Application of a Sediment-Transport Model to Estimate Bridge Scour at Selected Sites in Colorado, 1991-93

by J.E. Vaill

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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
millimeter (mm)	0.03937	inch
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

°C = 5/9 (°F-32).

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By J.E. Vaill

Abstract

A bridge-scour study by the U.S. Geological Survey, in cooperation with the Colorado Department of Transportation, was begun in 1991 to evaluate bridges in the State for potential scour during floods. A part of that study was to apply a computer model for sediment-transport routing to simulate channel aggradation or degradation and pier scour during floods at three bridge sites in Colorado. Stream-channel reaches upstream and downstream from the bridges were simulated using the BRIdge Stream Tube model for Alluvial River Simulation (BRI-STARS). Synthetic flood hydrographs for the 500-year floods were developed for Surveyor Creek near Platner and for the Rio Grande at Wagon Wheel Gap. A part of the recorded mean daily hydrograph for the peak flow of record was used for the Yampa River near Maybell. The recorded hydrograph for the peak flow of record exceeded the computed 500-year-flood magnitude for this stream by about 22 percent. Bed-material particle-size distributions were determined from samples collected at Surveyor Creek and the Rio Grande. Existing data were used for the Yampa River. The model was used to compute a sediment-inflow hydrograph using particle-size data collected and a specified sediment-transport equation at each site. Particle sizes ranged from less than 0.5 to 16 millimeters for Surveyor Creek, less than 4 to 128 millimeters for the Yampa River, and 22.5 to 150 millimeters for the Rio Grande. Computed scour at the peak steamflows ranged from –2.32 feet at Surveyor Creek near Platner to +0.63 foot at the Rio Grande at Wagon Wheel Gap. Pier-scour depths computed at the peak streamflows ranged from 4.46 feet at the Rio Grande at Wagon Wheel Gap to 5.94 feet at the Yampa River near Maybell. The number of streamtubes used in the model varied at each site.

INTRODUCTION

The Federal Highway Administration (FHWA), recognizing the need for a comprehensive national program to address scour and related failures at bridges, issued Technical Advisory 5140.20 in September 1988. It required State highway departments to screen and identify those bridges on the Federal Highway System that are most likely to be susceptible to scour damage and failure. Three levels of analysis of increasing detail and complexity were established (Lagasse and others, 1991): (1) Qualitative geomorphic evaluation (level 1), (2) detailed hydraulic scour analysis (level 2), and (3) a fluvial model study using either a physical or a digital model (level 3). The level 1 analysis is used as a screening mechanism and indicates the relative susceptibility of a bridge to scour. Detailed scour analyses then can proceed to determine the potential scour limit (the ability of the structure to withstand a given magnitude of lost material) at those bridges determined to be the most scour susceptible. The level 2 analysis is used to determine depths of maximum potential scour resulting from a flood. The FHWA recommends that scour be evaluated for an extreme flood at existing bridges (Richardson and others, 1991). Guidelines and procedures are detailed in Richardson and others (1991) for performing level 2 analysis. A level 3 analysis commonly is used in complex situations and in forensic studies of bridge failure.

The U.S. Geological Survey (USGS), in cooperation with the Colorado Department of Transportation (CDOT), began a bridge-scour study in 1991 that was completed in 1993. A summary of bridge-scour analyses at selected sites in Colorado is in Vaill and others (1995). A part of that study was to compute scour at three sites using a sediment-transport model (level 3 analysis) in an approach similar to a level 2 analysis.

This report describes the application of the BRIdge Stream Tube model for Alluvial River Simulation (BRI-STARS) (Molinas, 1990) to estimate scour depths at three study sites that represent various physiographic regions of Colorado. Results of the model computations for channel changes and pier-scour depths are tabulated in the report. Example

BRI-STARS input files for each site are included in Appendixes 1–3 at the back of the report. Program variables are defined in Appendix 4.

Sediment-transport routing for bridge-scour estimates using BRI-STARS was applied to stream-channel reaches upstream and downstream from the U.S. Highway 34 bridge on Surveyor Creek near Platner (fig. 1, Appendix 1), the U.S. Highway 40 bridge on the Yampa River near Maybell (fig. 2, Appendix 2), and the State Highway 149 bridge on the Rio Grande at Wagon Wheel Gap (fig. 3, Appendix 3). Surveyor Creek is located in the eastern plains region where the predominant bed material is classified as sand. The Yampa River is located in the plateau regions where bed material ranges from fine gravel to cobbles. The Rio Grande is located in the mountainous region where boulders, cobbles, and gravel are the predominant bed materials.

MODEL INPUT

The BRI-STARS model has three major components: (1) Step-backwater computations for water-surface profiles, (2) streamtube computations, and (3) sediment-routing computations. Discharge hydrographs are approximated by time periods of constant discharge. During each time period, step-backwater computations are automatically completed for all states of flow (subcritical, supercritical, or a combination of both).

Data needs for the model include channel cross-section geometry, bed-material size distributions, hydrographs (streamflow and sediment), water-surface elevations at the initial downstream cross section, water temperature, roughness coefficients, and a sediment-transport equation. Channel cross-section geometry can be determined from field surveys

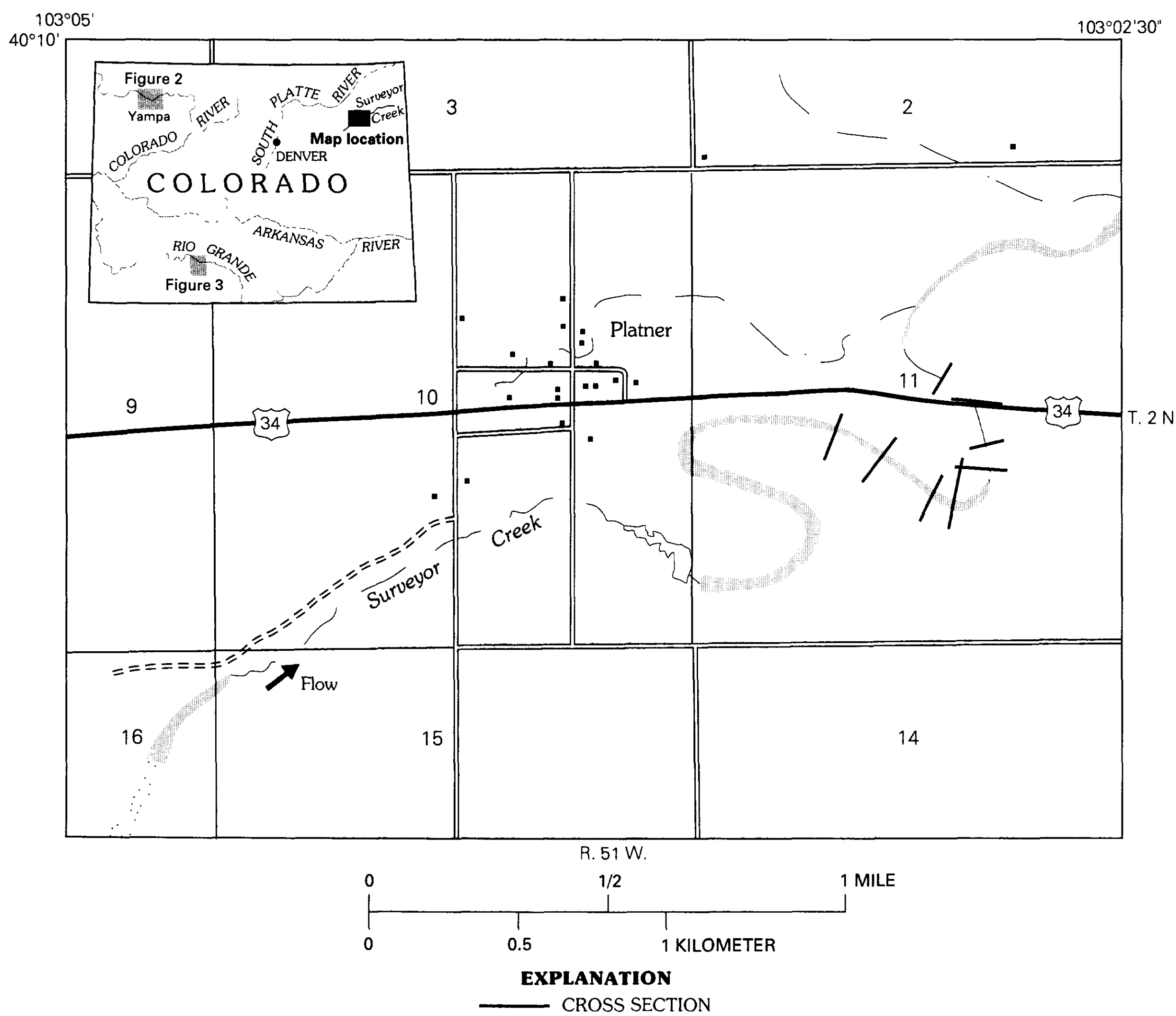

Figure 1. Location of surveyed cross sections for Surveyor Creek near Platner.

