A P P E N D I X A

References

Adkinson, E. (1996) The Feasibility of Flushing Sediment from Reservoirs, HR Wallingford, Report OD 137, 99p

Barkau, Robert L., 1992. UNET, One-Dimensional Unsteady Flow Through a Full Network of Open Channels, Computer Program, St. Louis, MO.

Binkley, D., G.G. Ice, J. Kaye, and C.A. Williams, 2004. Nitrogen and Phosphorus Concentrations in Forest Streams of the United States. Journal of the American Water Resources Association, 40(5), 2004, pp. 1277-1291.

Briaud, Jean-Louis. (2008). "Case Histories in Soil and Rock Erosion: Woodrow Wilson Bridge, Brazos River Meander, Normandy Cliffs, and New Orleans Levees," *Journal of Geotechnical and Geoenvironmental Engineering, Vol. 134, No. 10*, Zachry Dept. of Civil Engineering, Texas A&M Univ., College Station, TX

Brownlie, W. (1983). "Flow Depth in Sand-Bed Channels." *J. Hydraul. Eng.*, 109(7), 959–990.

Brown and Barnwell, 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and Users Manual. Environmental Research Laboratory. Office of Research and Development. U.S. Environmental Protection Agency, Athens Georgia 30613.

Brunner, Gary W., August 1994. "Improved Hydraulic Features of the HEC River Analysis System," presented at the ASCE Hydraulic engineering conference, Buffalo, NY

Brunner, Gary W. and John H. Hunt, 1995. A Comparison of the One-Dimensional Bridge Hydraulic Routines from: HEC-RAS, HEC-2, and WSPRO, Research Document No. 41, Hydrologic Engineering Center, U.S. Army Corps of Engineers, September 2009, Davis, CA.

Brunner, Gary W., June 1996. "HEC-RAS (River Analysis System)," presented at the ASCE North American Water and Environmental Congress, Anaheim, CA.

Brunner, Gary W., June 1996. "Computing Bridge Scour With HEC-RAS," presented at the ASCE North American Water and Environmental Congress, Anaheim, CA.

Brunner, Gary W., Mark R. Jensen, and Steven S. Piper, 2000. Unsteady Flow Routing with the Hydrologic Engineering Center River Analysis System (HEC-RAS), Watershed Management and Operations Management, ASCE, EWRI, June 2000, Fort Collins, CO.

Brunner, Gary W. and Mark E. Forest, 2002. Unsteady Flow Routing With HEC-RAS – Truckee River, Joint Federal Interagency Conference, April 2002, Las Vegas, NV

Brunner, Gary W., 2003. Dam and Levee Breaching With HEC-RAS, World Water & Environmental Resources Congress, ASCE, EWRI, June 2003, Philadelphia, PA.

Brunner, Gary W. and Stanford S. Gibson, 2005. Sediment Transport Modeling in HEC-RAS, World Environmental & Water Resources Congress, ASCE, EWRI, May 2005, Anchorage, AL.

Brunner, Gary W. and Cameron T. Ackerman, 2012. "HEC-RAS Modeling for Operation of the Birds Point - New Madrid Floodway, Mississippi River Flood of 2011", World Environmental & Water Resources Congress, ASCE, EWRI, May 2012, Albuquerque, NM.

Brunner, Gary W., 2014. Using HEC-RAS for Dam Break Studies, Training Document No. 39, Hydrologic Engineering Center, U.S. Army Corps of Engineers, August 2014, Davis, CA.

Brunner, Gary W., Steven S. Piper, Mark R. Jensen, and Ben Chacon, 2015. Combined 1D and 2D Hydraulic Modeling within HEC-RAS, World Environmental & Water Resources Congress, ASCE, EWRI, May 2015, Austin, TX.

Bureau of Public Roads (BPR), 1965. Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular No. 5, U.S. Department of Commerce.

Bureau of Reclamation, 1977. Design of Small Dams, Water Resources Technical Publication, Washington D.C..

Bureau of Reclamation, 1998. Prediction of Embankment Dam Breach Parameters, Dam Safety Research Report DSO-98-004, Dam Safety Office, U.S. Department of the Interior.

Cantelli, A., Paola, C., and Parker, G. (2005) Experiments on upstream-migrating erosional narrowing and widening of an incisional channel caused by dam removal," WATER RESOURCES RESEARCH, VOL. 40, W03304, doi:10.1029/2003WR002940.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R. W. Howarth, A.N. Sharpley, and V.H. Smith (1998) Nonpoint Pollution of Surface Waters With Phosphorus and Nitrogen Ecological Applications, 8(3), 1998, pp. 559-568.

Copeland, R. and Lombard, L. (2009) Numerical Sedimentation Investigation Mississippi River Vicksburg to Pilots Station 94p.

Cui, Y., Parker, G., Braudrick, C., Dietrich, W., and Cluer, B. (2005) "Dam Removal Express Assessment Models (DREAM). Part 1: Model development and validation," Journal of Hydraulic Research 0(0) 1–17.

Copeland, R (1993) Numerical Modeling of Hydraulic Sorting and Armoring in Alluvial Rivers, PhD Thesis, The University of Iowa, 284 p.

Dietrich, E. W. (1982). "Settling velocity of natural particles," *Water Resources Research*, 18 (6), 1626-1982.

Echevarria, W. (2012) *Analysis of Sediment Transport following Removal of the Springville Dam*.

Federal Emergency Management Agency, 1985. Flood Insurance Study Guidelines and Specifications for Study Contractors, FEMA 37, Washington D.C., September 1985.

Federal Highway Administration, 1978. Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1, by Joseph N. Bradley, U.S. Department of Transportation, Second Edition, revised March 1978, Washington D.C..

Federal Highway Administration, 1985. Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5, U.S. Department of Transportation, September 1985, Washington D.C.

Ferguson. R.I. 1986. "River loads underestimated by rating curves," Water Resources Research, Vol. 22, No.1, pp74-76, January.

Fread, D.L., 1988 (revised 1991). BREACH: An Erosion Model For Earth Dam Failures, National Weather Service, NOAA, Silver Springs Maryland.

Fread, D.L., Ming Jin and Janice M. Lewis, 1996. An LPI Numerical Solution for Unsteady Mixed Flow Simulation, North American Water Congress, Anehiem, CA June 22-28, 1996, American Society of Civil Engineers.

FHWA, 1996. Evaluating Scour at Bridges, Federal Highway Administration, HEC No. 18, Publication No. FHWA-IP-90-017, 2nd Edition, April 1993, Washington D.C.

Froehlich, D.C., 1988. Analysis of Onsite Measurements of Scour at Piers, Proceedings of the ASCE National Hydraulic Engineering Conference, Colorado Springs, CO.

Froehlich, D.C., 1989. Local Scour at Bridge Abutments, Proceedings of the 1989 National Conference on Hydraulic Engineering, ASCE, New Orleans, LA, pp. 13-18.

Froehlich, D.C., 1995. Embankment Dam Breach Parameters Revisited, Water Resources Engineering, Proceedings of the 1995 ASCE Conference on Water Resources Engineering, San Antonio, Texas, August 14-18, 1995.

Garbrecht, J. and Gary W. Brunner, "Hydrologic Channel-Flow Routing for Compound Sections," ASCE Journal of Hydraulic Engineering, Vol. 117, No. 5, May 1991.

Gibson, S. (2010) *Simulating Hydraulic Conductivity Evolution Due to Sediment Dynamics in the Russian River.* U. S. Army Corps of Engineers - Hydrologic Engineering Center, 93p.

Gibson, S., Pak, J., & Fleming, M. (2010). Modeling watershed and riverine sediment processes with HEC-HMS and HEC-RAS. *EWRI Watershed Management 2010: Innovations in Watershed Management*, 1340-1349.

Gibson, S. and Boyd, P. (2014) "Modeling Long Term Alternatives for Sustainable Sediment Management Using Operational Sediment Transport Rules," *Reservoir Sedimentation* –Scheiss et al. (eds), 229-236.

