity of bed material present in the study reach.

BRI-STARS is designed to simulate long-term scour and deposition with limited data. The model uses a sediment-transport equation and bed-material-size data to internally produce a sediment-inflow hydrograph for the most upstream cross section in the model. Options for sediment-transport equations include Yang's method, the Ackers and White method, the Engelund and Hansen method, the Meyer-Peter-Muller method, or a generic sediment-transport equation (Molinas, 1994). Yang's method was selected for this study because of its ability to handle the sand- and gravel-sized bed material in the study reach.

Two bed-material samples were collected at the site as part of the bridge-scour study by Miller and Wilson (1996). Both samples were collected at the bridge but are considered to be representative of the study reach. An Iowa BMH-53 piston sampler and a clam-bucket sampler were used to collect those samples. The results of the sieve analysis of these samples are shown in table 1. Sample sizes are biased toward the type of sediment sampler used and, generally, the sediment-size within the sample collected by the BMH-53 sampler was smaller than the sediment size within the clam-bucket sample. BRI-STARS simulations were done independently for each sediment analysis to determine the variation in simulated scour depths from these two sediment-collection methods.

Table 1. Bed-material particle-size distributions from BMH-53 and clam-bucket sediment samples at bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Ind.

[BMH-53, hand-held bed-material sediment sampler; clam-bucket, clam bucket grab-sampler; %, percent material in sediment-size group; --, no data]

Sediment-size fractions (millimeters)	BMH-53 sediment sample (%)	Clam-bucket sediment sample (%)
0.0625 - 0.125	6.7	1.26
.125 - .250	10.0	1.13
.250 - .50	29.3	6.45
.50 - 1.0	23.8	6.09
1.0 - 2.0	13.0	5.16
2.0 - 4.0	11.6	6.90
4.0 - 10.0	5.5	--
4.0 - 8.0	--	10.11
8.0 - 16.0	--	12.74
16.0 - 32.0	--	15.8
32.0 - 128.0	--	34.36

Computer Simulations and Results

The BRI-STARS model was calibrated, using data from the work by Miller and Wilson (1996). BRI-STARS simulations were run without the WSPRO subroutines incorporated into the program. WSPRO routines were used for the work by Miller and Wilson (1996), and the hydraulic properties calculated by BRI-STARS were calibrated to those WSPRO results. The model was calibrated by adjusting the BRI-STARS starting water-surface elevations and coefficients of losses through the model reach. Once the hydraulic properties in BRI-STARS were calibrated to the WSPRO results, the sediment-routing subroutine was added to the model and scour was computed.

Several equations for computing various scour components described by Richardson and others (1991, 1993) and Richardson and Davis (1995) are available in the model (Molinas, 1994). The CSU equation was selected for the pier-scour calculations at this site. Abutment-scour calculations used Froehlich's live-bed equation; for contraction scour, Laursen's equation was used. The BRI-STARS model recomputes cross-section bed elevations at each time step, using the selected scour equations. Generally, maximum scour occurred at or near the peak discharge.

Pier Scour

Pier scour at the site was calculated with the CSU equation, and it was determined that scour occurred during the rise and at the peak of the flood hydrograph. Maximum scour generally occurred during the peak discharge, and some infilling occurred during the falling stages. Therefore, the hydrograph was truncated after the peak of the flood and during the falling stage. The hydrograph was truncated because the focus of the study was to determine the maximum scour prediction at the site. Sediment-size data had a minimal effect on the simulated pier-scour depths.

Pier scour during the peak flow of the modeled 100-year flood was calculated to be 3.69, 4.23, and 3.47 ft for piers 2, 3, and 4, respectively, using the BMH-53 sediment-sample data. Using the coarser material described from the clam-bucket sample data, pier-scour depths were calculated to be 3.72, 4.25, and 3.50 ft, respectively. These values were also the maximum scour calculated over the duration of the flood hydrographs.

Pier scour during the peak flow of the modeled 500-year flood was calculated to be 3.92, 4.53, and 3.71 ft for piers 2, 3, and 4, respectively, using the BMH-53 sediment-sample data. Using the coarser material described from the clam-bucket sample data, the model calculated pier-scour depths to be 3.97, 4.58, and 3.76 ft, respectively (table 2).These values were also the maximum scour calculated over the duration of the flood hydrographs.

Bridge-construction plans indicate the bottom of the pier footers were placed at elevations of 774.8, 774.7, and 774.5 ft. Elevation of the streambed at the piers during maximum calculated pier scour are 781.8, 779.9, and 788.1 ft, respectively. Based on these numbers, the simulated scour at the site would not expose the pier footers or pilings.

Figure 4 shows the maximum calculated pier and contraction scour cross-section profiles, using the BMH-53 sediment data compared to the surveyed cross section at the starting point for the model.

Abutment Scour

BRI-STARS calculates abutment scour based on the assumption that local scour does not change the hydraulic properties in the bridge opening, and the calculations are coupled with the water and sediment-routing computations (Molinas, 1994). Abutment scour was calculated by the model with the Froehlich live-bed scour equation, as recommended in HEC-18 by Richardson and Davis (1995). Mechanisms for abutment scour are the same as those for the piers, with the obvious exception of the scour occurring only on the stream side of the abutment. Although there are sloping concrete spill-through abutments at the bridge, abutment scour was calculated to be in the range of 26.37 to 43.84 ft during the 500-year flood and from 23.04 to 39.16 ft during the 100-year flood event (table 2). Because of the magnitude of the calculated abutment scour, these data were not shown graphically in figure 4.

Table 2. Scour-depth calculations at peak of flow from BRI-STARS model output for bridge 101-17-5096A, State Road 101 crossing the St. Joseph River at St. Joe, Ind.

[ft, foot]

Hydrograph	Pier 2 scour (ft)	Pier 3 scour (ft)	Pier 4 scour (ft)	Left abutment scour (ft)	Right abutment scour (ft)	Contraction scour (ft) (- indicates aggradation)
100-year hydrograph BMH-53 sediment-sample data	3.69	4.23	3.47	38.58	23.04	0.00
100-year hydrograph clam-bucket sediment-sample data	3.72	4.25	3.50	39.16	23.32	-3.33
500-year hydrograph BMH-53 sediment-sample data	3.92	4.53	3.71	42.66	26.37	.00
500-year hydrograph clam-bucket sediment-sample data	3.97	4.58	3.76	43.84	26.98	-3.80

Contraction Scour

Contraction scour was calculated at each time step with Laursen's contraction-scour equation; the results indicated that scour occurred primarily at the initial stages of the rising hydrograph. These results possibly are indicative of changes in the energy gradient with the initial increases in discharge that resulted in scour within the contracted opening of the bridge cross section. Simulations using the sediment data from the clam-bucket sampler resulted in calculations indicating aggrading conditions. Simulations using the BMH-53 sediment data indicated no contraction scour in the bridge opening at the peak of the discharge hydrographs.

The output from the contraction-scour equation indicates, when BMH-53 sample data are used, the modeled 100-year flood hydrograph resulted in a maximum of 1.00 ft of scour, and the modeled 500-year flood resulted in 0.78 ft maximum scour—although the contraction scour did not occur on the peak of the hydrographs. With the clam-bucket sediment data, no contraction scour was predicted, but bottom sediments aggraded a maximum of 3.33 ft and 3.80 ft for the modeled 100-year- and 500-year-flood hydrographs, respectively.