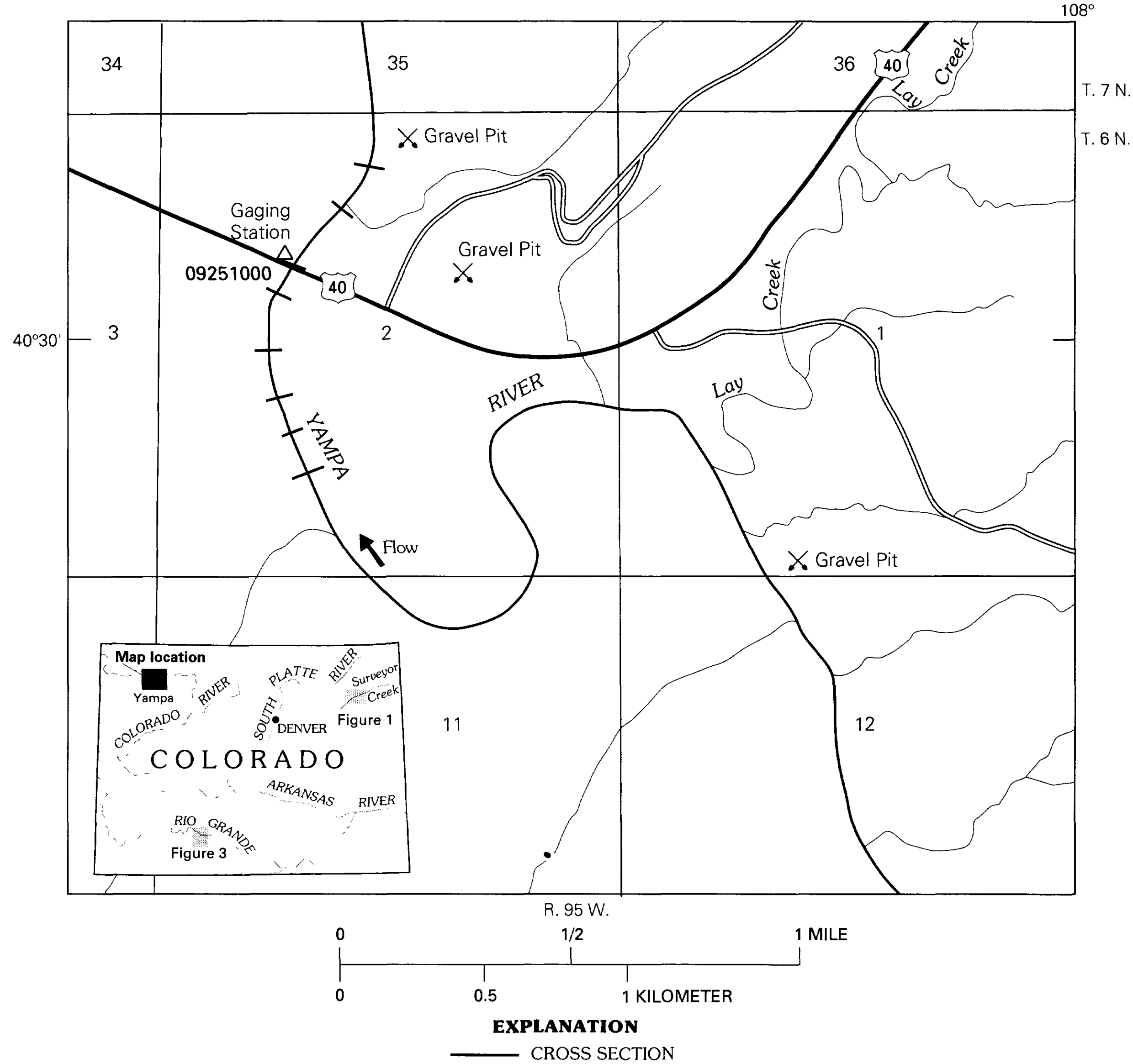

Figure 2. Location of surveyed cross sections for Yampa River near Maybell.

or from topographic maps. Cross sections can be synthesized at different locations in the study reach by extending survey data by using valley slopes from field surveys or computed from topographic maps. Bed-material size distributions are determined from sieve analyses of samples collected at the study site or particle counts obtained from the study site. Initial water-surface elevations are determined from stage-discharge rating curves or from a separate water-surface profile computation analysis. Water temperature can be estimated or a measured value can be used. Roughness coefficients can be estimated during a field inspection of the study site.

Channel Geometry

Channel cross-section geometry was determined by field surveys at each site. The channel reach surveyed for Surveyor Creek near Platner begins about 2,800 ft upstream from the bridge and ends about 560 ft downstream (fig. 1). In the vicinity of the bridge, and farther downstream, the bed material in the active channel mostly is sand, and sparse grass and weeds are on the banks. Upstream from the bridge, the left bank has a fairly flat slope, whereas the right bank has a steeper slope and is covered by grassy vegetation and sparse clumps of mature sagebrush and occasional cottonwood trees. Downstream from the bridge, vegeta-

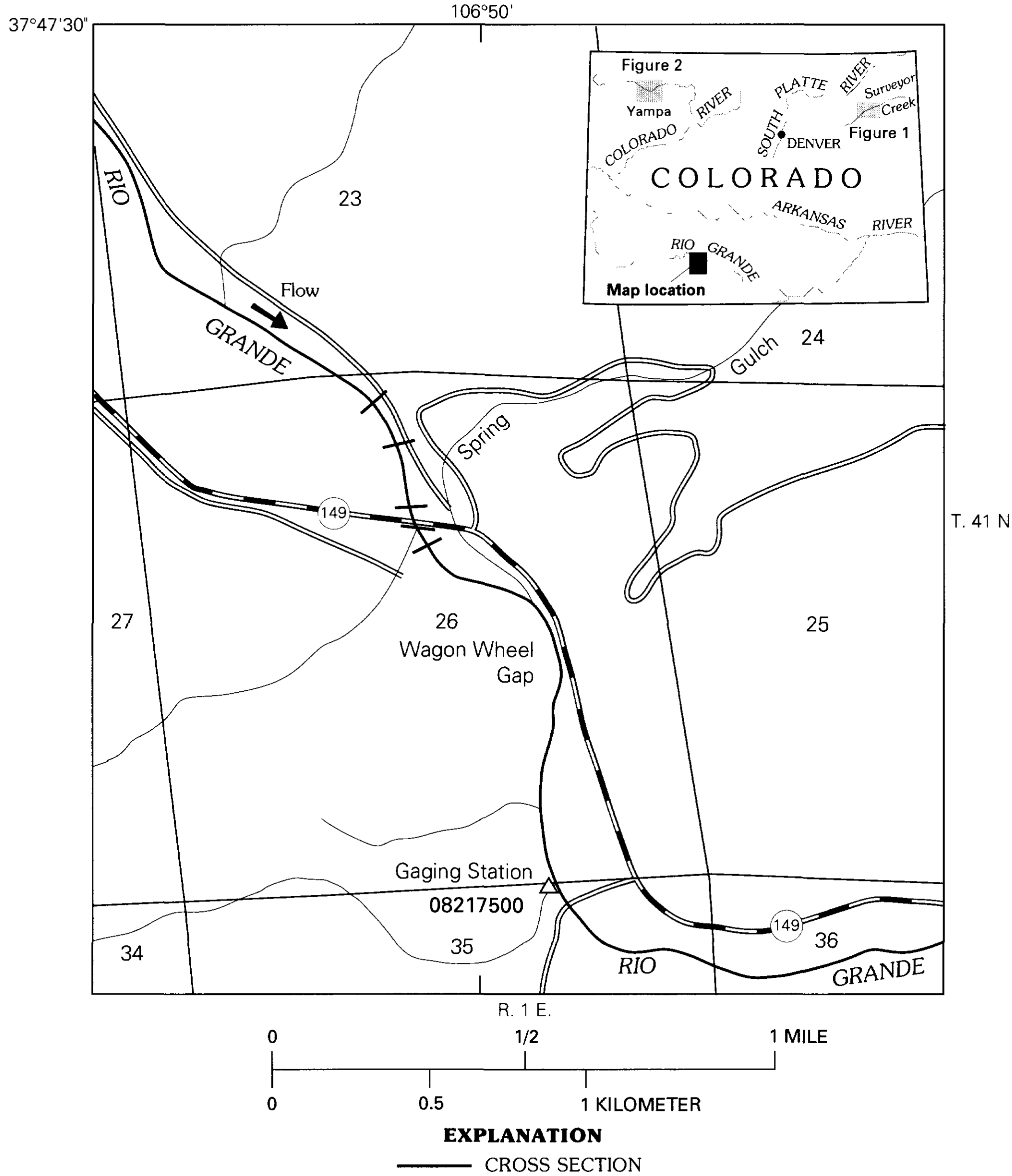

Figure 3. Location of surveyed cross sections for Rio Grande at Wagon Wheel Gap.

tion cover on the banks remains the same as upstream. Bank slopes increase as the channel becomes more incised downstream from the bridge. The cross-section shape of the channel beyond the limits of the reach surveyed was assumed to be similar to that of the last surveyed cross section. On the basis of this assumption, the length of the channel reach to be modeled was extended, using synthetic cross sections, to about 3,800 ft upstream from the bridge and 1,700 ft downstream from the bridge.

A 3,810-ft channel reach was surveyed for the Yampa River near Maybell (fig. 2), 2,440 ft upstream and 1,370 ft downstream from the bridge. The upstream left bank is a steep hillside with mature willows lining the bank, and sagebrush is located higher on the hillside. Upstream from the bridge, the right bank is a 3- to 5-ft vertical bank covered with tall grass and willows. A wide, gently sloped flood plain begins at the top of the bank and mostly is covered by short grass with sparsely scattered sagebrush. Downstream from the bridge, the left bank is less steep. The channel is incised 4 to 6 ft and has a wide, gently sloping flood plain covered with sagebrush. The right bank becomes steeper as the channel bends to the left downstream from the bridge and transitions to a rocky, sagebrush-covered hillside. Based on the uniformity of the channel cross-section geometry, the length of reach modeled was extended using synthetic cross sections to about 4,400 ft upstream from the bridge and 3,600 ft downstream.