Gibson, S., Simon, A., Langendoen, E., Bankhead, N., and Shelley, J. (2015) "A Physically-Based Channel-Modeling Framework Integrating HEC-RAS Sediment Transport Capabilities and the USDA-ARS Bank-Stability and Toe-Erosion Model (BSTEM)," Federal Interagency Sediment Conference, SedHyd Proceedings.

Gibson, S. and Pridal, D. (2015) "Negotiating Hydrologic Uncertainty in Long Term Reservoir Sediment Models: Simulating Arghandab Reservoir Deposition with HEC-RAS," Federal Interagency Sediment Conference, SedHyd Proceedings.

Hem, John D. (1985) Study and Interpretation of the Chemical Characteristics of Natural Water. Third Edition. U.s. Geological Survey Water-Supply Paper 2254.

Hunt, John, Gary W. Brunner, and Bruce E. Larock. "Flow Transitions in Bridge Backwater Analysis," ASCE Journal of Hydraulic Engineering, Vol. 125 No. 9, September 1999.

Hydrologic Engineering Center, 1991. HEC-2, Water Surface Profiles, User's Manual, U.S. Army Corps of Engineers, Davis CA.

Hydrologic Engineering Center, 1993. UNET, One-Dimensional Unsteady Flow Through a Full Network of Open Channels, User's Manual, U.S. Army Corps of Engineers, Davis, CA.

Hydrologic Engineering Center, 1994. HECDSS, User's Guide and Utility Programs Manual, U.S. Army Corps of Engineers, Davis CA.

Hydrologic Engineering Center, 1995. RD-41, A Comparison of the One-Dimensional Bridge Hydraulic Routines from: HEC-RAS, HEC-2, and WSPRO, U.S. Army Corps of Engineers, Davis CA., September 1995

Hydrologic Engineering Center, 1995. RD-42, Flow Transitions in Bridge Backwater Analysis, U.S. Army Corps of Engineers, Davis CA., September 1995

Johnson, Billy, and T. Gerald, 2006. Development of a Distributed nutrient Sub-Model (NSM Version 1.0) for Watersheds – Kinetic Process Descriptions. Environmental Laboratory. U.S. Army Engineer Research and Development Center. Vicksburg, MS. 39180. ERDC/EL TR-06-X September 2006

Laursen, E.M., 1960. Scour at Bridge Crossings, ASCE Journal of Hydraulic Engineering, Vol. 89, No. HY 3.

Laursen, E.M., 1963. An Analysis of Relief Bridges, ASCE Journal of Hydraulic Engineering, Vol. 92, No. HY 3.

Leonard, B. P., 1991. The ULTIMATE Conservative Difference Scheme Applied to Unsteady One-Dimensional Advection, Computer Methods in Applied Mechanics and Engineering, vol 88, pp 17-74.

Leonard, B.P., 1979. A Stable and Accurate convective Modelling Procedure Based on Quadratic Upstream Interpolation, Computer Methods in Applied Mechanics and Engineering, vol 19, pp 59-98.

Little, C. and Biedenharn, D. (2014) Mississippi River Hydrodynamic and Delta Management Stuey (MRHDM) – Geomorphic Assement, ERDC/CHL TR 14-5, 309p.

Martin, J.L., and S. C. McCutcheon, 1999. Hydrodynamics and Transport for Water Quality Modeling. CRC Press, Boca Raton, Florida.

McDonald, Thomas C. and Jennifer Langridge-Monopolis, 1984. Breaching Characteristics of Dam Failures, Journal of Hydraulic Engineering, vol. 110, No. 5, pp 567-586.

Meybek, Michel, 1982. Carbon, Nitrogen, and Phosphorus Transport by World Rivers. American Journal of Science, Vol. 282, April, 1982, P. 401-450.

Microsoft Corporation, 2007. Microsoft Windows Vista, User's Manual, Redmond WA.

Morris, G., Annandale, G., and Hotchkiss, R. (2008) "Reservoir Sedimentation," *Sedimentation Engineering: Processes, Measurements, Modeling, and Practices*, ASCE Manuals and Reports on Engineering Practice No. 110, 579-612.

Parker, G. (2008) "Transport of Gravel and Sediment Mixtures," *Sedimentation Engineering: Processes, Measurements, Modeling, and Practices*, ASCE Manuals and Reports on Engineering Practice No. 110, 165-252.

Richardson, E.V., D.B. Simons and P. Julien, 1990. Highways in the River Environment, FHWA-HI-90-016, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Shelley, J. and Gibson, S. (2015) "Modeling Bed Degradation of a Large, Sand-Bed River with In-Channel Mining with HEC-RAS," Federal Interagency Sediment Conference, SedHyd Proceedings.

Thomas, W. and Chang, H. (2008) "Computational Modeling of Sediment Processes," *Sedimentation Engineering: Processes, Measurements, Modeling, and Practices*, ASCE Manuals and Reports on Engineering Practice No. 110, 649-682.

U.S. Army Corps of Engineers, 1965. Hydraulic Design of Spillways, EM 1110-2-1603, Plate 33.

van Rijn, L. (1984). "Sediment Transport, Part III: Bed forms and Alluvial Roughness." J. Hydraul. Eng., 110(12), 1733–1754.

Wong, M. and Parker, G. (2006). "Reanalysis and Correction of Bed-Load Relation of Meyer-Peter and Müller Using Their Own Database." J. Hydraul. Eng., 132(11), 1159–1168.

Wunderlich, W.O. 1972. Heat and mass transfer between a water surface and the atmosphere, TN Report 14, Tennessee Valley Authority Water Resources Research Engineering Laboratory, Norris, TN.

APPENDIX B

HEC-RAS Data Exchange

At Version 2.0, HEC-RAS introduced a geospatial component to the geometry for the description of river networks and cross sections. This capability makes it possible to import channel geometry from CADD or GIS programs though automated data extraction procedures. Similarly, water surface elevations and other HEC-RAS results can be exported to CADD and GIS where they can be used to created model water surfaces for inundation mapping.

The spatial data the HEC-RAS can import and export are evolving - each new version of the software results in additional capabilities. HEC-RAS Version 3.1.3 will import and export data using in a spatial data format in an ASCII text file.

Data import options include:

- The structure of the river network, as represented by a series of interconnected reaches.
- The location and geometric description of cross sections for elevation data, bank positions, downstream reach lengths, Manning's *n* values data, levee positions and elevations (limited to one per bank), ineffective flow area positions and elevations.
- Bridge deck information for top-of-weir profile, deck width, and distance to the upstream cross section.
- Lateral and inline structure information top-of-weir profile, deck width, and distance to the upstream cross section for inline structures.
- Storage area elevation-volume information.

Data export options include:

- Cross section locations and elevation data.
- Water surface elevations at each cross section.
- Bounding polygon information for each water surface profile.
- Cross-sectional properties.

Spatial Data Format

HEC-RAS Version 3.1.3 will import and export data using a formatted ASCII text file. In general, the spatial data format consists of records, keywords and values. This section provides the general rules for constructing the and HEC-RAS import and export file.

This file format is evolving in that additional data types will be added and existing one may be modified for future versions. If you are writing software to read and write to the HEC-RAS spatial data

format, keep in mind that you may need to modify your software to remain compatible with future versions of HEC-RAS.

Records

The spatial data format is composed of records, which are composed of keywords and values. All records must begin with a keyword. A record can also contain a value or a set of values following the keyword. Spaces, tabs, or line ends can be used as delimiters within a record.

A record that contains a keyword and no value marks the beginning or end of a group of related records. For example, the record "BEGIN HEADER:" MARKS the beginning of the header section of the file. A record that contains a keyword and a value assigns that value to the part of the model being named by the keyword.

Keywords

Keywords are used to identify that values unique to the part of the model being named by the keyword will follow. Keywords must end with a colon separating the keyword and the values. All keywords will have the spaces removed up to the colon and the letters capitalized. The keywords "Begin Header:", "Begin header:", and "Be GiNH eadEr:" are all equivalent. For readability, keywords named in this document will contain internal spaces.

Values

A record can assign a single value to a single variable or multiple values in an array. Values can be integers, floating point numbers, text strings, or locations (X, Y, Z, label). A single value in an array of values is called an "element" of that array.