ANALYSIS OF THE BRIDGE STREAM TUBE MODEL FOR ALLUVIAL RIVER SIMULATIONS (BRI-STARS)

Comparison of BRI-STARS calculations with the work by Miller and Wilson (1996) indicate that HEC-18 (Richardson and others, 1991) pier scour equations predicted more scour and BRI-STARS predicted less scour than what was determined to be the historical scour depths at the site. Because the measurements taken to determine the historical pier scour depths at the site were indirect and because there is no way to determine the circumstances under which scour holes formed and refilled, direct comparison of model output to actual scour at the site cannot be made. Historical scour measurements by Miller and Wilson (1996) at the site indicate pier scour in the range of 5.5 to 6.8 ft at the two piers in the main channel. BRI-STARS predicts scour at those piers to be 3.47 to 4.58 ft, depending on the sediment-size analysis and magnitude of the flood hydrograph used.

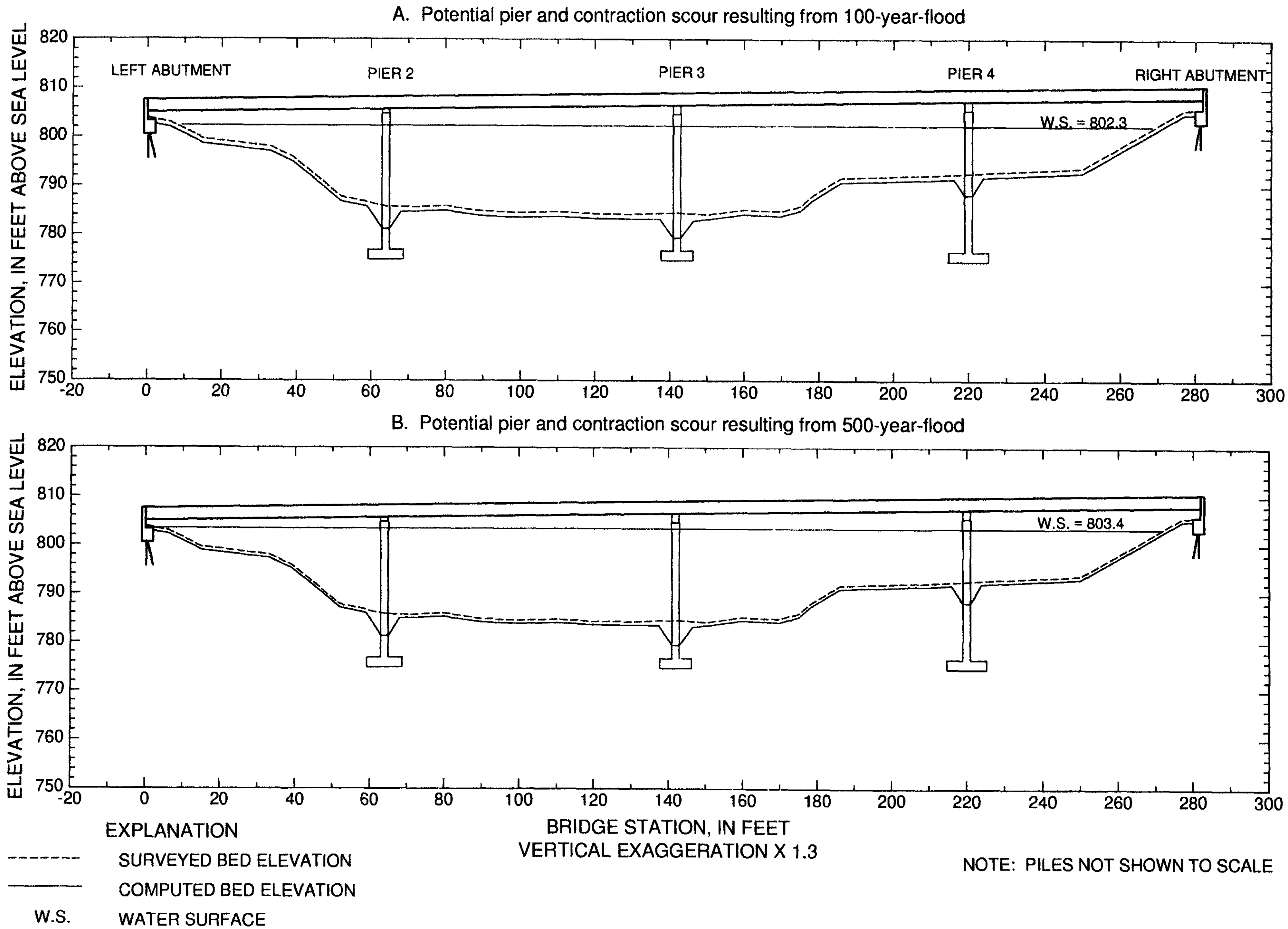

Figure 4. Initial surveyed and maximum calculated pier and contraction scour cross-section profiles, based on the BMH-53 sediment data at bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Indiana.

HEC-18 analysis at these piers indicates scour from 6.7 to 14.7 ft under similar conditions (Miller and Wilson, 1996). The estimated historical-flood flow at the site was approximately 9,840 ft^3/s, which is between the 25- and 50-year recurrence interval; the model simulated-flood flows of 11,900 ft^3/s and 15,100 ft^3/s have 100- and 500-year recurrence intervals, respectively. These differences indicate the BRI-STARS simulations may be underpredicting pier scour at this site.

BRI-STARS predicted either minimal contraction scour or aggradation, whereas HEC-18 computed this scour in the range of 3.6 to 11.9 ft. Abutment scour calculations were predicted to be in the range of 10.7 to 17.7 ft by HEC-18 methods and 23.32 to 43.84 ft by BRI-STARS calculations. No data are available to indicate historical depths of contraction or abutment scour at the site. Based on model results for the 100-year- and 500-year-flood hydrographs, BRI-STARS predicted less contraction scour and more abutment scour than the HEC-18 calculations.

Preparation for the BRI-STARS model to run effectively is labor intensive. The field work required to use the model involves surveying cross-section and bridge-opening geometry; collecting sediment information; and determining adequate discharge hydrographs whether through field measurements or analytical methods, using nearby streamgaging stations. Cross sections were limited in the number of input points permitted to define the shape of each cross section. The hydrologists' or hydraulic engineers' judgment on selecting the location of cross sections, determining roughness coefficients, and developing the flood-hydrograph can affect model results. Molinas (1994) examined model sensitivity and noted that model-simulation results are most sensitive to changes in certain physical and operational parameters—roughness coefficients, sediment inflow, water inflow, cross-section geometry, and active layer thickness. The simulation results were less sensitive to variation of bed elevation and sediment-size distribution and least sensitive to variation in water temperature and coefficients of losses. Sediment data used in the model were derived from bed material collected in the vicinity of the bridge. No suspended-sediment or bed-load samples were collected for input to the model or to calibrate the model's sediment-transport calculations.

The data from Miller and Wilson (1996) were used to represent site characteristics under flood-flow conditions. Because WSPRO analysis uses cross-section information differently than does BRI-STARS—in particular, how the cross sections need to be spaced longitudinally or how skew is accounted for—cross-section information was calculated separately for this study. The hydraulic properties calculated by BRI-STARS were calibrated with those calculated by WSPRO in the previous study (Miller and Wilson, 1996); the sediment routing routines then were added to the model.

SUMMARY AND CONCLUSIONS

Scour of the streambed deposits around bridge piers is a major concern in the analysis of bridge safety during flood events. The USGS, in cooperation with INDOT, conducted a study to estimate scour at a bridge crossing using the sediment-transport model BRI-STARS. The model was used to estimate pier, abutment, and general contraction scour at bridge 101-17-5096A, State Road 101 over the St. Joseph River at Saint Joe, Ind.