A channel length of 1,460 ft was surveyed for the Rio Grande at Wagon Wheel Gap (fig. 3), 1,300 ft upstream and 160 ft downstream from the bridge. The upstream left bank is a steep, rocky hillside sparsely covered with sagebrush to just upstream from the bridge where the bank becomes less steep. Dense willows line the banks at the edge of the water through most of the reach. The upstream right bank is a gradually sloping, grassy flood plain above the top of a 2- to 4-ft cutbank. Downstream on the left bank, grass and scattered clumps of mature willows cover a gently sloping pasture. The right bank becomes progressively steeper as the channel bends to the left and enters a short, narrow canyon. Scattered sagebrush covers the hillside. The length of channel reach modeled was extended to about 5,400 ft upstream and 2,600 ft downstream from the bridge by using synthesized cross sections.

Roughness coefficients for the stream reaches modeled were selected during the field surveys at each site. Roughness coefficients selected for Surveyor Creek near Platner ranged from 0.045 to 0.055 for the left bank overflow, 0.035 to 0.045 for the main channel, and 0.050 to 0.055 for the right bank overflow.

A roughness coefficient of 0.040 was used for the Yampa River near Maybell. Coefficients were selected in the field for the left bank (0.055 to 0.075) and right bank (0.050 to 0.070) overflows, but were not used because the modeled water-surface elevations indicated the flow was confined to the main channel.

Roughness coefficients selected for the Rio Grande at Wagon Wheel Gap ranged from 0.055 to 0.075 for the left bank overflow, 0.040 to 0.045 for the main channel, and 0.050 to 0.060 for the right bank overflow.

Bed Material

Bed-material size distributions for Surveyor Creek near Platner represent material at the streambed surface and material 2 to 3 ft below the surface. Bed-material samples were collected by hand during 1992 in the vicinity of the approach cross section located upstream from the bridge. The upstream channel consists of sand and a few small gravel-size particles. Samples from the streambed surface were collected from equally spaced locations across the channel, and the subsurface sample was collected from a single location in mid-channel to a depth of about 4 ft. Visual inspection of the sides of the sample hole and material removed from the hole indicated that no inactive layer was present to that depth. An inactive layer is a layer of material that commonly will resist scour (for example, large boulders or bedrock) and will limit scour depth. Visual observation of the bed material through the reach indicated slightly compacted mixed-size sand. Size fractions and percentages of material within each size group are listed in table 1.

Table 1. Bed-material particle-size distributions

[--, outside range of sample]

Size fractions (millimeters)	Percent retained by weight		
	Surveyor Creek	Yampa River	Rio Grande[1]
<0.5	7.3	--	--
0.5–1.0	19.0	--	--
1.0–2.0	24.8	--	--
2.0–4.0	27.6	[2]7.5	--
4.0–8.0	15.9	5.2	--
8.0–16.0	5.4	10.5	--
16.0–22.5	--	8.2	--
22.5–32.0	--	15.7	2.0
32.0–45.0	--	18.4	11.0
45.0–64.0	--	13.7	23.0
64.0–90.0	--	13.4	36.0
90.0–128.0	--	7.4	22.0
128.0–150.0	--	--	6.0

[1]From grid-sampling particle count.
[2]Total less than 4.0 millimeters.

Bed-material size distributions for the Yampa River near Maybell were determined from samples collected October 21, 1981 (Andrews, 1984). Visual inspection of the bed material at the time of the field survey in 1993 was not possible due to the depth of the water. Exposed channel banks at an elevation below the vegetation line indicated medium gravel and a few cobbles. During the field survey, the channel bed was very firm, indicating the lack of fine material. Size fractions and percentages of material within each size group are listed in table 1.

Because of the presence of coarse bed material and a semiarmored layer, a mechanical sampler could not be used at the Rio Grande at Wagon Wheel Gap. Bed-material size distribution was determined during 1993 using pebble counts from a uniform grid (Wolman, 1954) laid out in the approximate location of the approach cross section. Kellerhals and Bray (1971) concluded that grid sampling is roughly comparable to volumetric sampling. Samples collected at each site probably are comparable, even though they were collected by different methods. Size fractions and percentages of material within each size group are listed in table 1.

Flood Hydrology

Magnitudes of the 500-year floods for the sites were computed from regionalized regression equations presented by Kircher and others (1985) and Livingston and Minges (1987). The method described by Kircher and others (1985) for weighting flows computed from regional-regression equations with flows computed from streamflow-gaging-station records was used for the Yampa River near Maybell and the Rio Grande at Wagon Wheel Gap. No gaging-station record was available to use in the weighting procedure for Surveyor Creek near Platner. Values of the 500-year floods computed from regional-regression equations were 37,500 ft^3/s for Surveyor Creek near Platner, 20,000 ft^3/s for the Yampa River near Maybell, and 6,700 ft^3/s for the Rio Grande at Wagon Wheel Gap.

Computation of the water-surface profile for the 500-year flood at Surveyor Creek near Platner, using a model for Water-Surface PROfile computations (WSPRO) (Shearman, 1990), indicated the bridge and roadway would be overtopped and that pressure flow through the bridge would occur. Pressure flow occurs when the water surface is in contact with the low steel in the bridge opening. Richardson and others (1991) recommend that WSPRO be used to determine the discharge through the bridge for scour evaluation when flow affects the bridge superstructure. The discharge that produces pressure flow is determined by making successive water-surface profile computations, using WSPRO, while increasing the discharge incrementally, until a change from free-surface flow (no water-surface contact with low steel) to pressure flow is noted in the WSPRO output (Shearman and others, 1986). The maximum flow that can be routed through the bridge before a flow change occurs was recorded and used in the scour analysis.

The maximum free-surface flow that could be routed through the Surveyor Creek bridge was 18,000 ft^3/s, which is substantially less than the computed 500-year flood discharge of 37,500 ft^3/s. A synthetic flood hydrograph for the 18,000 ft^3/s free-surface flow was developed for use in the BRI-STARS model using a method modified from that described by Livingston and Minges (1987). The method described by Livingston and Minges (1987) was refined from a dimensionless hydrograph developed by Commons (1942) and was applied to small watersheds in Wyoming by Craig and Rankl (1978). The synthetic hydrograph described by Livingston and Minges (1987) is based on a discharge constant computed from a given peak flow and a time constant computed from the volume of the peak flow. The time constant computed, 2.68 minutes, for the flow of 18,000 ft^3/s seemed unrealistically short. The 2.68-minute time constant resulted in a synthetic hydrograph that had a time to peak of 32 minutes and a time base of only 3.1 hours. A new time constant was computed using a method described by Linsley and others (1958). The new time constant of 56 minutes was used in the Livingston and Minges (1987) method to determine the coordinates of the synthetic flood hydrograph used in the BRI-STARS model. The flood hydrograph used in the BRI-STARS model seemed more realistic for the basin drainage area (150 mi^2) at the bridge and magnitude of the flow. The final hydrograph had a time to peak of 11.2 hours and a time base of 65.3 hours. A 30-hour part of the synthetic hydrograph that was greater than 2,500 ft^3/s was arbitrarily selected for modeling and was discretized into 5-minute intervals of constant discharge to approximate the synthetic flood hydrograph (fig. 4A). The selection of 5-minute time intervals was based on the shape of the synthetic hydrograph. Short duration time intervals were necessary to avoid large increases in discharge between adjacent time intervals on the sharply rising limb of the hydrograph.

Rather than computing a synthetic hydrograph, the hydrograph for the peak flow of record was analyzed for the gaging station located at the Yampa River near Maybell, about 750 ft downstream from the bridge. The USGS gaging station, Yampa River near Maybell (09251000), has 75 years of record. The maximum mean daily streamflow recorded for the period of record was 24,400 ft^3/s (May 17, 1984). This streamflow was about 122 percent of the 500-year flood estimated from regional-regression equations. The decision was made to use the known hydrograph and eliminate the uncertainties of using a synthetic hydrograph, even though the recorded peak flow exceeded the regional-regression-equation flood magnitude by 22 percent. A 30-day period of the mean daily streamflow hydrograph greater than about 5,000 ft^3/s from the hydrograph of the peak flow of record (May 8 to June 6, 1984) was arbitrarily selected for use in the model to simulate a flood peak due to snowmelt typical of the region (fig. 4B). The hydrograph was discretized into time steps of 12-hour duration using the recorded mean daily streamflows for each time step.

The USGS gaging station, Rio Grande at Wagon Wheel Gap (08217500), is located about 0.5 mi downstream from the highway bridge (fig. 3) and has 41 years of record. The maximum daily discharge recorded for the period of record was 4,970 ft^3/s (June 9, 1985). The instantaneous peak flow of record was 5,190 ft^3/s (June 9, 1985). The maximum daily discharge for the period of record was about 74 percent of the 500-year flood computed from regional-regression equations. A daily discharge flood hydrograph was synthesized using the shape of the recorded mean daily streamflow hydrograph for the peak flow of record at the gaging station and the computed 500-year flood as an upper limit for the maximum daily discharge (fig. 4C). The synthetic hydrograph was discretized into time steps of 12-hour duration using mean daily discharges for each time step to simulate a snowmelt peak typical of the region.

BRI-STARS requires a water-surface elevation that corresponds to each discharge of the discretized flood hydrograph to define the downstream boundary condition at the initial cross section. The water-surface elevations for each discharge of the discretized hydrograph were computed using the field-surveyed data and WSPRO (Shearman, 1990). The water-surface computed by WSPRO and the corresponding discharge were used as input data for BRI-STARS.