A **numerical value** cannot contain internal blanks. A floating point number can contain a decimal point; an integer cannot. Elements in an array can be separated by commas, blanks, tabs, or line ends.

A **text string** can contain internal blanks, tabs, and commas, but cannot contain internal line ends.

A **location** consists of three coordinate values and a label (X, Y, Z, label). The first two coordinates are planar and the third is elevation. The coordinate values are floating point numbers and the label can by any type of value. In certain contexts, the elevation value or the label may not be required. If a label is used, all three coordinate values must be given; the value of "NULL" is valid for the elevation coordinate only. The coordinate values and the label can be separated by commas, blanks, or tabs, but a location cannot contain internal line ends.

Data Groups

Records in the data file can be collected in two types of groups: objects and file sections. An object is a group of records that combine to describe an entity within the model – a cross section, for example. A file section is a logical or functional grouping of data. The file header, for example, is a section that contains a description of the entire file.

Objects and file sections begin and end with records that contain keywords but no values. A file section stats with a record containing the a keyword composed of the word "BEGIN" followed by the section name and a colon and ends with a keyword composed of the word "END" followed by the section name and a colon. For example, records containing only the keywords "BEGIN HEADER:" and "END HEADER:" are used to start and end the header section of a file. An object starts with a record containing a keyword naming an object type and "END:" only. For example, a cross-section object begins and ends with records containing the keywords "CROSS-SECTION:" and "END:" only.

Comments

Hash characters (#) are used to identify comments. When a hash character is encountered in the file all data from the hash to the next line end is ignored. A line that begins with a hash is equivalent to a blank line.

RAS GIS Import File (RASImport.sdf)

HEC-RAS reads channel geometry from a text file composed of several sections. A discussion of the sections in the import file is provided. And example RAS GIS import File is provided at the end of this appendix.

Header

The header is bounded by the records "BEGIN HEADER:" and "END HEADER:" and should contain a record to identify the units system used in the imported data set. The units system can be "US CUSTOMARY" or "METRIC". A summary of record that may be used in the Header section are provided in Table B-1.

Table B-1. Header options for the spatial data file.

Keyword	Value Type	Value
UNITS:	String	US CUSTOMARY or METRIC
DTM TYPE:	String	Type of terrain model (TIN or GRID)
DTM:	String	Name of terrain model
STREAM LAYER:	String	Name of Stream Centerline layer used in the CADD or GIS.
NUMBER OF REACHES:	Integer	Number of hydraulic reaches in the SDF file.
CROSS-SECTION LAYER:	String	Name of the Cross-Sectional Cut Lines layer used in the CADD or GIS.
NUMBER OF CROSS-SECTIONS:	Integer	Number of cross sections in the SDF file.
MAP PROJECTION:	String	Projection (coordinate) system used (e.g. Stateplane)
PROJECTION ZONE:	String	Projection zone (if applicable, e.g. 5101)
DATUM:	String	Reference datum for planar coordinates.
VERTICAL DATUM:	String	Reference datum for vertical coordinates.
BEGIN SPATIAL EXTENT:	None	None. Begin of Spatial Extents object.
Xmin:	Float	Minimum easting of geospatial data.
Ymin:	Float	Minimum northing of geospatial data.
Xmax:	Float	Maximum easting of geospatial data.
Ymax:	Float	Maximum northing of geospatial data.
END SPATIAL EXTENT:	None	None. End of Spatial Extents object.
NUMBER OF PROFILES:	Integer	Number of profile exported from HEC-RAS. RAS GIS Export File only.
PROFILE NAMES:	String array	Water surface profile names exported from HEC-RAS. RAS GIS Export File only.

River Network

The river network section is bounded by the records "BEGIN STREAM NETWORK:" and "END STREAM NETWORK:" and contains records describing reaches and reach endpoints. At a minimum, the stream network section must contain at least two endpoints and one reach.

A reach endpoint is represented by a record containing the keyword "ENDPOINT:" followed by four comma-delimited values containing the endpoint's X, Y, Z coordinates and an integer ID.

A reach consists of a multi-record object that begins with a record containing only the keyword "REACH:" and ends with a record only containing the keyword "END:". At a minimum, a reach object must contain records setting values for a Stream ID, a Reach ID, a FROM point, and a TO point. A reach's FROM and TO point IDs must match IDs for endpoints listed before the reach object in the file. The reach object must also contain an array of locations defining the stream centerline. This array begins with a record containing only the keyword "CENTERLINE:" and ends when any keyword is encountered. A location element in the array contains the X, Y, and Z coordinates of a point on the stream centerline, and the point's river station. In HEC-RAS, elevation and stationing are optional in the stream network definition. If a location element includes a station value, it must occupy the fourth field in the element. If the elevation is not known, the word "NULL" must take its place.

Stationing is used for indexing locations along reaches, and is not used to precisely locate objects in the model. A summary of record that may be used in the River Network section are provided in Table B-2.

Table B-2. River network options for the spatial data file.

Keyword	Value Type	Value
ENDPOINT:	Location	X, Y, Z coordinates and integer ID.
REACH:	None	Marks beginning of Reach object.
END:	None	Marks end of Reach object.
The following records are required for a Reach object.		
STREAM ID:	String	River identifier to include reach.
REACH ID:	String	Unique ID for reach within river.
FROM POINT:	String	Integer reference to upstream endpoint.
TO POINT:	String	Integer reference to downstream endpoint.
CENTERLINE:	Location array	Array elements contain coordinates and station values.

Cross Sections

The cross-sectional data section begins with a record containing the only the keyword "BEGIN CROSS-SECTIONS:" and ends with a record containing the only the keyword "END CROSS-SECTIONS:". A cross section is represented by multi-record object beginning with a record containing only the keyword

"CROSS-SECTION:" and ending with a record containing only the keyword "END:."

A cross-sectional object must include records identifying the Stream ID, Reach ID, and Station value of the cross-section, a 2D cut line, and a series of 3D locations on the cross section. Stationing is given in miles for data sets with plane units of feet and in kilometers for data sets with plane units of meters. A cut line is composed of the label "CUT LINE:" followed by an array of 2D locations. A cross-sectional polyline consists of the label "SURFACE LINE:" plus 3D coordinates written as comma-delimited X, Y, Z real-number triples, one triple to a line. A summary of record that may be used in the River Network section are provided in Table B-3.

Table B-3. Cross-sectional data section options for the spatial data format.

Keyword	Value Type	Value
CROSS-SECTION:	None	Marks beginning of Cross Section object.
END:	None	Marks end of a Cross Section object.
The following records are required for a Cross Section object.		
STREAM ID:	String	Identifier for the River on which the cross section resides.
REACH ID:	String	Identifier for the Reach on which the cross section resides.
STATION:	Float	Relative position of the cross section on the river reach.
CUT LINE:	Location array	Array elements contain planar coordinates of cross section strike line.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of cross section.
The following records are optional for a Cross Section object.		
NODE NAME:	String	Description of cross section.
BANK POSITIONS:	Float	Fraction of length along cut line where main channel bank stations are located. (*Left, Right*)
REACH LENGTHS:	Float	Distance along left overbank, main channel and right overbank flow paths to next cross section downstream. (*Left, Channel, Right*)
N VALUES:	Float	Manning's n values expressed as a fraction along cut line to start of *n* value. (*fraction, n value*)

Keyword	Value Type	Value
LEVEE POSITIONS:	String, Float	Levee positions expressed as a fraction along cut line to position with elevation. (ID, *fraction*, *elevation*)
INEFFECTIVE POSITIONS:	String, Float	Ineffective flow areas expressed as a fraction along cut line to beginning and end positions with trigger elevation. (ID, *begin fraction*, *end fraction*, *elevation*)
BLOCKED POSTITIONS:	Float	Blocked flow areas expressed as a fraction along cut line to beginning and end positions with trigger elevation. (ID, *begin fraction*, *end fraction*, *elevation*)
WATER ELEVATION:	String array	Water surface profile names exported from HEC-RAS. RAS GIS Export File only.