Channel cross sections upstream and downstream from the bridge crossing were surveyed or propagated. Flood hydrographs for the 100-year and 500-year-flood events were estimated on the basis of historical-flood flows in the basin. Because no sediment-transport analysis has been done at the site, the model was used to calculate conditions for transport and supply. Bed-material-size analyses from a previous study were used for input to the model. Model calculations were run, using two sediment-size analyses—the sediment sizes were determined from samples collected with an Iowa BMH-53 piston and clam-bucket sediment samplers.

BRI-STARS simulations predicted pier scour in the range of 3.47 to 4.25 ft, abutment scour of 23.04 to 39.16 ft, and general contraction scour of 0 to an aggradation of 3.33 ft at the peak of the simulated 100-year peak flood flow. During the simulated 500-year peak flood flow, pier scour ranged from 3.71 to 4.58 ft, abutment scour from

26.37 to 43.84 ft, and general contraction scour from 0 to an aggradation of 3.80 ft. Previous studies showed that historical pier scour at the site at lower flow was in the range of 5.5 to 6.8 ft, although the conditions under which that scour occurred cannot be determined. HEC-18 calculations predicted pier scour in the range of 6.7 to 14.7 ft, abutment scour of 10.7 to 17.7 ft, and contraction scour of 3.6 to 11.9 ft for the 100-year and 500-year-flood discharges.

The difference in the sediment-size analysis between the BMH-53 and clam-bucket samplers was insignificant for determining pier and abutment scour. The general contraction-scour calculations, however, were significantly different in that the clam-bucket sediment-size analysis resulted in streambed aggradation during the simulated peak-flood flows. Calculations with the BMH-53 sediment-size analysis showed no general scour during the peak-flood flow.

SELECTED REFERENCES

Anderson, A.G., 1974, Scour at bridge waterways—A review: Federal Highway Administration Report No. FHWA-RD-75-89, 29 p.

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., 1987 (3d printing), Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Bennett, J.P., and Nordin, C.F., 1977, Simulation of sediment transport and armouring: Hydrological Sciences-Bulletin-des Sciences Hydrologiques, XXII, 4, p. 555–569.

Crawford, C.G., and Mansue, L.J., 1988, Suspended-sediment characteristics of Indiana streams, 1952–84: U.S. Geological Survey Open-File Report 87-527, 79 p.

Indiana Department of Natural Resources, Division of Water, 1993, Coordinated discharges of selected streams in Indiana [variously paged].

Miller, R.L., and Wilson, J.T., 1996, Evaluation of scour at selected bridge sites in Indiana: U.S. Geological Survey Water-Resources Investigations Report 95-4259, 225 p.

Molinas, Albert, 1994, User's manual for BRI-STARS—(BRIdge Stream Tube Model for Alluvial River Simulation): National Academy of Sciences, National Cooperative Highway Research Program, Project No. HR15-11, 82 p.

Molinas, Albert, and Santoro, V.C., 1989, BRI-STARS model and its applications, *in* Proceedings of the bridge scour symposium October 17–19, 1989: Federal Highway Administration Report FHWA-RD-90-035, p. 256–271.

Molinas, Albert, and Yang, C.T., 1985, Generalized water surface profile computations: Journal of Hydraulic Engineering, v. III, no. 3, p. 381–397.

Mueller, D.S.; Miller, R.L.; and Wilson, J.T., 1994, Historical and potential scour around bridge piers and abutments of selected stream crossings in Indiana: U.S. Geological Survey Water-Resources Investigations Report 93-4066, 109 p.

Richardson, E.V., and Davis, S.R., 1995, Evaluating scour at bridges (3d ed.): Federal Highway Administration Hydraulic Engineering Circular 18, Publication FHWA-IP-90-017, 204 p.

Richardson, E.V., and Richardson, J.R., 1989, Bridge scour, *in* Proceedings of the bridge scour symposium October 17–19, 1989: Federal Highway Administration Report FHWA-RD-90-035, p. 1–42.

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

Richardson, E.V.; Harrison, L.J.; and Davis, S.R., 1991, Evaluating scour at bridges: Federal Highway Administration Hydraulic Engineering Circular 18, Publication FHWA-IP-90-017, 191 p.

Richardson, E.V.; Harrison, L.J.; Richardson, J.R.; and Davis, S.R., 1993, Evaluating scour at bridges (2d ed.): Federal Highway Administration Hydraulic Engineering Circular 18, Publication FHWA-IP-90-017, 242 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.

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, 177 p.

Southard, Rodney E., 1993, Scour at bridges on selected streams in Arkansas, *in* Transportation Research Record 1420, Highway Facility and Design, Hydrology, Hydraulics, and Water Quality, National Academy Press, Washington, D.C., 83 p.

Stevens, H.H., Jr., and Yang, C.T., 1989, Summary and use of selected fluvial sediment-discharge formulas: U.S. Geological Survey Water Resources Investigations Report 89-4026, 62 p.

Thompson, P.L., 1989, FHWA technical advisory—Scour at bridges, *in* Proceedings of the bridge scour symposium October 17–19, 1989: Federal Highway Administration Report FHWA-RD-90-035, p. 361–367.

U.S. Federal Highway Administration, 1988, Scour at bridges: Federal Highway Administration Technical Advisory 5140.20, 132 p.

_____1991, Evaluating scour at bridges: Federal Highway Administration Technical Advisory 5140.23, 6 p.

U.S. Geological Survey, Office of Water Data Coordination, 1982, Guidelines for determining flood flow frequency: Interagency Advisory Committee on Water Data, Bulletin 17B of the Hydrology Subcommittee, 28 p., 14 apps.

Vaill, J.E., 1995, Application of a sediment-transport model to estimate bridge scour at selected sites in Colorado, 1991–93: U.S. Geological Survey Water-Resources Investigations Report 95-4179, 37 p.