Water temperature was measured during the field surveys in late summer at Yampa River near Maybell (69.0°F) and Rio Grande at Wagon Wheel Gap (72.5°F). No water temperature was available for Surveyor Creek near Platner due to the channel being dry. A water temperature of 65°F was used in BRI-STARS because it was felt to be more indicative of the water temperature when snowmelt runoff peaks occur during late spring and early summer.

Sediment Transport

Bridge scour is limited by the availability of bed material and the capacity of the stream to transport eroded material. The term "availability limited" can be defined as the condition at which sediment transport that is predicted by a selected transport equation is greater than the amount of sediment that is available at a given size fraction. The term "capacity limited" can be defined as the condition for which there is sufficient bed material present to allow the sediment transport indicated by the selected equation.

The sediment-inflow hydrograph at the most upstream cross section in a study reach can be supplied by the user, or the user can allow the model to build a sediment-inflow hydrograph. If a sediment hydrograph is known, BRI-STARS requires it to be supplied in the form of discretized sediment discharges. If a sediment hydrograph is not known, BRI-STARS uses a specified sediment-transport equation from the model and the bed-material size data to produce an inflow sediment

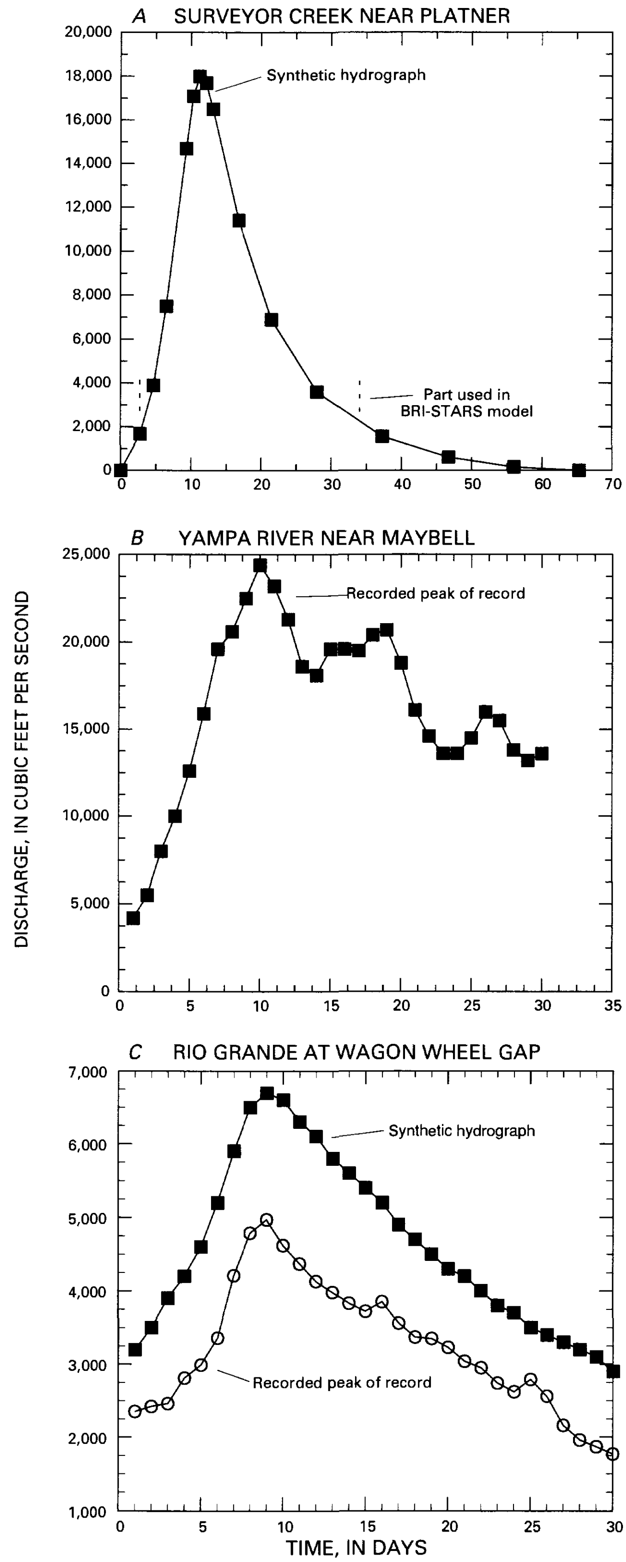

Figure 4. Modeled flood hydrographs for (A) synthetic flood hydrograph on Surveyor Creek near Platner, (B) 30-day flood on the Yampa River near Maybell, and (C) 30-day synthetic flood hydrograph for the Rio Grande at Wagon Wheel Gap.

hydrograph for the most upstream cross section. In the current (1995) version of the model, sediment-transport capacities can be determined by (1) the Yang method, (2) the Acker and White method, (3) the Engelund and Hansen method, (4) the Meyer-Peter Mueller method (methods 1–4 in Chang, 1988), or (5) a user-supplied generic equation of a given form. The methods were chosen for the model because of their accuracy and the short computational times associated with them. The sediment-transport equations are applicable to particle sizes of 0.0625 mm and greater. For the Yang method of computations, sediment transport can be performed for sizes as large as 10 mm. The Meyer-Peter Mueller method is available for larger sizes.

No previously determined sediment-transport equations were available for the study sites. The model was used to develop a sediment-inflow hydrograph at each site. Yang's method was applied to Surveyor Creek near Platner where the predominant bed-material size is sand. The Meyer-Peter Mueller equation was applied to the Yampa River near Maybell and the Rio Grande at Wagon Wheel Gap due to the relatively coarse sizes of the bed material present at the sites.

BRIDGE-SCOUR ANALYSIS

Scour is the result of the erosive action of flowing water as it excavates and carries away material from the bed and banks of the stream. All streambed material is susceptible to scour, but the magnitude of scour depth primarily depends on site conditions and hydraulic parameters of the bridge reach, so each site is unique. The rate at which maximum scour is reached depends on the ability of the streambed material to withstand the factors that cause scour. Total scour at a river crossing consists of three components that, in general, are additive:

1. General scour—Due to long-term changes in the riverbed elevation, whether from natural or man-induced causes.

2. Contraction scour—Resulting from the constriction of the channel, either naturally or due to the bridge and its approaches encroaching on the flood plain.

3. Local scour—The result of interference of the flow pattern by piers or abutments that accelerate the flow, creating vortices that erode material surrounding the piers or abutments.

BRI-STARS computes sediment transport as a function of shear stress, velocity, or some other variable and should compute contraction scour depending on the sediment-transport equation selected. Contraction scour is indicated by the amount of channel degradation (or aggradation) computed by the model. If bridge piers are present in the study reach, the user is given the option to compute local scour due to piers. Equations recommended for pier scour by Richardson and others (1991) are available as options in the model, and the Colorado State University equation was chosen for this study. Channel change and pier-scour depths for the bridge cross section at each site are summarized in table 2. Bridge cross sections showing initial channel bed elevations and elevations at the time of the peak streamflow are shown in figure 5A–C.

Table 2. Channel change and pier-scour depths at the peak streamflow

[WSPRO, Water-Surface PROfile]

Site name	With WSPRO bridge hydraulics routines		Without WSPRO bridge hydraulics routines	
	Channel change (feet)	Pier-scour depth (feet)	Channel change (feet)	Pier-scour depth (feet)
Surveyor Creek near Platner	−2.32	4.60	−1.89	4.60
Yampa River near Maybell	−.38	5.94	−.17	5.97
Rio Grande at Wagon Wheel Gap	.63	4.46	.69	4.58

The minimization routine available in BRI-STARS allows the model to vary channel width after each computation step. This routine was not used at any site. Based on observations during the field surveys, a fixed channel width was used in each model computation. All three stream study reaches appeared very stable with no indication of bank mass wasting or lateral channel migration.

The number of streamtubes used in the final model computations varied at each site. The user's manual suggests that calculated scour generally is not sensitive to the number of streamtubes (Molinas, 1990, p. 77). For the Yampa River and Rio Grande sites, the number of streamtubes affected model stability. Selecting more than a single streamtube resulted in an unstable simulation. One streamtube was an acceptable representation because all streamflow was contained within the banks, and channel subdivision was not necessary. At the Surveyor Creek site, five streamtubes were used to represent the varied water-surface profile and terraced cross section.