Additional Cross Section Properties

Geospatial data used for display purposes in HEC-RAS for levees, ineffective flow areas, are blocked obstructions are stored outside of the Cross Section block of information. A summary of additional cross section properties is summarized in Table B-4.

Table B-4. Addition cross section properties options for the spatial data file.

Keyword	Value Type	Value
Levee records		
BEGIN LEVEES:	None	Marks beginning of Levees object.
LEVEE ID:	String	Levee identifier. Corresponds to ID in LEVEE POSITIONS object on cross section.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of levee profile points. Array concludes with END:
END LEVEES:	None	Marks end of Levees object.
Ineffective flow area records		
BEGIN INEFFECTIVE AREAS:	None	Marks beginning of Ineffective Areas object.
INEFFECTIVE ID:	String	Ineffective area identifier. Corresponds to ID in INEFFECTIVE POSITIONS object on cross section. Concludes with an "END:".
POLYGON:	Location array	Array elements contain 2D coordinates of ineffective area polygon points.
END INEFFECTIVE AREAS:	None	Marks end of Ineffective Areas object.
Blocked obstruction records		
BEGIN BLOCKED AREAS:	None	Marks beginning Blocked Obstructions object.
BLOCKED ID:	String	Blocked obstructions identifier. Corresponds to ID in BLOCKED POSITIONS object on cross section.
POLYGON:	Location array	Array elements contain 2D coordinates of ineffective area polygon points.
END BLOCKED AREAS:	None	Marks end of Blocked Obstructions object.

Bridge/Culverts

The bridge/culvert data section begins with a record containing the only the keyword "BEGIN BRIDGE/CULVERTS:" and ends with a record containing the only the keyword "END BRIDGE/CULVERTS:". A bridge is represented by multi-record object beginning with a record containing only the keyword "BRIDGE/CULVERT:" and ending with a record containing only the keyword "END:."

Bridges/Culverts have the same required records as the Cross Sections object, but have other optional records. A summary of Bridge/Culvert records is provided in Table B-5.

Table B-5. Bridge/Culvert options in the spatial data format file.

Keyword	Value Type	Value
BRIDGE/CULVERT:	None	Marks beginning of Bridge/Culvert object.
END:	None	Marks end of a Bridge/Culvert object.
The following records are required for a Briodge/Culvert object.		
STREAM ID:	String	Identifier for the River on which the bridge/culvert resides.
REACH ID:	String	Identifier for the Reach on which the bridge/culvert resides.
STATION:	Float	Relative position of the bridge on the river reach.
CUT LINE:	Location array	Array elements contain planar coordinates of bridge location.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of bridge deck.
The following records are optional (but recommend) for a Bridge/Culvert object.		
NODE NAME:	String	Description of cross section.
US DISTANCE:	Float	Distance to upstream cross section.
TOP WIDTH:	Float	Top width of bridge deck.

Inline Structures

The inline structures data section begins with a record containing the only the keyword "BEGIN INLINE STRUCTURES:" and ends with a record containing the only the keyword "END INLINE STRUCTURES:". An inline structure is represented by multi-record object beginning with a record containing only

the keyword "INLINE STRUCTURES:" and ending with a record containing only the keyword "END:."

Inline structures have the same required records as the Bridge/Culvert object. A summary of Inline Structures records is provided in Table B-6.

Table B-6. Inline structure options in the spatial data format file.

Keyword	Value Type	Value
INLINE STRUCTURES:	None	Marks beginning of Inline Structure object.
END:	None	Marks end of a Inline Structure object.
The following records are required for a Inline Structure object.		
STREAM ID:	String	Identifier for the River on which the inline structure resides.
REACH ID:	String	Identifier for the Reach on which the inline structure resides.
STATION:	Float	Relative position of the inline structure on the river reach.
CUT LINE:	Location array	Array elements contain planar coordinates of inline structure location.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of inline weir profile.
The following records are optional (but recommend) for an Inline Structure object.		
NODE NAME:	String	Description of inline structure.
US DISTANCE:	Float	Distance to upstream cross section.
TOP WIDTH:	Float	Top width of inline weir.

Lateral Structures

The inline structures data section begins with a record containing the only the keyword "BEGIN LATERAL STRUCTURES:" and ends with a record containing the only the keyword "END INLINE STRUCTURES:". A lateral structure is represented by multi-record object beginning with a record containing only the keyword "LATERAL STRUCTURES:" and ending with a record containing only the keyword "END:."

Lateral structures have the same required records as the inline structures object. A summary of Lateral Structures records is provided in Table B-7.

Table B-7. Lateral structure options in the spatial data format file.

Keyword	Value Type	Value
LATERAL STRUCTURES:	None	Marks beginning of Lateral Structures object.
END:	None	Marks end of Lateral Structures object.
The following records are required for a Lateral Structure object.		
STREAM ID:	String	Identifier for the River on which the lateral structure resides.
REACH ID:	String	Identifier for the Reach on which the lateral structure resides.
STATION:	Float	Relative position of the lateral structure on the river reach.
CUT LINE:	Location array	Array elements contain planar coordinates of lateral structure location.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of weir profile.
The following records are optional (but recommend) for a Lateral Structure object.		
NODE NAME:	String	Description of lateral structure.
US DISTANCE:	Float	Distance to upstream cross section.
TOP WIDTH:	Float	Top width of weir.

Storage Areas

The storage areas data section begins with a record containing the only the keyword "BEGIN STORAGE AREAS:" and ends with a record containing the only the keyword "END STORAGE STRUCTURES:". The keyword "SA ID:" identifies a storage area object. A summary of Lateral Structures records is provided in

Table B-8.

Table B-8. Storage area options in the spatial data format file.

Keyword	Value Type	Value
SA ID:	String	Storage area identifier.
POLYGON:	Location array	Array elements contain 2D coordinates of storage area boundary. Concludes with an "END:"
ELEVATION-VOLUME:	Float array	Elevation volume information for storage area. (*Elevation, Volume*) Concludes with an "END:"
The following records are optional for a Storage Area object.		
TERRAIN:	Float array	X,Y,Z coordinates for terrain data within storage area. Concludes with an "END:".

Storage Area Connections

The storage areas data section begins with a record containing the only the keyword "BEGIN SA CONNECTIONS:" and ends with a record containing the only the keyword "END SA CONNECTIONS:". An inline structure is represented by multi-record object beginning with a record containing only the keyword "SA CONNECTION:" and ending with a record containing only the keyword "END:." A summary of Storage Area Connection records is provided in Table B-9.

Table B-9. Storage area connection options in the spatial data format file.

Keyword	Value Type	Value
SACONNID:	String	Storage area connection identifier.
USSA:	String	Identifier of upstream storage area (SA ID).
DSSA:	String	Identifier of downstream storage area (SA ID).
CUT LINE:	Location array	Array elements contain planar coordinates of storage area connection location.
SURFACE LINE:	Location array	Array elements contain 3D coordinates of weir profile.
The following records are optional for a Storage Area Connection object.		
NODE NAME:	String	Description of storage area connection.
TOP WIDTH:	Float	Top width of weir.

RAS GIS Export File (RASExport.sdf)

HEC-RAS exports model results to a text file using the same spatial data format as the data import file. The contents of the file, however, are not identical. An example HEC-RAS model export file is shown at the end of this appendix. A summary of model elements for data export from HEC-RAS that differs from the import file is provided in Table B-10.

Table B-10. HEC-RAS export options in the spatial data format file

Keyword	Value Type	Value
The following records are required for Header section of the RAS GIS Export File		
NUMBER OF PROFILES:	Integer	Number of profile exported from HEC-RAS. Required if greater than 1.
PROFILE NAMES:	String array	Water surface profile names exported from HEC-RAS. Required if number of profiles is greater than 1.
The following records area required in the Cross Section portion of the Export File		
WATER ELEVATION:	Float array	Elevation of water surface at the cross section. The array must contain a value for each profile.
PROFILE ID:	String array	Water surface profile name(s). This must match the name(s) in the Profile Names record.
The following records area optional in the Cross Section portion of the Export File		
VELOCITIES:	Float, paired array	Fraction along cut line and value of velocity (*fraction*, *value*). Velocity records must follow Profile ID record.
WATER SURFACE EXTENTS:	Location array	A series of 2D locations marking the limits of a water surface on the cross section.
The following records make up a section defining Storage Areas in the Export File		
BEGIN STORAGE AREAS:	None	Marks beginning of Storage Area object.
END STORAGE AREAS:	None	Marks end Storage Area object.
SA ID:	String	Storage area identifier.
WATER ELEVATION:	Float array	Elevation of water surface at the storage area. The array must contain a value for each profile.
POLYGON:	Location array	Array elements contain 2D coordinates of storage area limits.