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APPENDIXES

APPENDIX 1--BRI-STARS input file for 100-year flood, using BMH-53 sediment-sample data

```
TT  St. Joseph River at St. Joe, Indiana (SR101)
TT  Bri-stars bridge scour run - 100 year flood
TT  DCVoelker 1996
NS  10.0
*
* file final1b.dat using BMH53 data
*
* Cross section data
*
* 1  Sediment generating propagated section B
ST  5445    27.0    0.0    0.0   2.24    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 2  Sediment generating propagated section A
ST  4645    27.0    0.0    0.0   1.12    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 3  Section 1
ST  3845    27.0    0.0    0.0   0.00    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 4  Section 2
ST  3180    27.0    0.0    0.0   0.00    1.00
```

```
ND  3.0 1069.0 1211.0 1416.0
XS809.70   0.00 805.00  84.00 804.20 192.00 800.80 261.00 800.90 405.00
XS799.50 562.00 801.80 755.00 799.70 889.00 800.80 953.00 794.80 989.00
XS791.00 1028.00 792.50 1069.00 789.10 1076.00 786.30 1081.00 787.20 1103.00
XS784.60 1116.00 783.70 1126.00 783.20 1144.00 783.60 1160.00 783.70 1177.00
XS784.90 1201.00 789.10 1203.00 798.00 1211.00 797.70 1243.00 798.80 1340.00
XS804.00 1380.00 814.60 1416.00
*
* 5  Approach cross section 3
ST 2600   27.0   0.0    0.0   0.00   1.00
ND  3.0  798.0  921.0 1229.0
XS 808.0  47.00 799.30 128.00 798.70 355.00 799.00 505.00 799.20 660.00
XS 797.8 745.00 798.60 798.00 787.80 813.00 784.70 815.00 784.20 820.00
XS 784.0 835.00 784.10 845.00 784.10 855.00 784.00 861.00 783.9  870.00
XS 783.8 880.00 783.80 885.00 784.40 895.00 784.60 900.00 785.3  905.00
XS 787.8 910.00 792.20 921.00 793.50 974.00 797.60 1069.00 802.9 1146.00
XS 804.4 1201.00 813.40 1229.00
*
* 6  Bridge opening 4
ST 2282   27.0   0.0    0.0   0.00   1.00
ND  2.0  172.0 261.00
XS 805.0   0.00 803.80   0.00 803.00   6.00 799.60  14.00 798.00  31.00
XS 795.9  36.00 787.80  48.00 787.30  51.00 785.80  59.00 785.60  65.00
XS 785.9  74.00 784.70 102.00 784.20 121.00 784.50 132.00 784.10 139.00
XS 785.1 148.00 784.80 158.00 785.90 162.00 787.90 165.00 791.70 172.00
XS 792.4 200.00 791.90 204.00 792.80 208.00 793.70 232.00 805.70 257.00
XS 805.9 261.00 807.10 261.00
*
* 7  Exit cross section 5
ST 2000   27.0   0.0    0.0   0.00   1.00
ND  3.0  673.0  802.0 1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* 8  Propagated Exit cross section C
ST 1600   27.0   0.0    0.0  -0.56   1.00
ND  3.0  673.0  802.0 1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
```

```
XS 804.9 992.00 811.70 1076.00
*
* 9 Propagated Exit cross section D
ST 800 27.0 0.0 0.0 -1.68 1.00
ND 3.0 673.0 802.0 1076.0
XS 805.1 1.00 797.40 58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* 10 Propagated Exit cross section E
ST 0.0 27.0 1.0 1.0 -2.80 1.00
ND 3.0 673.0 802.0 1076.0
XS 805.1 1.00 797.40 58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* Roughness values
RE MANNING
*
* 1 Sediment generating propagated section B
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 2 Sediment generating propagated section A
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 3 Section 1
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 4 Section 2
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.1100 0.1100
RH0.1100 0.1100 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.1100 0.0800 0.0500 0.0500 0.0500
*
* 5 Approach cross section 3
```

```
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0500 0.0500 0.0500 0.0500 0.0500 0.0500
*
* 6  Bridge opening 4
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
*
* 7  Exit cross section 5
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 8  Propagated Exit cross section C
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 9  Propagated Exit cross section D
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 10  Propagated Exit cross section E
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* Local energy losses (1 per xsec)
*
CL0.0000 0.0000 0.0000 0.0000 0.0000 0.4000 0.0000 0.0000 0.0000 0.0000
*
CB     THALWEG
*
*   estimated 100 year flood hydrograph and water surface elevations
*
NT  3.0
IT  56.0   3.0  0.125
QQ     TABLE OF DISCHARGES
SS     STAGE DISCHARGE TABLE
TL  10.0
*
SQ  3000 796.73
SQ  3000 796.73
SQ  4000 797.75
```

SQ 4000 797.75
SQ 5000 798.60
SQ 5000 798.60
SQ 6000 799.25
SQ 6000 799.25
SQ 7000 799.87
SQ 7000 799.87
SQ 8000 800.35
SQ 8000 800.35
SQ 8700 800.82
SQ 8700 800.82
SQ 9400 801.08
SQ 9400 801.08
SQ 10200 801.30
SQ 10200 801.30
SQ 10800 801.45
SQ 10800 801.45
SQ 11300 801.74
SQ 11300 801.74
SQ 11600 801.90
SQ 11600 801.90
SQ 11800 802.00
SQ 11800 802.00
SQ 11900 802.05
SQ 11900 802.05
SQ 11800 802.00
SQ 11800 802.00
SQ 11700 801.95
SQ 11700 801.95
SQ 11600 801.90
SQ 11600 801.90
SQ 11500 801.85
SQ 11500 801.85
SQ 11400 801.79
SQ 11400 801.79
SQ 11300 801.74
SQ 11300 801.74
SQ 11150 801.65
SQ 11150 801.65
SQ 11000 801.56
SQ 11000 801.56
SQ 10875 801.49
SQ 10875 801.49
SQ 10750 801.44
SQ 10750 801.44
SQ 10625 801.41

```
SQ 10625 801.41
SQ 10400 801.35
SQ 10400 801.35
SQ 10200 801.30
SQ 10200 801.30
SQ 10000 801.25
SQ 10000 801.25
*
SO    SEDIMENT TRANSPORT IS REQUESTED
*
QS  56.0   0.00
* SE card set to use Yang's sediment transport eq.
SE   1.0
* Temperature set to a conservative value of 65 deg. f
TM  56.0  65.00
* SF = # size fractions to be used in sed transp. comps
SF   7.0
SG .0625   .125
SG 0.125   .250
SG 0.250   0.5
SG 0.5     1.0
SG 1.0     2.0
SG 2.0     4.0
SG 4.0     10.0
* SD = # size fractions at the cross sections (starting u.s.)
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
*
* Pier scour
*
PE   1.0    1.0
PS   6.0    3.0
PP  59.3    2.00    2.0    0.0   36.00   0.58
PP 131.6    2.00    2.0    0.0   36.00   0.58
PP 203.9    2.00    2.0    0.0   36.00   0.58
*
AE   5.0   1.0
AS   6.0   2.0
```

```
AP   0.0    36.0     3.0    45.0  788.0  0.58    3.16    0
AP 232.0   261.0     3.0    45.0  793.0  0.58    3.16    0
*
CS   6.0     1.0     1.0     1.0  0.58
*
* Plotting and printing options
*
PR   2.0    27.0     0.0
PV   6.0    55.0    70.0  770.00   810.0    0.0
PV   6.0   125.0   140.0  770.00   810.0    0.0
PV   6.0   195.0   210.0  770.00   810.0    0.0
PL     PLOTTING IS REQUESTED
PX     CHANNEL CROSS SECTION PLOTS          27
PW      WATER SURFACE PROFILE PLOTS         27
*
MN      NO MINIMIZATION IS REQUESTED
```