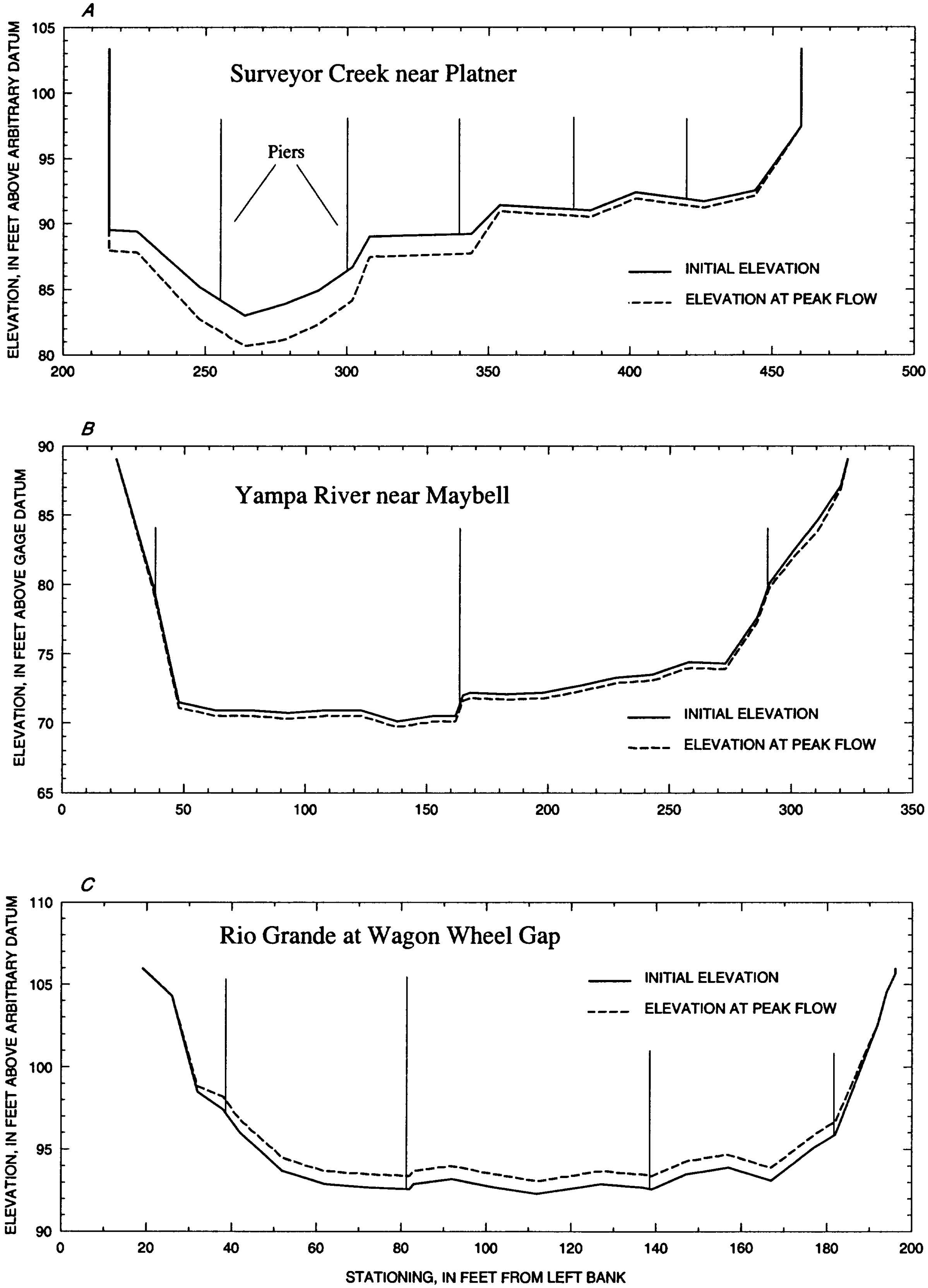

Figure 5. Bridge cross section and initial elevations and elevations at the 500-year peak flow for (A) Surveyor Creek near Platner, (B) Yampa River near Maybell, and (C) Rio Grande at Wagon Wheel Gap.

A part of WSPRO (Shearman, 1990) has been incorporated as an option in BRI-STARS to allow analysis of sediment transport through the bridge reach under bridge backwater conditions (the amount of backwater caused by encroachment on the flood plain by the bridge and how far upstream the bridge-affected water-surface elevations will be higher than water-surface elevations for unconstricted flow). If the use of WSPRO bridge hydraulics routines is requested, the WSPRO data are prepared separately and stored in a different data file. The associated data file must comply with restrictions imposed in WSPRO. These restrictions include location of a cross section one bridge width upstream from the bridge (approach section), a cross section at the downstream bridge opening that includes bridge geometry (bridge section), a cross section located at the downstream side of the bridge that represents natural channel conditions without the bridge in place (full valley section), and a cross section located one bridge width downstream from the bridge (exit section) for use in the bridge hydraulics routines. Including the cross sections dictated by WSPRO (approach, bridge, full valley, and exit) could substantially affect the BRI-STARS computations by decreasing the flow length between cross sections.

To determine if there were any adverse effects in model results when the WSPRO bridge hydraulics routines were used, scour depths computed using the WSPRO bridge hydraulics routines contained in BRI-STARS were compared to scour depths computed without the bridge hydraulics routines. In general, scour depths computed using the WSPRO bridge hydraulics routines did not substantially differ from scour depths computed without the bridge hydraulics routines (table 2). The effect of debris accumulation on or around the piers during the peak streamflows was not examined.

SUMMARY

The USGS, in cooperation with CDOT, began a bridge-scour study in 1991. A part of that study was to estimate bridge scour at three sites using a sediment-transport model. Sediment-transport routing was used to estimate channel changes and pier-scour depths at the U.S. Highway 34 bridge on Surveyor Creek near Platner, the U.S. Highway 40 bridge on the Yampa River near Maybell, and the State Highway 149 bridge on the Rio Grande at Wagon Wheel Gap. Synthetic flood hydrographs were developed for Surveyor Creek and the Rio Grande to simulate extreme flows for use in the model. A part of the recorded mean daily streamflow hydrograph for the peak flow of record was used for the Yampa River. Bed-material particle sizes ranged from less than 0.5 to 16 mm for Surveyor Creek, less than 4 to 128 mm for the Yampa River, and 22.5 to 150 mm for the Rio Grande. Model computations indicate –2.32 ft of channel change at the peak streamflow for Surveyor Creek, –0.38 ft for the Yampa River, and +0.63 ft for the Rio Grande. Pier-scour depths predicted by the model at the peak streamflows were 4.60 ft for Surveyor Creek near Platner, 5.94 ft for the Yampa River near Maybell, and 4.46 ft for the Rio Grande at Wagon Wheel Gap.

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APPENDIXES

Appendix 1—Example BRI-STARS Input File for Surveyor Creek Near Platner

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TT      BRI-STARS MODEL FOR SURVEYOR CREEK NEAR PLATNER, CO
TT           COMPARISON WITH LEVEL 2 SCOUR ESTIMATES
TT                JEVAILL     NOVEMBER 1992
NS  12.0
*****    SYNTHETIC CROSS SECTION NO.0 -- SEC. NO.1 MOVED UPSTREAM
ST  4500     16.0      0.0      0.0      0.0      1.0
ND   3.0     42.0    174.0    300.0
XS 111.9   -150.0    101.9      0.0    101.2     12.0     99.2     21.0     95.3     27.0
XS  93.4     42.0     94.0     57.0     93.3     78.0     94.3    108.0     94.7    138.0
XS  97.3    162.0     99.7    174.0    101.7    189.0    101.7    216.0    103.9    250.0
XS 111.9    300.0
*****   SYNTHETIC CROSS SECTION NO.1 -- SEC. NO.1 MOVED UPSTREAM
ST  4000     16        0.0      0.0      0.0      1.0
ND   3.0     42.0    174.0    300.0
XS 110.9   -150.0    100.9      0.0    100.2     12.0     98.2     21.0     94.3     27.0
XS  92.4     42.0     93.0     57.0     92.3     78.0     93.3    108.0     93.7    138.0
XS  96.3    162.0     98.7    174.0    100.7    189.0    100.7    216.0    102.9    250.0
XS 110.9    300.0
*****   CROSS SECTION NO.1
ST  3540     16.0      0.0      0.0      0.0      1.0
ND   3.0     42.0    174.0    300.0
XS 110.0   -150.0    100.0      0.0     99.3     12.0     97.3     21.0     93.4     27.0
XS  91.5     42.0     92.1     57.0     91.4     78.0     92.4    108.0     92.8    138.0
XS  95.4    162.0     97.8    174.0     99.8    189.0     99.8    216.0    102.0    250.0
XS 110.0    300.0
*****   CROSS SECTION NO.3
ST  3010     15.0      0.0      0.0      0.0      1.0
ND   3.0     36.0    171.0    250.0
XS 105.0   -150.0     99.5      0.0     99.5     18.0     97.0     27.0     92.8     36.0
XS  90.4     48.0     90.8     66.0     91.2     93.0     90.4    120.0     92.3    147.0
XS  93.5    171.0     94.9    186.0     98.2    192.0    100.2    204.0    110.0    250.0
*****   CROSS SECTION NO.5
ST  2355     15.0      0.0      0.0      0.0      1.0
ND   3.0     42.0    174.0    282.0
XS 105.0   -100.0     98.3      0.0     97.1     18.0     94.9     30.0     91.0     42.0
XS  89.2     69.0     89.9     99.0     89.0    123.0     90.0    144.0     88.8    165.0
XS  92.8    174.0     96.0    186.0    102.2    213.0    108.9    249.0    111.7    282.0
********
*****   SYNTHETIC CROSS SECTION NO.7 DELETED
********
*****   CROSS SECTION NO.8
ST  1505     15.0      0.0      0.0      0.0      1.0
ND   3.0    405.0    575.0    594.0
XS 110.0   -200.0    105.0    -80.0     98.8      0.0     94.7     21.0     89.6    117.0
XS  89.4    177.0     89.4    264.0     89.7    345.0     89.8    405.0     89.1    471.0
XS  89.4    522.0     87.0    534.0     85.6    564.0     85.5    575.0    109.9    594.0
```