Keyword	Value Type	Value
The following records make up a section defining Bounding Polygons for the water surface limits in the Export File		
BEGIN BOUNDARIES:	None	Marks start of boundaries section.
END BOUNDARIES:	None	Marks end of boundaries section.
PROFILE LIMITS:	None	Marks start of an object defining the limits of a single water surface profile. Concludes with and "END:"
PROFILE ID:	String	Name of the profile. This must match a name in the Profile Names record in the header.
POLYGON:	Location array	Array elements contain 2D coordinates of water surface limits. A single profile limit can be merged from multiple polygons.

Water Surface Bounding Polygon

In addition to a water surface elevation at each cross section (one for each profile), the HEC-RAS program sends a bounding polygon for each hydraulic reach in the model (the program outputs a new set of bounding polygons for each profile computed). The bounding polygon is used as an additional tool to assist the GIS (or CADD) software to figure out the boundary of the water surface on top of the terrain.

In most cases, the bounding polygon will represent the outer limits of the cross section data, and the actual intersection of the water surface with the terrain will be inside of the polygon. In this case, the GIS software will use the water surface elevations at each cross section and create a surface that extends out to the edges of the bounding polygon. That surface is then intersected with the terrain data, and the actual water limits are found as the location where the water depth is zero.

However, is some cases, the bounding polygon may not represent the extents of the cross-section data. For example, if there are levees represented in the HEC-RAS model, which limit the flow of water, then the bounding polygon will only extend out to the levees at each cross section. By doing this, when the information is sent to the GIS, the bounding polygon will prevent the GIS system from allowing water to show up on both sides of the levees.

In addition to levees, the bounding polygon is also used at hydraulic structures such as bridges, culverts, weirs, and spillways. For example, if all of the flow is going under a bridge, the bounding polygon is brought into the edges of the bridge opening along the road embankment on the upstream side, and then back out to the extent of the cross-section data on the downstream side. By doing this, the GIS will be able to show the contraction and expansion of the flow through the hydraulic structures, even if the hydraulic structures are not geometrically represented in the GIS.

Another application of the bounding polygon is in FEMA floodway studies. When a floodway study is done, the first profile represents the existing conditions of the floodplain. The second and subsequent profiles are run by encroaching on the floodplain until some target increase in water surface elevation is met. When the encroached profile is sent to the GIS, the bounding polygon is set to the limits of the encroachment for each cross section. This will allow the GIS to display the encroached water surface (floodway) over the terrain, even though the water surface does not intersect the ground.

Import/Export Guidelines

The following rules apply to channel and cross-section import/export data.

Defining the River Network

- The stream network is represented by a set of interconnected reaches. A stream is a set of one or more connected reaches that share a common Stream ID.
- A stream is composed of one or more reaches with the same Stream ID, and each reach in a stream must have a unique Reach ID. Every reach must be identified by a unique combination of stream and reach IDs.
- Stream IDs and Reach IDs are alphanumeric strings. Reach endpoint IDs are integers.
- Streams cannot contain parallel flow paths. (If three reaches connect at a node, only two can have the same Stream ID.) This prevents ambiguity in stationing along a stream.
- A reach is represented by an ordered series of 3D coordinates, and identified by a Stream ID, a Reach ID, and IDs for its endpoints.
- A reach endpoint is represented by its 3D coordinates and identified by an integer ID.
- Reaches are not allowed to cross, but can be connected at their endpoints (junctions) to form a network.
- The normal direction of flow on a reach is indicated by the order of its endpoints. One point marks the upstream or "from" end of the reach, the other marks the downstream or "to" end of the reach.

Defining Cross Sections

- Each cross section is defined by a series of 3D coordinates, and identified by a stream name and reach name (which must refer to an existing stream and reach) and a station, indicating the distance from the cross-section to the downstream end of the stream.
- A cross-section line can cross a reach line exactly once, and cannot cross another cross-section line.

Results of a water surface calculation are exported in a file that contains cross-section locations in plane (2D) coordinates, water-surface elevations for the cross-sections, and boundary polygons for the reaches.

Water Surface Export Data Rules

- A cross-section is represented by a water surface elevation and a series of 2D coordinates on the cross-section cut line. The full width of the cross-section is included.
- One bounding polygon is created for each reach in the stream network, and for each profile.
- A reach's bounding polygon is made up of the most upstream cross-section on the reach, the endpoints of all cross-sections on the reach, and the most upstream cross-sections of reaches downstream of the reach.
- For purposes of defining bounding polygons *only*, the endpoints of a cross-section are adjusted to the edge of the water surface at the cross-section if the cross-section is part of a floodway, a leveed section of the reach, or the water extent is controlled by a hydraulic structure. This allows calculated water surfaces that are higher than the land surface to be reported back to the CADD or GIS program.