APPENDIX 2--BRI-STARS input file for 100-year flood, using clam-bucket sediment-sample data

```
TT  St. Joseph River at St. Joe, Indiana (SR101)
TT  Bri-stars bridge scour run - 100 year flood
TT  DCVoelker 1996
NS  10.0
*
* file final1c.dat using clam-bucket data
* Cross section data
*
* 1  Sediment generating propagated section B
ST 5445    27.0    0.0    0.0   2.24    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20 314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 2  Sediment generating propagated section A
ST 4645    27.0    0.0    0.0   1.12    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20 314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 3  Section 1
ST 3845    27.0    0.0    0.0   0.00    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20 314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 4  Section 2
ST 3180    27.0    0.0    0.0   0.00    1.00
ND   3.0  1069.0  1211.0  1416.0
```

```
XS809.70   0.00 805.00  84.00 804.20 192.00 800.80 261.00 800.90 405.00
XS799.50 562.00 801.80 755.00 799.70 889.00 800.80 953.00 794.80 989.00
XS791.00 1028.00 792.50 1069.00 789.10 1076.00 786.30 1081.00 787.20 1103.00
XS784.60 1116.00 783.70 1126.00 783.20 1144.00 783.60 1160.00 783.70 1177.00
XS784.90 1201.00 789.10 1203.00 798.00 1211.00 797.70 1243.00 798.80 1340.00
XS804.00 1380.00 814.60 1416.00
*
* 5  Approach cross section 3
ST  2600   27.0    0.0    0.0   0.00    1.00
ND   3.0   798.0  921.0  1229.0
XS 808.0  47.00 799.30 128.00 798.70 355.00 799.00 505.00 799.20 660.00
XS 797.8 745.00 798.60 798.00 787.80 813.00 784.70 815.00 784.20 820.00
XS 784.0 835.00 784.10 845.00 784.10 855.00 784.00 861.00 783.9  870.00
XS 783.8 880.00 783.80 885.00 784.40 895.00 784.60 900.00 785.3  905.00
XS 787.8 910.00 792.20 921.00 793.50 974.00 797.60 1069.00 802.9 1146.00
XS 804.4 1201.00 813.40 1229.00
*
* 6  Bridge opening 4
ST  2282   27.0    0.0    0.0   0.00    1.00
ND   2.0  172.0  261.00
XS 805.0   0.00 803.80   0.00 803.00   6.00 799.60  14.00 798.00  31.00
XS 795.9  36.00 787.80  48.00 787.30  51.00 785.80  59.00 785.60  65.00
XS 785.9  74.00 784.70 102.00 784.20 121.00 784.50 132.00 784.10 139.00
XS 785.1 148.00 784.80 158.00 785.90 162.00 787.90 165.00 791.70 172.00
XS 792.4 200.00 791.90 204.00 792.80 208.00 793.70 232.00 805.70 257.00
XS 805.9 261.00 807.10 261.00
*
* 7  Exit cross section 5
ST  2000   27.0    0.0    0.0   0.00    1.00
ND   3.0  673.0  802.0  1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* 8  Propagated Exit cross section C
ST  1600   27.0    0.0    0.0  -0.56    1.00
ND   3.0  673.0  802.0  1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
```

```
*
* 9  Propagated Exit cross section D
ST   800    27.0     0.0     0.0   -1.68    1.00
ND   3.0   673.0   802.0  1076.0
XS 805.1    1.00  797.40   58.00  798.30  162.00  798.20  342.00  796.80  616.00
XS 797.8  673.00  787.80  691.00  785.40  698.00  785.30  718.00  783.90  728.00
XS 782.8  738.00  782.30  748.00  781.60  758.00  781.50  768.00  781.30  771.00
XS 781.6  778.00  781.60  781.00  783.40  788.00  784.80  793.00  787.80  798.00
XS 791.6  802.00  792.40  825.00  798.50  843.00  801.60  856.00  802.00  934.00
XS 804.9  992.00  811.70 1076.00
*
* 10  Propagated Exit cross section E
ST   0.0    27.0     1.0     1.0   -2.80    1.00
ND   3.0   673.0   802.0  1076.0
XS 805.1    1.00  797.40   58.00  798.30  162.00  798.20  342.00  796.80  616.00
XS 797.8  673.00  787.80  691.00  785.40  698.00  785.30  718.00  783.90  728.00
XS 782.8  738.00  782.30  748.00  781.60  758.00  781.50  768.00  781.30  771.00
XS 781.6  778.00  781.60  781.00  783.40  788.00  784.80  793.00  787.80  798.00
XS 791.6  802.00  792.40  825.00  798.50  843.00  801.60  856.00  802.00  934.00
XS 804.9  992.00  811.70 1076.00
*
* Roughness values
RE     MANNING
*
* 1  Sediment generating propagated section B
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0800  0.1100  0.1100
RH0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.0300  0.0300
RH0.0300  0.0300  0.0300  0.0300  0.1100  0.1100  0.1100
*
* 2  Sediment generating propagated section A
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0800  0.1100  0.1100
RH0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.0300  0.0300
RH0.0300  0.0300  0.0300  0.0300  0.1100  0.1100  0.1100
*
* 3  Section 1
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0800  0.1100  0.1100
RH0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.1100  0.0300  0.0300
RH0.0300  0.0300  0.0300  0.0300  0.1100  0.1100  0.1100
*
* 4  Section 2
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.1100  0.1100
RH0.1100  0.1100  0.0300  0.0300  0.0300  0.0300  0.0300  0.0300  0.0300  0.0300
RH0.0300  0.0300  0.1100  0.0800  0.0500  0.0500  0.0500
*
* 5  Approach cross section 3
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0300  0.0300  0.0300
```

```
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0500 0.0500 0.0500 0.0500 0.0500 0.0500
*
* 6 Bridge opening 4
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
*
* 7 Exit cross section 5
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 8 Propagated Exit cross section C
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 9 Propagated Exit cross section D
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 10 Propagated Exit cross section E
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* Local energy losses (1 per xsec)
*
CL0.0000 0.0000 0.0000 0.0000 0.0000 0.4000 0.0000 0.0000 0.0000 0.0000
*
CB    THALWEG
*
*  estimated 100 year flood hydrograph and water surface elevations
*
NT  3.0
IT  56.0   3.0  0.125
QQ    TABLE OF DISCHARGES
SS    STAGE DISCHARGE TABLE
TL  10.0
*
SQ  3000 796.76
SQ  3000 796.73
SQ  4000 797.75
SQ  4000 797.75
```

SQ 5000 798.60
SQ 5000 798.60
SQ 6000 799.25
SQ 6000 799.25
SQ 7000 799.87
SQ 7000 799.87
SQ 8000 800.35
SQ 8000 800.35
SQ 8700 800.82
SQ 8700 800.82
SQ 9400 801.08
SQ 9400 801.08
SQ 10200 801.30
SQ 10200 801.30
SQ 10800 801.45
SQ 10800 801.45
SQ 11300 801.74
SQ 11300 801.74
SQ 11600 801.90
SQ 11600 801.90
SQ 11800 802.00
SQ 11800 802.00
SQ 11900 802.05
SQ 11900 802.05
SQ 11800 802.00
SQ 11800 802.00
SQ 11700 801.95
SQ 11700 801.95
SQ 11600 801.90
SQ 11600 801.90
SQ 11500 801.85
SQ 11500 801.85
SQ 11400 801.79
SQ 11400 801.79
SQ 11300 801.74
SQ 11300 801.74
SQ 11150 801.65
SQ 11150 801.65
SQ 11000 801.56
SQ 11000 801.56
SQ 10875 801.49
SQ 10875 801.49
SQ 10750 801.44
SQ 10750 801.44
SQ 10625 801.41
SQ 10625 801.41

```
SQ 10400 801.35
SQ 10400 801.35
SQ 10200 801.30
SQ 10200 801.30
SQ 10000 801.25
SQ 10000 801.25
*
SO    SEDIMENT TRANSPORT IS REQUESTED
*
QS  56.0   0.00
* SE card set to use Yang's sediment transport eq.
SE  1.0
* Temperature set to a conservative value of 65 deg. f
TM  56.0  65.00
* SF = # size fractions to be used in sed transp. comps
SF  10.0
SG .0625  .125
SG 0.125  .250
SG 0.250  0.5
SG 0.5    1.0
SG 1.0    2.0
SG 2.0    4.0
SG 4.0    8.0
SG 8.0    16.0
SG 16.0   32.0
SG 32.0  128.0
* SD = # size fractions at the cross sections (starting u.s.)
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580   .3436
*
* Pier scour
*
PE  1.0   1.0
PS  6.0   3.0
PP  59.3   2.00   2.0   0.0  36.00  17.0
PP 131.6   2.00   2.0   0.0  36.00  17.0
PP 203.9   2.00   2.0   0.0  36.00  17.0
*
```

```
AE  5.0   1.0
AS  6.0   2.0
AP  0.0   36.0    3.0   45.0  788.0  17.0   3.16   0
AP 232.0  261.0   3.0   45.0  793.0  17.0   3.16   0
*
CS  6.0    1.0    1.0    1.0  17.0
*
* Plotting and printing options
*
PR  2.0   27.0    0.0
PV  6.0   55.0   70.0 770.00  810.0    0.0
PV  6.0  125.0  140.0 770.00  810.0    0.0
PV  6.0  195.0  210.0 770.00  810.0    0.0
PL     PLOTTING IS REQUESTED
PX     CHANNEL CROSS SECTION PLOTS        27
PW     WATER SURFACE PROFILE PLOTS        27
*
MN     NO MINIMIZATION IS REQUESTED
```