```
*****   APPROACH SECTION -- SECTION NO.10 MOVED UPSTREAM
ST  1055    11.0     0.0     0.0     0.0     1.0
ND   2.0    98.0   230.0
XS 102.2     0.0    86.8     5.0    86.8    24.0    85.2    54.0    84.2    70.0
XS  86.3    86.0    90.4    98.0    92.0   132.0    93.3   190.0    96.2   220.0
XS 104.5   230.0
*****   BRIDGE SECTION -- SEC. NO.11 MODIFIED WITH BRIDGE GEOMETRY
ST   785    17.0     0.0     0.0     0.0     1.0
ND   1.0   460.0
XS 103.4   216.0    89.5   216.0    89.4   226.0    85.2   248.0    83.0   264.0
XS  83.9   278.0    84.9   290.0    86.7   302.0    89.0   308.0    89.2   344.0
XS  91.4   354.0    91.0   386.0    92.4   402.0    91.7   426.0    92.5   444.0
XS  97.4   460.0   103.4   460.0
********
*****   FULL SECTION -- SEC.11 MOVED DOWNSTREAM 10FT, NO ELEV. ADJUSTMENT
********
*****   EXIT SECTION -- SEC. NO.12 MOVED UPSTREAM
ST   550    15.0     0.0     0.0     0.0     1.0
ND   3.0    56.0   158.0   236.0
XS 101.5  -100.0    93.4     0.0    90.8    24.0    86.7    44.0    84.4    56.0
XS  80.3    74.0    80.5    84.0    80.8    94.0    82.4   125.0    81.3   139.0
XS  81.8   146.0    88.6   158.0    92.3   188.0    95.8   210.0    96.8   236.0
*****   SYNTHETIC SECTION NO.A -- SEC. NO.12 MOVED DOWNSTREAM
ST     0    15.0     0.0     0.0     0.0     1.0
ND   3.0    56.0   158.0   236.0
XS  99.3  -100.0    91.2     0.0    88.6    24.0    84.5    44.0    82.2    56.0
XS  78.1    74.0    78.3    84.0    78.6    94.0    80.2   125.0    79.1   139.0
XS  79.6   146.0    86.4   158.0    90.1   188.0    93.6   210.0    95.6   236.0
*****   SYNTHETIC SECTION NO.D
ST  -500    15.0     0.0     0.0     0.0     1.0
ND   3.0    56.0   158.0   236.0
XS  98.3  -100.0    92.0     0.0    87.6    24.0    84.5    44.0    81.2    56.0
XS  77.1    74.0    77.3    84.0    77.7    94.0    79.2   125.0    78.1   139.0
XS  78.6   146.0    85.4   158.0    89.1   188.0    92.6   210.0    94.6   236.0
*****   SYNTHETIC SECTION NO.C
ST -1000    15.0     1.0     1.0     0.0     1.0
ND   3.0    56.0   158.0   236.0
XS  97.3  -100.0    89.2     0.0    86.6    24.0    82.5    44.0    80.2    56.0
XS  76.1    74.0    76.3    84.0    76.6    94.0    78.2   125.0    77.1   139.0
XS  77.6   146.0    84.4   158.0    88.1   188.0    91.6   210.0    95.6   236.0
RE      MANNING
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0450  0.0450  0.0450  0.0450
RH0.0450  0.0450  0.0550  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0450  0.0450  0.0450  0.0450
RH0.0450  0.0450  0.0550  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0450  0.0450  0.0450  0.0450
RH0.0450  0.0450  0.0550  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0450  0.0450  0.0450  0.0450  0.0450
RH0.0450  0.0550  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0450  0.0450  0.0450  0.0450  0.0450
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RH0.0450  0.0550  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0550  0.0400
RH0.0400  0.0400  0.4000  0.0400  0.0550
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0550  0.0550  0.0550
RH0.0550
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450
RH0.0450  0.0450  0.0450  0.0450  0.0450  0.0450  0.0450
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0350  0.0350  0.0350  0.0350  0.0350
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RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0350  0.0350  0.0350  0.0350  0.0350
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RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0350  0.0350  0.0350  0.0350  0.0350
RH0.0350  0.0350  0.0550  0.0550  0.0550
RH0.0550  0.0550  0.0550  0.0550  0.0550  0.0350  0.0350  0.0350  0.0350  0.0350
RH0.0350  0.0350  0.0550  0.0550  0.0550
CL0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CL0.0000  0.0000
CB      THALWEG
NT   5.0
IT 360.0     1.0 0.00347     0.0     0.0
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SS      STAGE DISCHARGE TABLE
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SQ  5000   84.94
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SQ  2500   82.39
SQ  2500   82.39
SQ  2500   82.39
SO      SEDIMENT TRANSPORT IS REQUESTED
QS 360.0      0.0
SE   1.0      0.0
TM 360.0     65.0
SF   8.0
SG0.0625  0.1250
SG0.1250  0.2500
SG0.2500  0.5000
SG0.5000  1.0000
SG1.0000  2.0000
SG2.0000  4.0000
SG4.0000  8.0000
SG8.0000 16.0000
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
```

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SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
SD 0.004   0.012   0.057   0.190   0.248   0.276   0.159   0.054
WB      8        SUR.DAT
PE   1.0     1.0
PS   8.0     5.0
PP 256.0     2.0     1.0
PP 300.0     2.0     1.0
PP 340.0     2.0     1.0
PP 380.0     2.0     1.0
PP 420.0     2.0     1.0
PR   1.0       2      92     104
PV   7.0     0.0     0.0     0.0     0.0     0.0
PV   8.0     0.0     0.0     0.0     0.0     0.0
PV   9.0     0.0     0.0     0.0     0.0     0.0
PL      PLOTTING IS REQUESTED
PX      CHANNEL CROSS SECTION PLOTS         30       0       0
PW      WATER SURFACE PROFILE PLOTS         30       0       0
MN      NO MINIMIZATION IS REQUESTED
```

Separate input file (SUR.DAT) for the WSPRO bridge hydraulics routines in BRI-STARS--[AS, approach section location and data; BP, horizontal datum correction for approach section; BR, bridge section location and data; CD, bridge geometry data; PW, pier location and elevation data; T1-3, title information; XS, cross-section location and data.]

```
T1        SURVEYOR CREEK NEAR PLATNER
T2        FIXED GEOMETRY MODE
T3        BRI-STARS INPUT FILE
*
XS   EXIT 550
*
XS   FULL 785
*
BR   BRDG 785  103.44
PW        83.0,2 86.7,2 86.7,4 89.2,4 89.2,6 91.0,6 91.0,8 91.7,8 91.7,10
CD        4  35  3  106.98  20
*
AS   APPR 1055
BP        -200
```