Sample RAS GIS Import File

```
#This file is generated by HEC-GeoRAS for ArcGIS
BEGIN HEADER:
   DTM TYPE: TIN
   DTM: C:\Examples\Baxter\baxter_tin
   STREAM LAYER: C:\Examples\Baxter\baxter.mdb\River
   NUMBER OF REACHES: 3
   CROSS-SECTION LAYER: C:\Examples\Baxter\baxter.mdb\XSCutLines
   NUMBER OF CROSS-SECTIONS: 173
   MAP PROJECTION: STATEPLANE
   PROJECTION ZONE:
   DATUM: NAD83
   VERTICAL DATUM:
   BEGIN SPATIAL EXTENT:
      XMIN: 6366478.85990533
      YMIN: 2010839.52690533
      XMAX: 6468128.45990533
      YMAX: 2112489.12690533
   END SPATIAL EXTENT:
   UNITS: FEET
END HEADER:

BEGIN STREAM NETWORK:

   ENDPOINT: 6453740, 2051685, 60, 1
   ENDPOINT: 6421541, 2051194, 34, 2
   ENDPOINT: 6387438, 2035323, 32.95776, 3
   ENDPOINT: 6426447, 2059280, 52.14808, 4

   REACH:
      STREAM ID: Baxter River
      REACH ID: Upper Reach
      FROM POINT: 1
      TO POINT: 2
      CENTERLINE:
         6453739.98997957, 2051684.77998051, 59.99999997, 89378.4140625
               --- many lines omitted ---
         6421540.44998505, 2051194.18999834, 34.00000001, 48157.06640625
   END:

   REACH:
      STREAM ID: Baxter River
      REACH ID: Lower Reach
      FROM POINT: 2
      TO POINT: 3
      CENTERLINE:
         6421540.44998505, 2051194.18999834, 34.00000001, 48157.06640625
               --- many lines omitted ---
         6387438.24001357, 2035323.14001705, 32.95775604, 0
   END:

   REACH:
      STREAM ID: Tule Creek
      REACH ID: Tributary
      FROM POINT: 4
      TO POINT: 2
      CENTERLINE:
         6426446.76000561, 2059279.84000069, 52.14807890, 12551.4970703125
               --- many lines omitted ---
         6421540.44998505, 2051194.18999834, 34.00000001, 0
   END:
```

```
END STREAM NETWORK:


BEGIN CROSS-SECTIONS:

   CROSS-SECTION:
      STREAM ID: Baxter River
      REACH ID: Upper Reach
      STATION: 84815.69
      NODE NAME:
      BANK POSITIONS: 0.5417204, 0.6313727
      REACH LENGTHS: 343.447, 815.2449, 627.6476
      NVALUES:
         0, 0.06
         0.2595427, 0.035
         0.6867172, 0.06
      LEVEE POSITIONS:
      INEFFECTIVE POSITIONS:
      BLOCKED POSITIONS:
      CUT LINE:
         6451252.61043617, 2049658.48075948
         6450473.97548097, 2050754.33739816
         6449753.01716107, 2051480.10208855
      SURFACE LINE:
         6451252.61043617, 2049658.48075948, 125.00000002
                --- many lines omitted ---
         6449753.01716107, 2051480.10208855, 110.31235503
   END:

   CROSS-SECTION:
      STREAM ID: Baxter River
      REACH ID: Upper Reach
      STATION: 77909.16
      NODE NAME:
      BANK POSITIONS: 0.4635276, 0.572924
      REACH LENGTHS: 223.1558, 229.2013, 233.3537
      NVALUES:
         0, 0.06
         0.4353712, 0.035
         0.6486487, 0.06
      LEVEE POSITIONS:
      INEFFECTIVE POSITIONS:
         354, 0, 0.3630761, 93.26781
         355, 0.6235623, 1, 105.4026
      BLOCKED POSITIONS:
         379, 0.37786, 0.9548786, 79.19141
      CUT LINE:
         6446531.40685930, 2048445.67038340
         6446341.91498890, 2048655.03933954
         6446207.54346581, 2049102.94440073
         6446140.35770426, 2049409.01289628
         6446028.38145080, 2049909.17358660
         6445838.02350501, 2050713.98307530
      SURFACE LINE:
         6446531.40685930, 2048445.67038340, 93.26781466
                --- many lines omitted ---
         6445838.02350501, 2050713.98307530, 105.40263370
   END:

   --- many Cross Sections omitted ---
   CROSS-SECTION:
      STREAM ID: Baxter River
```

```
        REACH ID: Lower Reach
        STATION: 34251.78
        NODE NAME:
        BANK POSITIONS: 0.2088515, 0.2746628
        REACH LENGTHS: 678.4368, 652.6373, 592.5861
        NVALUES:
           0, 0.06
           0.2023585, 0.035
           0.5760272, 0.05
        LEVEE POSITIONS:
           380, 0.5949767, 72.00802
        INEFFECTIVE POSITIONS:
        BLOCKED POSITIONS:
        CUT LINE:
           6412787.19596798, 2042663.48848210
           6412627.43755387, 2043633.45026854
           6412056.87180271, 2047399.18430193
        SURFACE LINE:
           6412787.19596798, 2042663.48848210, 80.15862274
                  --- many lines omitted ---
           6412056.87180271, 2047399.18430193, 77.57256318
     END:

  END CROSS-SECTIONS:


  BEGIN BRIDGES/CULVERTS:

     BRIDGE/CULVERT:
        STREAM ID: Tule Creek
        REACH ID: Tributary
        STATION: 4514.028
        NODE NAME: Yosemite Street
        US DISTANCE: 100
        TOP WIDTH: 96
        CUT LINE:
           6422221.24109452, 2055203.79594125
           6421766.89378999, 2055127.22052519
           6421302.33643314, 2054958.75468559
           6421128.76554372, 2054912.80947382
           6420924.56454467, 2054892.38936919
        SURFACE LINE:
           6422221.24109452, 2055203.79594125, 88.73309329
                  --- many lines omitted ---
              6420924.56454467, 2054892.38936919, 83.88871764
     END:

     --- many Bridges/Culverts omitted ---
  END BRIDGES/CULVERTS:


  BEGIN LEVEES:

     LEVEE ID: 380
        SURFACE LINE:
                  6416224.46794023, 2048201.03890064, 80.30300144
                  --- many lines omitted ---
                  6408127.91921907, 2047348.05802148, 73.83999635
     END:

  END LEVEES:

  BEGIN INEFFECTIVE AREAS:
```

```
   INEFFECTIVE ID: 354
      POLYGON:
         6446126.65267778, 2049275.06766575
         6446347.63945516, 2049062.58037434
         6446466.63230616, 2048960.58649530
               --- many lines omitted ---
         6446126.65267778, 2049275.06766575
   END:

   INEFFECTIVE ID: 355
      POLYGON:
         6446009.40721919, 2049877.88188569
         6445816.78229256, 2050758.82118551
               --- many lines omitted ---
         6446009.40721919, 2049877.88188569
   END:

   --- many Ineffective Areas omitted ---
END INEFFECTIVE AREAS:


BEGIN BLOCKED OBSTRUCTIONS:

   BLOCKED ID: 379
      POLYGON:
         6422107.09773554, 2052558.24567028
         6423542.24950153, 2052503.04750541
         6422076.43212521, 2052184.12491178
         6422107.09773554, 2052558.24567028
   END:

END BLOCKED OBSTRUCTIONS:


BEGIN LATERAL STRUCTURES:

   LATERAL STRUCTURE:
         STREAM ID: Baxter River
         REACH ID: Lower Reach
         STATION: 27469.68
         NODE NAME: North LS
         US DISTANCE: 0
         TOP WIDTH: 20
         CUT LINE:
               6407389.53497197, 2047168.40301990
               6406371.11447597, 2046886.24321303
                     --- many lines omitted ---
               6402363.56369299, 2045153.60574580
         SURFACE LINE:
               6407389.53497197, 2047168.40301990, 69.83999637
                     --- many lines omitted ---
               6402363.56369299, 2045153.60574580, 65.27986148
   END:

END LATERAL STRUCTURES:




   BEGIN STORAGE AREAS:
```

```
        SA ID: 369
        POLYGON:
              6402631.96981374, 2045430.51958869
                    --- many lines omitted ---
              6402631.96981374, 2045430.51958869
        END:
        ELEVATION-VOLUME:
              63.34, 0
              64.59, 272682.8
              65.84, 2102153
              67.09, 1.130536E+07
              68.34, 2.241535E+07
              69.59, 3.505853E+07
              70.84, 4.921408E+07
              72.09, 6.477892E+07
              73.34, 8.095226E+07
              74.59, 9.734569E+07
              75.84, 1.142249E+08
        END:
        TERRAIN:
        END:

END STORAGE AREAS:

BEGIN SA CONNECTIONS:

    SA CONNECTION:
        SACONN ID: 444
        NODE NAME:
        US SA:  369
        DS SA:  371
        TOP WIDTH: 20
        CUT LINE:
              6407389.53497197, 2047168.40301990
              6406371.11447597, 2046886.24321303
                    --- many lines omitted ---
              6402363.56369299, 2045153.60574580
        SURFACE LINE:
              6407389.53497197, 2047168.40301990, 69.83999637
                    --- many lines omitted ---
              6402363.56369299, 2045153.60574580, 65.27986148

    END:

END SA CONNECTIONS:
```