APPENDIX 3--BRI-STARS input file for 500-year flood, using BMH-53 sediment-sample data

```
TT  St. Joseph River at St. Joe, Indiana (SR101)
TT  Bri-stars bridge scour run - 500 year flood
TT  DCVoelker 1996
NS  10.0
*
* file final5b.dat using BMH53 data
*
* Cross section data
*
* 1  Sediment generating propagated section B
ST  5445   27.0    0.0    0.0   2.24    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 2  Sediment generating propagated section A
ST  4645   27.0    0.0    0.0   1.12    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 3  Section 1
ST  3845   27.0    0.0    0.0   0.00    1.00
ND   3.0  1996.0  2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 4  Section 2
ST  3180   27.0    0.0    0.0   0.00    1.00
```

```
ND  3.0  1069.0  1211.0  1416.0
XS809.70   0.00  805.00   84.00  804.20  192.00  800.80  261.00  800.90  405.00
XS799.50  562.00  801.80  755.00  799.70  889.00  800.80  953.00  794.80  989.00
XS791.00 1028.00  792.50 1069.00  789.10 1076.00  786.30 1081.00  787.20 1103.00
XS784.60 1116.00  783.70 1126.00  783.20 1144.00  783.60 1160.00  783.70 1177.00
XS784.90 1201.00  789.10 1203.00  798.00 1211.00  797.70 1243.00  798.80 1340.00
XS804.00 1380.00  814.60 1416.00
*
* 5  Approach cross section 3
ST  2600    27.0     0.0     0.0    0.00     1.00
ND   3.0   798.0   921.0  1229.0
XS 808.0   47.00  799.30  128.00  798.70  355.00  799.00  505.00  799.20  660.00
XS 797.8  745.00  798.60  798.00  787.80  813.00  784.70  815.00  784.20  820.00
XS 784.0  835.00  784.10  845.00  784.10  855.00  784.00  861.00  783.9   870.00
XS 783.8  880.00  783.80  885.00  784.40  895.00  784.60  900.00  785.3   905.00
XS 787.8  910.00  792.20  921.00  793.50  974.00  797.60 1069.00  802.9  1146.00
XS 804.4 1201.00  813.40 1229.00
*
* 6  Bridge opening 4
ST  2282    27.0     0.0     0.0    0.00     1.00
ND   2.0   172.0  261.00
XS 805.0    0.00  803.80    0.00  803.00    6.00  799.60   14.00  798.00   31.00
XS 795.9   36.00  787.80   48.00  787.30   51.00  785.80   59.00  785.60   65.00
XS 785.9   74.00  784.70  102.00  784.20  121.00  784.50  132.00  784.10  139.00
XS 785.1  148.00  784.80  158.00  785.90  162.00  787.90  165.00  791.70  172.00
XS 792.4  200.00  791.90  204.00  792.80  208.00  793.70  232.00  805.70  257.00
XS 805.9  261.00  807.10  261.00
*
* 7  Exit cross section 5
ST  2000    27.0     0.0     0.0    0.00     1.00
ND   3.0   673.0   802.0  1076.0
XS 805.1    1.00  797.40   58.00  798.30  162.00  798.20  342.00  796.80  616.00
XS 797.8  673.00  787.80  691.00  785.40  698.00  785.30  718.00  783.90  728.00
XS 782.8  738.00  782.30  748.00  781.60  758.00  781.50  768.00  781.30  771.00
XS 781.6  778.00  781.60  781.00  783.40  788.00  784.80  793.00  787.80  798.00
XS 791.6  802.00  792.40  825.00  798.50  843.00  801.60  856.00  802.00  934.00
XS 804.9  992.00  811.70 1076.00
*
* 8  Propagated Exit cross section C
ST  1600    27.0     0.0     0.0   -0.56     1.00
ND   3.0   673.0   802.0  1076.0
XS 805.1    1.00  797.40   58.00  798.30  162.00  798.20  342.00  796.80  616.00
XS 797.8  673.00  787.80  691.00  785.40  698.00  785.30  718.00  783.90  728.00
XS 782.8  738.00  782.30  748.00  781.60  758.00  781.50  768.00  781.30  771.00
XS 781.6  778.00  781.60  781.00  783.40  788.00  784.80  793.00  787.80  798.00
XS 791.6  802.00  792.40  825.00  798.50  843.00  801.60  856.00  802.00  934.00
```

```
XS 804.9 992.00 811.70 1076.00
*
* 9 Propagated Exit cross section D
ST  800   27.0    0.0    0.0  -1.68   1.00
ND  3.0  673.0  802.0  1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* 10 Propagated Exit cross section E
ST  0.0   27.0    1.0    1.0  -2.80   1.00
ND  3.0  673.0  802.0  1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* Roughness values
RE    MANNING
*
* 1 Sediment generating propagated section B
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 2 Sediment generating propagated section A
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 3 Section 1
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 4 Section 2
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.1100 0.1100
RH0.1100 0.1100 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.1100 0.0800 0.0500 0.0500 0.0500
*
* 5 Approach cross section 3
```

```
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0500 0.0500 0.0500 0.0500 0.0500 0.0500
*
* 6  Bridge opening 4
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
*
* 7  Exit cross section 5
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 8  Propagated Exit cross section C
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 9  Propagated Exit cross section D
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 10  Propagated Exit cross section E
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* Local energy losses (1 per xsec)
*
CL0.0000 0.0000 0.0000 0.0000 0.0000 0.4000 0.0000 0.0000 0.0000 0.0000
*
CB     THALWEG
*
*   estimated 500 year hydrograph and water surface elevations
*
NT   3.0
IT 114.0    3.0  0.125
QQ     TABLE OF DISCHARGES
SS     STAGE DISCHARGE TABLE
TL  10.0
SQ  4600 798.25
SQ  4600 798.25
SQ  6000 799.25
SQ  6000 799.25
```

SQ 7400 800.09
SQ 7400 800.09
SQ 8750 800.85
SQ 8750 800.85
SQ 9800 801.20
SQ 9800 801.20
SQ 10700 801.43
SQ 10700 801.43
SQ 11950 802.06
SQ 11950 802.06
SQ 12850 802.22
SQ 12850 802.22
SQ 13750 802.45
SQ 13750 802.45
SQ 14400 802.65
SQ 14400 802.65
SQ 14750 802.86
SQ 14750 802.86
SQ 14950 802.98
SQ 14950 802.98
SQ 15100 803.05
SQ 15100 803.05
SQ 15100 803.05
SQ 15100 803.05
SQ 15050 803.03
SQ 15050 803.03
SQ 14950 802.98
SQ 14950 802.98
SQ 14850 802.90
SQ 14850 802.90
SQ 14800 802.89
SQ 14800 802.89
SQ 14700 802.83
SQ 14700 802.83
SQ 14600 802.77
SQ 14600 802.77
SQ 14400 802.65
SQ 14400 802.65
SQ 14300 802.62
SQ 14300 802.62
SQ 14100 802.56
SQ 14100 802.56
SQ 13950 802.51
SQ 13950 802.51
SQ 13750 802.45
SQ 13750 802.45