Appendix 2—Example BRI-STARS Input File for the Yampa River Near Maybell

```
TT      BRI-STARS RUN -- YAMPA RIVER NR MAYBELL, CO
TT          STURCTURE ID NO --  B-04-A
TT              JEVAILL   JUNE 1993
NS    14
*****  SYNTHETIC X.S.  SYN4 -- SEC.1 MOVED UPSTREAM
ST  6000    18.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 110.6       0   106.0      12   103.2      26    94.0      47    85.8      74
XS  83.5      79    78.0     102    78.0     124    77.0     154    76.6     198
XS  76.8     264    76.2     287    76.0     327    75.6     337    76.2     353
XS  83.6     376    85.8     400    90.8     500
*****  SYNTHETIC X.S.  SYN3 -- SEC.1 MOVED UPSTREAM
ST  5000    18.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 109.6       0   105.0      12   102.2      26    93.0      47    84.8      74
XS  82.6      79    77.2     102    77.0     124    76.2     154    75.6     198
XS  75.8     264    75.4     287    75.0     327    74.8     337    75.4     353
XS  82.6     376    84.8     400    89.8     500
*****  SURVEYED SECTION -- SEC1
ST  4050    18.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 108.8       0   104.2      12   101.4      26    92.2      47    84.0      74
XS  81.8      79    76.3     102    76.2     124    75.3     154    74.8     198
XS  75.0     264    74.5     287    74.2     327    73.9     337    74.5     353
XS  81.8     376    84.0     400    89.0     500
*****  SURVEYED SECTION -- SEC2
ST  3570    22.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 107.0       0   105.7      33    97.4      51    87.5      65    81.6      83
XS  73.9     107    77.1     127    76.0     173    73.8     203    74.1     254
XS  74.1     299    74.2     304    73.9     309    73.9     314    73.3     330
XS  73.8     348    73.7     355    78.2     373    81.6     387    85.0     387
XS  90.0     400    91.0     500
*****  SURVEYED SECTION -- SEC3
ST  3110    22.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 105.5       0   103.6      38    93.1      60    83.8      73    81.2      80
XS  73.2     100    73.0     125    72.2     158    72.5     180    72.7     205
XS  73.5     231    73.4     247    73.6     255    73.2     270    72.9     294
XS  73.4     302    72.8     315    76.2     328    81.2     340    82.5     340
XS  85.0     360    89.0     500
*****  SURVEYED SECTION -- SEC4
ST  2650    19.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 104.2       0   100.0      37    90.7      55    82.0      86    81.0      90
XS  73.3     112    71.6     133    71.8     172    72.1     179    72.4     197
XS  72.3     228    72.6     255    72.9     273    72.8     295    73.6     306
XS  74.1     319    81.0     334    83.0     350    90.0     500
```

```
*****  SYNTHETIC SECTION "APPR" -- SEC5 MOVED DOWNSTREAM
ST  1950    26.0     0.0     0.0     0.0     1.0
ND   1.0   500.0
XS 102.9       0    97.5      24    83.8      39    80.4      45    72.0      55
XS  71.5      89    71.3     104    71.0     126    71.4     147    71.8     160
XS  72.1     182    72.0     200    72.0     208    71.9     212    72.3     222
XS  72.6     226    72.7     236    72.8     246    72.9     250    73.2     254
XS  73.5     262    73.3     270    73.9     282    80.4     302    82.9     330
XS  89.9     500
*****  SURVEYED SECTION "BRIDGE" -- SECTION 6
ST  1610    26.0     0.0     0.0     0.0     1.0
ND   1.0   323.0
XS  89.1      22    80.1      37    71.5      48    70.9      63    70.9      78
XS  70.7      93    70.9     108    70.9     123    70.1     138    70.5     153
XS  70.5     162    72.0     165    72.2     168    72.1     183    72.2     198
XS  72.7     213    73.3     228    73.5     243    74.4     258    74.3     273
XS  77.6     286    80.1     291    82.5     301    84.7     311    87.1     320
XS  89.1     323
*****  FULL VALLEY SECTION
ST  1600      25       0       0       0     1.0
ND   1.0     320
XS  89.0      22    80.1      37    71.5      48    70.9      63    70.9      78
XS  70.7      93    70.9     108    70.9     123    70.1     138    70.5     153
XS  70.0     162    72.0     165    72.2     168    72.1     183    72.2     198
XS  72.7     213    73.3     228    73.5     243    74.4     258    74.3     273
XS  77.6     286    80.1     291    82.5     301    84.7     311    87.1     320
*****  SYNTHETIC SECTION  "EXIT" -- SECTION 7 AT CABLEWAY MOVED UPSTREAM
ST  1300    27.0     0.0     0.0     0.0     1.0
ND   1.0   380.0
XS  88.2       0    85.8      10    82.2      12    79.3      23    74.7      28
XS  70.8      38    70.8      58    71.3      68    71.3      78    70.6     108
XS  70.7     118    71.8     128    72.2     148    71.8     158    71.5     168
XS  71.4     178    72.0     208    73.0     218    74.1     228    74.9     238
XS  75.0     248    74.9     258    76.1     268    79.3     276    85.2     280
XS  86.2     330    89.2     380
*****  SURVEYED SECTION -- SEC7 AT CABLEWAY
ST   840    27.0     0.0     0.0     0.0     1.0
ND   1.0   380.0
XS  88.0       0    85.6      10    82.0      12    79.1      23    74.5      28
XS  70.6      38    70.6      58    71.1      68    71.1      78    70.4     108
XS  70.5     118    71.6     128    72.0     148    71.6     158    71.3     168
XS  71.2     178    71.8     208    72.8     218    73.9     228    74.7     238
XS  74.8     248    74.7     258    75.9     268    79.1     276    85.0     280
XS  86.0     330    89.0     380
*****  SURVEYED SECTION -- SECTION 8
ST   240    16.0     0.0     0.0     0.0     1.0
ND   1.0   300.0
XS  89.0    -200    82.0    -100    80.5       0    78.6      10    72.1      59
XS  71.3      84    70.1     112    69.4     121    68.2     123    68.6     161
XS  69.3     183    70.4     218    72.2     233    77.0     262    78.6     270
XS  89.0     300
```

```
*****  SYNTHETIC SECTION - SYN2 --  SECTION 8 MOVED DOWNSTREAM
ST -1000    16.0     0.0     0.0     0.0     1.0
NS   1.0   300.0
XS  87.9    -200    80.9    -100    79.4       0    77.4      10    71.0      59
XS  70.2      84    69.0     112    68.3     121    67.1     123    67.5     161
XS  68.2     183    69.3     218    71.1     233    75.9     262    77.5     270
XS  88.9     300
*****  SYNTHETIC SECTION - SYN1 --  SECTION 8 MOVED DOWNSTREAM
ST -2000    16.0     1.0     1.0     0.0     1.0
NS   1.0   300.0
XS  87.0    -200    80.0    -100    78.5       0    76.6      10    70.1      59
XS  69.3      84    68.1     112    67.4     121    66.2     123    66.6     161
XS  67.3     183    68.4     218    70.2     233    75.0     262    76.6     270
XS  88.0     300
RE      MANNING
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040
```

```
RH 0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040   0.040
RH 0.040   0.040   0.040   0.040   0.040   0.040
CL0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
CL0.0000  0.0000  0.0000  0.0000
CB       THALWEG
NT      1
IT     60       1    0.50       0       0
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL     14
SQ  4190   74.50
SQ  4190   74.50
SQ  5500   75.60
SQ  5500   75.60
SQ  8000   77.35
SQ  8000   77.35
SQ 10000   78.68
SQ 10000   78.68
SQ 12600   80.70
SQ 12600   80.70
SQ 15900   82.10
SQ 15900   82.10
SQ 19600   83.45
SQ 19600   83.45
SQ 20600   83.80
SQ 20600   83.80
SQ 22500   84.45
SQ 22500   84.45
SQ 24400   84.95
SQ 24400   84.95
SQ 23200   84.60
SQ 23200   84.60
SQ 21300   84.00
SQ 21300   84.00
SQ 18600   83.10
SQ 18600   83.10
SQ 18100   82.90
SQ 18100   82.90
SQ 19600   83.45
SQ 19600   83.45
SQ 19600   83.45
SQ 19600   83.45
SQ 19500   83.40
SQ 19500   83.40
SQ 20400   83.70
SQ 20400   83.70
SQ 20700   83.80
SQ 20700   83.80
SQ 18800   83.15
```

```
SQ 18800   83.15
SQ 16100   82.20
SQ 16100   82.20
SQ 14600   81.60
SQ 14600   81.60
SQ 13600   81.15
SQ 13600   81.15
SQ 13600   81.15
SQ 13600   81.15
SQ 14500   81.55
SQ 14500   81.55
SQ 16000   82.12
SQ 16000   82.12
SQ 15500   81.95
SQ 15500   81.95
SQ 13800   81.25
SQ 13800   81.25
SQ 13200   81.00
SQ 13200   81.00
SQ 13600   81.15
SQ 13600   81.15
SO      SEDIMENT TRANSPORT REQUESTED
QS     60        0
SE      4        0
TM     60     65.0
SF     10
SG      4      5.6
SG    5.6        8
SG      8       11
SG     11       16
SG     16     22.5
SG   22.5       32
SG     32       45
SG     45       64
SG     64       90
SG     90      128
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
SD 0.030   0.022   0.030   0.075   0.082   0.157   0.184   0.137   0.134   0.074
```

```
WB      8          MAY.DAT
PE      1       1
PS      8       3
PP  38.0      2.0       1
PP 163.5      3.0       2
PP 290.0      2.0       1
PR      1      10       1       60
PV      7       0       0        0       0       0
PV      8       0       0        0       0       0
PV     10       0       0        0       0       0
PL      PLOTTING IS REQUESTED
PX      CHANNEL CROSS SECTION PLOTS             1       0       0
PW      WATER SURFACE PROFILE PLOTS             1       0       0
MN      NO MINIMIZATION IS REQUESTED
```

Separate input file (MAY.DAT) for the WSPRO bridge hydraulics routines in BRI-STARS--[AB, abutment data; AS, approach section location and data; BP, horizontal datum correction for approach section; BR, bridge section location and data; CD, bridge geometry data; PW, pier location and elevation data; T1-3, title information; XS, cross-section location and data.]

```
T1        YAMPA RIVER NEAR MAYBELL
T2        FIXED GEOMETRY MODE
T3        BRI-STARS INPUT FILE
*
XS   EXIT 1300
*
XS   FULL 1610
*
BR   BRDG 1610  89.11  0
PW        71.0,4  79.0,4  79.0,8
CD        2  30  4  89.8
AB        *  *  95.0  87.1
*
AS   APPR 1950
BP        20
```