Sample RAS GIS Export File

```
# RAS export file created on DAY DAYMONTHYEAR TIME
# by HEC-RAS Version 3.1.3

BEGIN HEADER:
  UNITS:
  DTM TYPE: TIN
  DTM: C:\Examples\Baxter\baxter_tin
  STREAM LAYER: C:\Examples\Baxter\baxter.mdb\River
  CROSS-SECTION LAYER: C:\Examples\Baxter\baxter.mdb\XSCutLines
  MAP PROJECTION: STATEPLANE
  PROJECTION ZONE:
  DATUM: NAD83
  VERTICAL DATUM:
  BEGIN SPATIALEXTENT:
    Xmin: 6386768.00418383
    Ymin: 2029042.52107352
    Xmax: 6454403.07894787
    Ymax: 2059837.49270508
  END SPATIALEXTENT:
  NUMBER OF PROFILES:  3
  PROFILE NAMES:
    50yr
    100yr
    500yr
  NUMBER OF REACHES:  3
  NUMBER OF CROSS-SECTIONS:  179
END HEADER:

BEGINSTREAMNETWORK:

ENDPOINT:6421540.50,2051194.25, , 1
ENDPOINT:6453739.99,2051684.78, , 2
ENDPOINT:6387438.24,2035323.14, , 3
ENDPOINT:6426446.76,2059279.84, , 4

REACH:
 STREAM ID: Baxter River
 REACH ID: Upper Reach
 FROM POINT:  2
 TO POINT:  1
 CENTERLINE:
       6453739.99,     2051684.78, ,
       6421540.45,     2051194.19, ,
END:

REACH:
 STREAM ID: Baxter River
 REACH ID: Lower Reach
 FROM POINT:  1
 TO POINT:  3
 CENTERLINE:
       6421540.45,     2051194.19, ,
       6387438.24,     2035323.14, ,
END:

REACH:
 STREAM ID: Tule Creek
 REACH ID: Tributary
 FROM POINT:  4
 TO POINT:  1
```

```
 CENTERLINE:
     6426446.76,     2059279.84, ,
     6421540.45,     2051194.19, ,
 END:

ENDSTREAMNETWORK:


BEGIN CROSS-SECTIONS:

  CROSS-SECTION:
    STREAM ID:Baxter River
    REACH ID:Upper Reach
    STATION:84815.69
    NODE NAME:
    CUT LINE:
      6451252.6104362 , 2049658.4807595
      6450473.975481 , 2050754.3373982
      6449753.0171611 , 2051480.1020886
    REACH LENGTHS:826.24,806.49,525.17
    BANK POSITIONS:0.45159,0.51309
    LEVEE POSITIONS:
             380,0.93260,79.95625
    WATER ELEVATION:70.39427,76.72782,86.74971
    WATER SURFACE EXTENTS:
      6450877.21,   2050186.83,   6450289.15,   2050940.40
      6450896.85,   2050159.18,   6450262.99,   2050966.73
      6450912.28,   2050137.47,   6450189.98,   2051040.23
    PROFILE ID:50yr
        VELOCITIES:
          0.32733,   1.558
          0.46174,   2.381
          0.55094,   3.764
          0.56925,   4.280
          0.58721,   6.164
          0.60317,   5.713
          0.62166,   3.942
          0.64436,   1.926
    PROFILE ID:100yr
        VELOCITIES:
          0.31866,   2.972
          0.45698,   3.829
          0.55086,   5.019
          0.56908,   5.459
          0.58709,   7.245
          0.60341,   6.737
          0.62189,   5.168
          0.65404,   3.202
    PROFILE ID:500yr
        VELOCITIES:
          0.31332,   4.739
          0.45464,   5.533
          0.55081,   6.526
          0.56894,   6.860
          0.58698,   8.456
          0.60365,   7.890
          0.62206,   6.635
          0.66467,   4.272
    SURFACE LINE:
     6451252.61,   2049658.48,   125.00
       --- many lines omitted ---
     449753.02,   2051480.10,   110.31
  END:
```

```
CROSS-SECTION:
    STREAM ID:Tule Creek
    REACH ID:Tributary
    STATION:1595.102
    NODE NAME:
    CUT LINE:
      6422369.1971783 , 2052943.6596315
      6421588.0439919 , 2052573.50648
          --- many lines omitted ---
      6420275.0509832 , 2052670.3666247
    WATER ELEVATION:62.67044,69.44948,78.49661
    WATER SURFACE EXTENTS:
      6421432.49,   2052554.70,   6420609.83,   2052432.00
      6421570.89,   2052571.43,   6420459.69,   2052510.35
      6422048.65,   2052791.77,   6420316.40,   2052634.53
    PROFILE ID:50yr
        VELOCITIES:
          0.47364,   0.016
          0.65126,   0.056
          0.74604,   0.171
          0.75411,   0.221
          0.76221,   0.247
          0.77030,   0.207
          0.77842,   0.151
          0.79265,   0.059
    PROFILE ID:100yr
        VELOCITIES:
          0.44844,   0.116
          0.62783,   0.185
          0.74591,   0.383
          0.75406,   0.466
          0.76221,   0.514
          0.77035,   0.444
          0.77857,   0.350
          0.81222,   0.177
          0.86985,   0.096
    PROFILE ID:500yr
        VELOCITIES:
          0.21051,   0.019
          0.42227,   0.092
          0.62301,   0.192
          0.74582,   0.350
          0.75403,   0.407
          0.76221,   0.444
          0.77039,   0.393
          0.77866,   0.327
          0.81602,   0.232
          0.88706,   0.146
          0.94874,   0.075
    SURFACE LINE:
       6422369.20,   2052943.66,   80.22
          --- many lines omitted ---
       6420275.05,   2052670.37,   85.26
  END:

END CROSS-SECTIONS:




BEGIN STORAGE AREAS:
```

```
  SA ID: 369
    WATER ELEVATION:65,65,65
  POLYGON:
      6402631.9698137  , 2045430.5195887  ,
      6402648.7543614  , 2046009.5857725  ,
            --- many lines omitted ---
      6402631.9698137  , 2045430.5195887  ,
  END:

  SA ID: 370
    WATER ELEVATION:65,65,65
  POLYGON:
      6411089.902679  , 2043584.9518455  ,
      6411100.24735  , 2041762.9675571  ,
           --- many lines omitted ---
      6411089.902679  , 2043584.9518455  ,
  END:

END STORAGE AREAS:


BEGIN BOUNDS:

  PROFILE LIMITS:
    PROFILE ID:50yr
    POLYGON:
     6449753.02,2051480.10,70.39
      --- many lines omitted ---
     6449462.09,2051308.23,70.35
    POLYGON:
     6424775.60,2059535.58,62.69
      --- many lines omitted ---
     6424246.32,2059434.43,62.69
    POLYGON:
     6420221.24,2052718.80,62.36
      --- many lines omitted ---
     6420143.38,2052744.69,62.32
  END:

  PROFILE LIMITS:
    PROFILE ID:100yr
    POLYGON:
     6449753.02,2051480.10,76.73
       --- many lines omitted ---
     6449462.09,2051308.23,76.73
    POLYGON:
     6424775.60,2059535.58,69.51
       --- many lines omitted ---
     6424246.32,2059434.43,69.52
    POLYGON:
     6420221.24,2052718.80,69.19
      --- many lines omitted ---
     6420143.38,2052744.69,69.17
  END:

  PROFILE LIMITS:
    PROFILE ID:500yr
    POLYGON:
     6449753.02,2051480.10,86.75
      --- many lines omitted ---
     6449462.09,2051308.23,86.83
    POLYGON:
     6424775.60,2059535.58,78.54
```

```
      --- many lines omitted ---
     6424246.32,2059434.43,78.54
    POLYGON:
     6420221.24,2052718.80,78.18
      --- many lines omitted ---
     6420143.38,2052744.69,78.16
  END:

END BOUNDS:
```

APPENDIX C

HEC-RAS Output Variables

Hydraulic Output Variables

Variable Name	Units	Description
# Barrels	#	Number of barrels in a culvert.
Alpha	-	Alpha - energy weighting coefficient.
Area	sq ft	Flow area of the entire cross section including ineffective flow.
Area Channel	sq ft	Flow area of the main channel including ineffective flow.
Area Left	sq ft	Flow area of the left overbank including ineffective flow.
Area Right	sq ft	Flow area of the right overbank including ineffective flow.
Base WS	ft	Water surface for first profile (used in comparison to encroachment profiles).
Beta	-	Beta - momentum weighting coefficient.
BR Open Area	sq ft	Total area of the entire bridge opening.
BR Open Vel	ft/s	Average velocity inside the bridge opening (Maximum of BU and BD).
Br Sel Mthd	-	Selected bridge hydraulic modeling method.
Breach CL	ft	Center line of weir breach.
Breach WD	ft	Bottom width of weir breach.
Breach Bottom El	ft	Bottom Elevation of weir breach.
Breach Top El	ft	Top Elevation of weir breach.
Breach SSL	ft	Left side slope of weir breach.
Breach SSR	ft	Right side slope of weir breach.
C & E Loss	ft	Contraction or expansion loss between two cross sections.
Center Station	ft	Stationing of the center of the main channel.
Ch Sta L	ft	Left station of main channel.
Ch Sta R	ft	Right station of main channel.
Clv EG No Wr	ft	Energy grade elevation at the culvert when calculated without the weir.
Coef of Q	-	WSPRO bridge method coefficient of discharge.
Conv. Chnl	cfs	Conveyance of main channel.
Conv. Left	cfs	Conveyance of left overbank.
Conv. Ratio	-	Ratio of the conveyance of the current cross section to the conveyance of the downstream cross section.
Conv. Right	cfs	Conveyance of right overbank.
Conv. Total	cfs	Conveyance of total cross section.
Crit Depth	ft	Critical depth. Corresponds to critical water surface.
Crit E.G.	ft	Critical energy elevation. Minimum energy on the energy versus depth curve.
Crit Enrgy 1	ft	Energy associated with first critical depth.