SQ	13650	802.42
SQ	13650	802.42
SQ	13500	802.38
SQ	13500	802.38
SQ	13250	802.32
SQ	13250	802.32
SQ	13000	802.25
SQ	13000	802.25
SQ	12800	802.21
SQ	12800	802.21
SQ	12600	802.18
SQ	12600	802.18
SQ	12400	802.14
SQ	12400	802.14
SQ	12100	802.09
SQ	12100	802.09
SQ	11900	802.05
SQ	11900	802.05
SQ	11750	801.98
SQ	11750	801.98
SQ	11650	801.93
SQ	11650	801.93
SQ	11550	801.88
SQ	11550	801.88
SQ	11400	801.79
SQ	11400	801.79
SQ	11150	801.65
SQ	11150	801.65
SQ	11000	801.56
SQ	11000	801.56
SQ	10800	801.45
SQ	10800	801.45
SQ	10650	801.41
SQ	10650	801.41
SQ	10500	801.38
SQ	10500	801.38
SQ	10250	801.31
SQ	10250	801.31
SQ	10050	801.26
SQ	10050	801.26
SQ	9900	801.23
SQ	9900	801.23
SQ	9750	801.19
SQ	9750	801.19
SQ	9600	801.15
SQ	9600	801.15

```
SQ  9450 801.10
SQ  9450 801.10
SQ  9300 801.04
SQ  9300 801.04
SQ  9150 800.99
SQ  9150 800.99
SQ  9000 800.94
SQ  9000 800.94
SQ  8850 800.89
SQ  8850 800.89
SQ  8700 800.82
SQ  8700 800.82
SQ  8600 800.75
SQ  8600 800.75
SQ  8500 800.68
SQ  8500 800.68
SQ  8400 800.62
SQ  8400 800.62
*
SO     SEDIMENT TRANSPORT IS REQUESTED
*
QS 114.0   0.00
* SE card set to use Yang's sediment transport eq.
SE   1.0
* Temperature set to a conservative value of 65 deg. f
TM 114.0  65.00
* SF = # size fractions to be used in sed transp. comps
SF   7.0
SG .0625   .125
SG 0.125   .250
SG 0.250   0.5
SG 0.5     1.0
SG 1.0     2.0
SG 2.0     4.0
SG 4.0     10.0
* SD = # size fractions at the cross sections (starting u.s.)
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
SD .067   .101   .293   .238   .130   .116   .055
```

```
*
* Pier scour
*
PE  1.0    1.0
PS  6.0    3.0
PP  59.3   2.00    2.0    0.0  36.00  0.58
PP 131.6   2.00    2.0    0.0  36.00  0.58
PP 203.9   2.00    2.0    0.0  36.00  0.58
*
AE  5.0    1.0
AS  6.0    2.0
AP  0.0   36.0    3.0   45.0  788.0  0.58   3.16  0
AP 232.0  261.0    3.0   45.0  793.0  0.58   3.16  0
*
CS  6.0   1.0     1.0    1.0   0.58
*
* Plotting and printing options
*
PR  2.0   25.0    0.0
PV  6.0   55.0   70.0 770.00  810.0    0.0
PV  6.0  125.0  140.0 770.00  810.0    0.0
PV  6.0  195.0  210.0 770.00  810.0    0.0
PL     PLOTTING IS REQUESTED
PX     CHANNEL CROSS SECTION PLOTS        25
PW     WATER SURFACE PROFILE PLOTS        25
*
MN     NO MINIMIZATION IS REQUESTED
```

APPENDIX 4--BRI-STARS input file for 500-year flood, using clam-bucket sediment-sample data

```
TT  St. Joseph River at St. Joe, Indiana (SR101)
TT  Bri-stars bridge scour run - 500 year flood
TT  DCVoelker 1996
NS  10.0
*
* file final5c.dat using clam-bucket data
*
* Cross section data
*
* 1  Sediment generating propagated section B
ST 5445    27.0    0.0    0.0   2.24    1.00
ND   3.0  1996.0 2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 2  Sediment generating propagated section A
ST 4645    27.0    0.0    0.0   1.12    1.00
ND   3.0  1996.0 2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 3  Section 1
ST 3845    27.0    0.0    0.0   0.00    1.00
ND   3.0  1996.0 2089.0  2131.0
XS815.20  314.00  805.40  484.00  804.50  597.00  800.00  813.00  797.90 1022.00
XS799.80 1087.00  801.80 1249.00  798.80 1482.00  801.10 1529.00  794.60 1568.00
XS793.20 1629.00  795.20 1690.00  798.60 1795.00  797.20 1885.00  799.80 1914.00
XS796.90 1931.00  795.00 1963.00  792.90 1996.00  789.40 2005.00  784.70 2020.00
XS784.00 2029.00  783.90 2057.00  784.50 2068.00  785.10 2089.00  789.40 2098.00
XS795.30 2109.00  816.20 2131.00
*
* 4  Section 2
ST 3180    27.0    0.0    0.0   0.00    1.00
```

```
ND  3.0 1069.0 1211.0 1416.0
XS809.70   0.00 805.00  84.00 804.20 192.00 800.80 261.00 800.90 405.00
XS799.50 562.00 801.80 755.00 799.70 889.00 800.80 953.00 794.80 989.00
XS791.00 1028.00 792.50 1069.00 789.10 1076.00 786.30 1081.00 787.20 1103.00
XS784.60 1116.00 783.70 1126.00 783.20 1144.00 783.60 1160.00 783.70 1177.00
XS784.90 1201.00 789.10 1203.00 798.00 1211.00 797.70 1243.00 798.80 1340.00
XS804.00 1380.00 814.60 1416.00
*
* 5  Approach cross section 3
ST  2600    27.0     0.0     0.0    0.00    1.00
ND  3.0   798.0   921.0  1229.0
XS 808.0   47.00 799.30 128.00 798.70 355.00 799.00 505.00 799.20 660.00
XS 797.8  745.00 798.60 798.00 787.80 813.00 784.70 815.00 784.20 820.00
XS 784.0  835.00 784.10 845.00 784.10 855.00 784.00 861.00 783.9  870.00
XS 783.8  880.00 783.80 885.00 784.40 895.00 784.60 900.00 785.3  905.00
XS 787.8  910.00 792.20 921.00 793.50 974.00 797.60 1069.00 802.9 1146.00
XS 804.4 1201.00 813.40 1229.00
*
* 6  Bridge opening 4
ST  2282    27.0     0.0     0.0    0.00    1.00
ND  2.0   172.0  261.00
XS 805.0    0.00 803.80    0.00 803.00    6.00 799.60   14.00 798.00   31.00
XS 795.9   36.00 787.80   48.00 787.30   51.00 785.80   59.00 785.60   65.00
XS 785.9   74.00 784.70 102.00 784.20 121.00 784.50 132.00 784.10 139.00
XS 785.1  148.00 784.80 158.00 785.90 162.00 787.90 165.00 791.70 172.00
XS 792.4  200.00 791.90 204.00 792.80 208.00 793.70 232.00 805.70 257.00
XS 805.9  261.00 807.10 261.00
*
* 7  Exit cross section 5
ST  2000    27.0     0.0     0.0    0.00    1.00
ND  3.0   673.0   802.0  1076.0
XS 805.1    1.00 797.40   58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8  673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8  738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6  778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6  802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9  992.00 811.70 1076.00
*
* 8  Propagated Exit cross section C
ST  1600    27.0     0.0     0.0   -0.56    1.00
ND  3.0   673.0   802.0  1076.0
XS 805.1    1.00 797.40   58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8  673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8  738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6  778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6  802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
```

```
XS 804.9 992.00 811.70 1076.00
*
* 9 Propagated Exit cross section D
ST  800   27.0    0.0    0.0  -1.68   1.00
ND  3.0  673.0  802.0 1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* 10 Propagated Exit cross section E
ST  0.0   27.0    1.0    1.0  -2.80   1.00
ND  3.0  673.0  802.0 1076.0
XS 805.1   1.00 797.40  58.00 798.30 162.00 798.20 342.00 796.80 616.00
XS 797.8 673.00 787.80 691.00 785.40 698.00 785.30 718.00 783.90 728.00
XS 782.8 738.00 782.30 748.00 781.60 758.00 781.50 768.00 781.30 771.00
XS 781.6 778.00 781.60 781.00 783.40 788.00 784.80 793.00 787.80 798.00
XS 791.6 802.00 792.40 825.00 798.50 843.00 801.60 856.00 802.00 934.00
XS 804.9 992.00 811.70 1076.00
*
* Roughness values
RE    MANNING
*
* 1 Sediment generating propagated section B
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 2 Sediment generating propagated section A
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 3 Section 1
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0800 0.1100 0.1100
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.1100 0.1100 0.1100
*
* 4 Section 2
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.1100 0.1100
RH0.1100 0.1100 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.1100 0.0800 0.0500 0.0500 0.0500
*
* 5 Approach cross section 3
```

```
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0500 0.0500 0.0500 0.0500 0.0500 0.0500
*
* 6  Bridge opening 4
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
*
* 7  Exit cross section 5
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 8  Propogated Exit cross section C
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 9  Propogated Exit cross section D
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* 10  Propogated Exit cross section E
RH0.1100 0.1100 0.1100 0.1100 0.1100 0.1100 0.0300 0.0300 0.0300 0.0300
RH0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300 0.0300
RH0.0450 0.0450 0.0450 0.0450 0.0450 0.0450 0.0450
*
* Local energy losses (1 per xsec)
*
CL0.0000 0.0000 0.0000 0.0000 0.0000 0.4000 0.0000 0.0000 0.0000 0.0000
*CL0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
*
CB    THALWEG
*
*  estimated 500 year hydrograph and water surface elevations
*
NT  3.0
IT 114.0   3.0  0.125
QQ    TABLE OF DISCHARGES
SS    STAGE DISCHARGE TABLE
TL  10.0
*
SQ  4600 798.25
SQ  4600 798.25
```