Appendix 3—Example BRI-STARS Input File for the Rio Grande at Wagon Wheel Gap

```
TT      RIO GRANDE RIVER AT WAGON WHEEL GAP, CO
TT      BRI-STARS RUN    STRUCTURE  M-09-B
TT      JEVAILL    JUNE 1993
NS    13
****** SYNTHETIC SECTION SYN7 -- SEC.1 MOVED UPSTREAM
ST  6000      24       0       0       0       1
ND     1     200
XS 114.4     -50   111.0      -5   107.6       6   106.4      10   106.4      20
XS 105.9      30   104.9      40   103.6      50   103.4      60   103.7      70
XS 103.5      80   104.1      90   104.4     100   104.3     110   104.9     120
XS 104.8     130   105.1     140   105.5     145   107.6     150   110.4     152
XS 110.4     162   112.4     172   112.9     182   114.4     200
****** SYNTHETIC SEC. SYN6
ST  5000      24       0       0       0       1
ND     1     200
XS 112.6     -50   109.2      -5   105.8       6   104.6      10   104.6      20
XS 104.1      30   103.1      40   101.8      50   101.6      60   101.9      70
XS 101.7      80   102.3      90   102.6     100   102.5     110   103.1     120
XS 103.0     130   103.3     140   103.7     145   105.8     150   108.6     152
XS 108.6     162   110.6     172   111.1     182   112.6     200
****** SYNTHETIC SEC. SYN5
ST  4000      24       0       0       0       1
ND     1     200
XS 110.8     -50   107.4      -5   104.0       6   102.8      10   102.8      20
XS 102.3      30   101.3      40   100.0      50    99.8      60   100.1      70
XS  99.9      80   100.5      90   100.8     100   100.7     110   101.3     120
XS 101.2     130   101.5     140   101.9     145   104.0     150   106.8     152
XS 106.8     162   108.8     172   109.3     182   110.8     200
****** SYNTHETIC SEC. SYN4
ST  3000      24       0       0       0       1
ND     1     200
XS 109.0     -50   105.6      -5   102.2       6   101.0      10   101.0      20
XS 100.5      30    99.5      40    98.2      50    98.0      60    98.3      70
XS  98.1      80    98.7      90    99.0     100    98.9     110    99.5     120
XS  99.4     130    99.7     140   100.1     145   102.2     150   105.0     152
XS 105.0     162   107.0     172   107.5     182   109.0     200
****** SURVEYED SEC. 1
ST  1910      24       0       0       0       1
ND     1     200
XS 107.0     -50   103.6     -50   100.2       6    99.0      10    99.0      20
XS  98.5      30    97.5      40    96.2      50    96.0      60    96.3      70
XS  96.1      80    96.7      90    97.0     100    96.9     110    97.5     120
XS  97.4     130    97.7     140    98.1     145   100.2     150   103.0     152
XS 103.0     162   105.0     172   105.5     182   107.0     200
```

```
****** SURVEYED SEC. 2
ST  1440      22        0       0       0       1
ND     1     200
XS 105.0     -15    102.8      -4    99.4       6    97.9      10    97.5      20
XS  97.2      30     95.4      40    95.5      50    95.5      60    95.6      70
XS  95.1      80     95.6      90    95.7     100    95.8     110    95.8     120
XS  97.5     130     98.5     135    99.4     137   100.4     140   102.4     150
XS 104.8     156    107.0     200
****** SYNTHETIC SEC. APPR -- SURVEYED SEC. AT 865 MOVED TO 820
ST   820      25        0       0       0       1
ND     1     225
XS 104.9     -25    102.3      -5   101.5       7    97.5      12    96.6      12
XS  94.6      20     93.5      30    92.9      40    93.6      50    94.4      60
XS  95.1      70     95.6      80    95.8      90    95.8     100    95.9     110
XS  96.1     120     95.9     130    95.4     140    95.5     150    94.9     160
XS  95.7     170     97.5     175    98.5     180   101.9     187   104.9     225
****** SURVEYED SEC.  BRIDGE
ST   605      26        0       0       0       1
ND     1     196
XS 106.0      19    106.0      19   104.3      26    98.5      32    97.4      38
XS  96.0      42     93.7      52    92.9      62    92.7      72    92.6      82
XS  92.9      83     93.2      92    92.7     102    92.3     112    92.9     127
XS  92.7     137     92.6     139    93.5     147    93.9     157    93.1     167
XS  95.1     177     95.9     182   102.6     192   104.5     194   105.6     196
XS 106.0     196
***********
****** FULL VALLEY SECTION
ST   595      24        0       0       0       1
ND     1     196
XS 104.5      19    104.3      26    98.5      32    97.4      38    96.0      42
XS  93.7      52     92.9      62    92.7      72    92.6      82    92.9      83
XS  93.2      92     92.7     102    92.3     112    92.9     127    92.7     137
XS  92.6     139     93.5     147    93.9     157    93.1     167    95.1     177
XS  95.9     182    102.6     192   104.0     194   104.5     196
***********
****** SYNTHETIC SEC. EXIT -- SURVEYED SEC. AT 455 MOVED TO 430
ST   430      20        0       0       0       1
ND     1     162
XS 105.0     -50     99.4      -4    96.0       4    95.7       4    93.6      10
XS  92.4      20     91.8      30    91.1      40    92.6      50    92.1      60
XS  92.0      70     91.8      80    93.1      90    93.6     100    94.4     110
XS  94.4     120     96.0     128    99.5     140   101.0     150   102.0     162
****** SYNTHETIC SEC.  SYN3
ST     0      20        0       0       0       1
ND     1     162
XS 104.2     -50     98.6      -4    95.2       4    94.9       4    92.8      10
XS  91.6      20     91.0      30    90.3      40    91.9      50    91.3      60
XS  91.2      70     91.0      80    92.3      90    92.8     100    93.7     110
XS  93.7     120     95.2     128    98.7     140   100.2     150   101.2     162
```

```
****** SYNTHETIC SEC.  SYN2
ST -1000     20      0      0      0      1
ND     1    162
XS 102.4    -50   96.8     -4   93.4      4   93.1      4   91.0     10
XS  89.8     20   89.2     30   88.5     40   90.1     50   89.5     60
XS  89.4     70   89.2     80   90.5     90   91.0    100   91.9    110
XS  91.9    120   93.4    128   96.9    140   98.4    150   99.4    162
****** SYNTHETIC SEC.  SYN1
ST -2000     20      1      1      0      1
ND     1    162
XS 100.6    -50   95.0     -4   91.6      4   91.3      4   89.2     10
XS  88.0     20   87.4     30   86.7     40   88.3     50   87.7     60
XS  87.6     70   87.3     80   88.7     90   89.2    100   90.1    110
XS  90.1    120   91.6    128   95.1    140   96.6    150   97.6    162
*****
RE      MANNING
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
RH 0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040  0.040
```

```
RH 0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040
RH 0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040
RH 0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040
RH 0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040    0.040
CL 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
CL 0.000    0.000    0.000
CB       THALWEG
NT      1
IT     60        1      0.5        0        0
QQ       TABLE OF DISCHARGES
SS       STAGE DISCHARGE TABLE
TL     13
SQ  3000    93.52
SQ  3000    93.52
SQ  3200    93.70
SQ  3200    93.70
SQ  3500    94.01
SQ  3500    94.01
SQ  3900    94.38
SQ  3900    94.38
SQ  4200    94.65
SQ  4200    94.65
SQ  4600    95.00
SQ  4600    95.00
SQ  5200    95.58
SQ  5200    95.58
SQ  5900    96.18
SQ  5900    96.18
SQ  6500    96.68
SQ  6500    96.68
SQ  6700    96.83
SQ  6700    96.83
SQ  6600    96.75
SQ  6600    96.75
SQ  6300    96.50
SQ  6300    96.50
SQ  6100    96.33
SQ  6100    96.33
SQ  5800    96.10
SQ  5800    96.10
SQ  5600    95.93
SQ  5600    95.93
SQ  5400    95.75
SQ  5400    95.75
SQ  5200    95.58
SQ  5200    95.58
```

```
SQ  4900   95.28
SQ  4900   95.28
SQ  4700   95.10
SQ  4700   95.10
SQ  4500   94.91
SQ  4500   94.91
SQ  4300   94.75
SQ  4300   94.75
SQ  4200   94.65
SQ  4200   94.65
SQ  4000   94.47
SQ  4000   94.47
SQ  3800   94.28
SQ  3800   94.28
SQ  3700   94.20
SQ  3700   94.20
SQ  3500   94.01
SQ  3500   94.01
SQ  3400   93.90
SQ  3400   93.90
SQ  3300   93.80
SQ  3300   93.80
SQ  3200   93.70
SQ  3200   93.70
SQ  3100   93.60
SQ  3100   93.60
SO       SEDIMENT TRANSPORT REQUESTED
QS     60        0
SE      4        0
TM     60     65.0
SF      6
SG  22.5        32
SG     32       45
SG     45       64
SG     64       90
SG     90      128
SG    128      150
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
SD 0.020    0.110    0.230    0.360    0.220    0.060
```

```
SD 0.020   0.110   0.230   0.360   0.220   0.060
SD 0.020   0.110   0.230   0.360   0.220   0.060
SD 0.020   0.110   0.230   0.360   0.220   0.060
WB      8        RIO.DAT
PE      1       1
PS      8       4
PP     38       2       1
PP     83       2       1
PP    139       2       1
PP    182       2       1
PR      1      10       1      60
PV      7       0       0       0       0       0
PV      8       0       0       0       0       0
PV     10       0       0       0       0       0
PL       PLOTTING IS REQUESTED
PX       CHANNEL CROSS SECTION PLOTS           1       0       0
PW       WATER SURFACE PROFILE PLOTS           1       0       0
MN       NO MINIMIZATION IS REQUESTED
```

Separate input file (RIO.DAT) for the WSPRO bridge hydraulics routines in BRI-STARS--[AS, approach section location and data; BP, horizontal datum correction for approach section; BR, bridge section location and data; CD, bridge geometry data; PW, pier location and elevation data; T1-3, title information; XS, cross-section location and data.]

```
T1          RIO GRANDE NEAR WAGON WHEEL GAP
T2          FIXED-GEOMETRY MODE
T3          BRI-STARS INPUT FILE
*
XS   EXIT   430
*
XS   FULL   605
*
BR   BRDG   605  106.59
PW          92.6,4  95.9,4  95.9,6  97.4,6  97.4,8
CD          3  38  4.86  109.8
*
AS   APPR   820
BP          30
```

Appendix 4—Definitions of Program Variables for BRI-STARS

Variable Definitions

**	Comment lines.
CB	Type of channel-bottom-elevation computation.
CL	Local energy loss coefficients.
IT	Number of iterations and duration of time step used.
MN	Activates total stream-power minimization computations.
ND	Number of subsections in the cross section.
NS	Number of cross sections.
NT	Number of streamtubes.
PE	Local pier-scour equation used.
PL	Option to create plotting files.
PP	Location of bridge piers.
PR	Amount and interval of printing.
PS	Cross section containing piers and number of piers.
PV	Specifies onscreen plotting boundaries.
PW	Water-surface-profile plot intervals.
PX	Cross-section plot intervals.
QQ	Discharge input options.
QS	Sediment-discharge intervals.
RE	Roughness equation used in hydraulic computations.
RH	Channel roughness coefficients.
SD	Bed-material size fractions.
SE	Sediment-transport equation option.
SF	Number of sediment-size fractions.
SG	Sediment-size groups.
SO	Activates sediment-transport computations.
SQ	Discharge and stage values at different time steps.
SS	Stage input option at control sections.
ST	Cross-section data.
TL	Station number for stage-discharge pairs on SQ record.
TM	Water temperature.
TT	Title of the study.
WB	WSPRO bridge hydraulics routines option.
XS	Cross-section geometry data.

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