SQ 6000 799.25
SQ 6000 799.25
SQ 7400 800.09
SQ 7400 800.09
SQ 8750 800.85
SQ 8750 800.85
SQ 9800 801.20
SQ 9800 801.20
SQ 10700 801.43
SQ 10700 801.43
SQ 11950 802.06
SQ 11950 802.06
SQ 12850 802.22
SQ 12850 802.22
SQ 13750 802.45
SQ 13750 802.45
SQ 14400 802.65
SQ 14400 802.65
SQ 14750 802.86
SQ 14750 802.86
SQ 14950 802.98
SQ 14950 802.98
SQ 15100 803.05
SQ 15100 803.05
SQ 15100 803.05
SQ 15100 803.05
SQ 15050 803.03
SQ 15050 803.03
SQ 14950 802.98
SQ 14950 802.98
SQ 14850 802.90
SQ 14850 802.90
SQ 14800 802.89
SQ 14800 802.89
SQ 14700 802.83
SQ 14700 802.83
SQ 14600 802.77
SQ 14600 802.77
SQ 14400 802.65
SQ 14400 802.65
SQ 14300 802.62
SQ 14300 802.62
SQ 14100 802.56
SQ 14100 802.56
SQ 13950 802.51
SQ 13950 802.51

SQ 13750 802.45
SQ 13750 802.45
SQ 13650 802.42
SQ 13650 802.42
SQ 13500 802.38
SQ 13500 802.38
SQ 13250 802.32
SQ 13250 802.32
SQ 13000 802.25
SQ 13000 802.25
SQ 12800 802.21
SQ 12800 802.21
SQ 12600 802.18
SQ 12600 802.18
SQ 12400 802.14
SQ 12400 802.14
SQ 12100 802.09
SQ 12100 802.09
SQ 11900 802.05
SQ 11900 802.05
SQ 11750 801.98
SQ 11750 801.98
SQ 11650 801.93
SQ 11650 801.93
SQ 11550 801.88
SQ 11550 801.88
SQ 11400 801.79
SQ 11400 801.79
SQ 11150 801.65
SQ 11150 801.65
SQ 11000 801.56
SQ 11000 801.56
SQ 10800 801.45
SQ 10800 801.45
SQ 10650 801.41
SQ 10650 801.41
SQ 10500 801.38
SQ 10500 801.38
SQ 10250 801.31
SQ 10250 801.31
SQ 10050 801.26
SQ 10050 801.26
SQ 9900 801.23
SQ 9900 801.23
SQ 9750 801.19
SQ 9750 801.19

```
SQ 9600 801.15
SQ 9600 801.15
SQ 9450 801.10
SQ 9450 801.10
SQ 9300 801.04
SQ 9300 801.04
SQ 9150 800.99
SQ 9150 800.99
SQ 9000 800.94
SQ 9000 800.94
SQ 8850 800.89
SQ 8850 800.89
SQ 8700 800.82
SQ 8700 800.82
SQ 8600 800.75
SQ 8600 800.75
SQ 8500 800.68
SQ 8500 800.68
SQ 8400 800.62
SQ 8400 800.62
*
SO    SEDIMENT TRANSPORT IS REQUESTED
*
QS 114.0   0.00
* SE card set to use Yang's sediment transport eq.
SE  1.0
* Temperature set to a conservative value of 65 deg. f
TM 114.0  65.00
* SF = # size fractions to be used in sed transp. comps
SF  10.0
SG .0625  .125
SG 0.125  .250
SG 0.250  0.5
SG 0.5    1.0
SG 1.0    2.0
SG 2.0    4.0
SG 4.0    8.0
SG 8.0    16.0
SG 16.0   32.0
SG 32.0  128.0
* SD = # size fractions at the cross sections (starting u.s.)
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580  .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580  .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580  .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580  .3436
SD.0126  .0113  .0645  .0609  .0516  .0690  .1011  .1274  .1580  .3436
```

```
SD.0126 .0113 .0645 .0609 .0516 .0690 .1011 .1274 .1580 .3436
SD.0126 .0113 .0645 .0609 .0516 .0690 .1011 .1274 .1580 .3436
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SD.0126 .0113 .0645 .0609 .0516 .0690 .1011 .1274 .1580 .3436
SD.0126 .0113 .0645 .0609 .0516 .0690 .1011 .1274 .1580 .3436
*
* Pier scour
*
PE  1.0   1.0
PS  6.0   3.0
PP  59.3  2.00  2.0  0.0  36.00  17.0
PP 131.6  2.00  2.0  0.0  36.00  17.0
PP 203.9  2.00  2.0  0.0  36.00  17.0
*
AE  5.0   1.0
AS  6.0   2.0
AP  0.0   36.0   3.0  45.0  788.0  17.0  3.16  0
AP 232.0  261.0  3.0  45.0  793.0  17.0  3.16  0
*
CS  6.0  1.0   1.0   1.0   17.0
*
* Plotting and printing options
*
PR  2.0  25.0   0.0
PV  6.0   55.0   70.0 770.00  810.0   0.0
PV  6.0  125.0  140.0 770.00  810.0   0.0
PV  6.0  195.0  210.0 770.00  810.0   0.0
PL    PLOTTING IS REQUESTED
PX    CHANNEL CROSS SECTION PLOTS        25
PW    WATER SURFACE PROFILE PLOTS        25
*
MN    NO MINIMIZATION IS REQUESTED
```