Crit Enrgy 2	ft	Energy associated with second critical depth.
Crit Enrgy 3	ft	Energy associated with third critical depth.
Crit Num	#	Number of critical depths found.
Crit W.S.	ft	Critical water surface elevation. Water surface corresponding to the minimum energy on the energy versus depth curve.
Crit W.S. 1	ft	Water surface elevation of first critical depth.
Crit W.S. 2	ft	Water surface elevation of second critical depth.
Crit W.S. 3	ft	Water surface elevation of third critical depth.
Culv Crt Depth	ft	Critical depth inside the culvert.
Culv Depth Blocked	ft	Depth of fill in a culvert.
Culv EG In	ft	Energy gradeline inside the culvert at the inlet.
Culv EG Out	ft	Energy gradeline inside the culvert at the outlet.
Culv Ent Lss	ft	Culvert entrance loss (energy loss due only to entrance).
Culv Ext Lss	ft	Culvert exit loss (energy loss due to exit).
Culv Frctn Ls	ft	Friction loss through the culvert barrel.
Culv Ful Lngh	ft	The length that the culvert flows full.
Culv Inlet Mann n		The composite n value at the culvert inlet.
Culv Inv El Dn	ft	Culvert inside invert elevation downstream.
Culv Inv El Up	ft	Culvert inside invert elevation upstream.
Culv Length	ft	Length of the culvert barrel.
Culv Nml Depth	ft	Normal depth for this culvert (and flow).
Culv Outlet Mann n		The composite n value at the culvert outlet.
Culv Q	cfs	Flow through all barrels in a culvert group.
Culv Vel DS	ft/s	Velocity inside of culvert at inlet.
Culv Vel US	ft/s	Velocity inside of culvert at outlet.
Culv WS In	ft	Water surface elevation inside the culvert at the inlet.
Culv WS Out	ft	Water surface elevation inside the culvert at the outlet.
Cum Ch Len	ft	Cumulative Channel Length.
Deck Width	ft	Width of bridge/culvert Deck (top of embankment), in direction of flow.
Delta EG	ft	Change in energy grade line through culvert(s) and bridge(s).
Delta WS	ft	Change in water surface through culvert(s) and bridge(s).
Dist Center L	ft	Distance from center of channel to left encroachment.
Dist Center R	ft	Distance from center of channel to right encroachment.
E.G. DS	ft	Energy grade elevation at downsteam end of bridge or culvert.
E.G. Elev	ft	Energy gradeline for calculated WS Elev.
E.G. IC	ft	Upstream energy gradeline at culvert based on inlet control.
E.G. OC	ft	Upstream energy gradeline at culvert based on outlet control.
E.G. Slope	ft/ft	Slope of the energy grade line.
E.G. US.	ft	Energy grade elevation at upstream end of bridge or culvert (final answer).
Enc Method	-	Encroachment method used at this cross section.
Enc Sta L	ft	Left station of encroachment.
Enc Sta R	ft	Right station of encroachment.
Enc Val 1	ft	Target for encroachment analysis.
Enc Val 2	ft	Second target for encroachment analysis.
Encr WD	ft	Top width between encroachments.
Energy EG	ft	Energy grade elevation upstream of bridge for energy only method.

Energy WS	ft	Water surface elevation upstream of bridge for energy only method.
Energy/Wr EG	ft	Energy grade elevation upstream of bridge for low energy and weir method.
Energy/Wr WS	ft	Water surface elevation upstream of bridge for low flow energy method and weir flow.
Flow Area	sq ft	Total area of cross section active flow.
Flow Area Ch	sq ft	Area of main channel active flow.
Flow Area L	sq ft	Area of left overbank active flow.
Flow Area R	sq ft	Area of right overbank active flow.
Frctn Loss	ft	Friction loss between two cross sections.
Frctn Slope	ft/ft	Representative friction slope between two cross sections.
Frctn Slp Md	-	Friction slope averaging method used.
Froude # Chl	-	Froude number for the main channel.
Froude # XS	-	Froude number for the entire cross section.
Gate #Open	#	The number of gates opened in the current group.
Gate Area	sq ft	The flow area in an opened gate.
Gate Group Q	cfs	Flow through all gate openings in a gate group.
Gate Invert	ft	Gate spillway invert elevation.
Gate Open Ht	ft	Height of gate opening.
Gate Submerg	-	Degree of gate submergence. The ratio of the downstream depth above the gate to the upstream depth above the gate.
Headloss	ft	Total energy loss between two cross sections.
Hydr Depth	ft	Hydraulic depth for cross section (Area/Topwidth of active flow).
Hydr Depth C	ft	Hydraulic depth in channel (channel flow area/topwidth of channel flow).
Hydr Depth L	ft	Hydraulic depth in left overbank (left overbank flow area/topwidth of left overbank flow).
Hydr Depth R	ft	Hydraulic depth for right over bank (right overbank flow area/topwidth of right overbank flow).
Ice Btm Chan	ft	The bottom elevation of ice in the main channel.
Ice Btm LOB	ft	The bottom elevation of ice in the left overbank.
Ice Btm ROB	ft	The bottom elevation of ice in the right overbank.
Ice Err	ft	Convergence error in ice thickness for dynamic ice jam.
Ice Thick Chan	ft	Ice thickness in the main channel.
Ice Thick LOB	ft	Ice thickness in the left overbank.
Ice Thick ROB	ft	Ice thickness in the right overbank.
Ice Top Chan	ft	The top elevation of ice in the main channel.
Ice Top LOB	ft	The top elevation of ice in the left overbank.
Ice Top ROB	ft	The top elevation of ice in the right overbank.
Ice Vol Total	cu ft	Cumulative volume of ice in an ice jam.
Ice Vol. Chan	cu ft	Cumulative volume of ice in the main channel for an ice jam.
Ice Vol. LOB	cu ft	Cumulative volume of ice in the left overbank for an ice jam.
Ice Vol. ROB	cu ft	Cumulative volume of ice in the right overbank for an ice jam.
Ice WS Err	ft	Convergence error in water surface for dynamic ice jam.
Ineff El Left	ft	The elevation of the left ineffective area.
Ineff El Right	ft	The elevation of the right ineffective area.

Inflow	cfs	Net inflow into a storage area.
Invert Slope	ft/ft	The slope from the invert of this cross section to the next cross section downstream.
IW Gate Flow	cfs	Total flow through all of the gate groups of an inline weir/spillway.
K Perc L	ft	Conveyance reduction from left encroachment.
K Perc R	ft	Conveyance reduction from right encroachment.
L. Freeboard	ft	The freeboard in the main channel at the left bank (left bank elevation minus water surface elevation).
L. Levee Frbrd	ft	The freeboard before the left levee is over-topped.
Left Sta Eff	ft	Furthest left station where there is effective flow.
Length Chnl	ft	Downstream reach length of the main channel.
Length Left	ft	Downstream reach length of the left overbank.
Length Rght	ft	Downstream reach length of the right overbank.
Length Wtd.	ft	Weighted cross section reach length, based on flow distribution, in left bank, channel, and right bank.
Levee El Left	ft	The elevation of the left levee.
Levee El Right	ft	The elevation of the right levee.
LOB Elev	ft	The ground elevation at the left bank of the main channel.
Mann Comp	-	Composite Manning's n value for main channel.
Mann Wtd Chnl		Conveyance weighted Manning's n for the main channel.
Mann Wtd Chnl		Conveyance weighted Manning's n for the left overbank.
Mann Wtd Rght		Conveyance weighted Manning's n for the right overbank.
Mann Wtd Total		Manning's n value for the total main cross section.
Max Chl Dpth	ft	Maximum main channel depth.
Min Ch El	ft	Minimum main channel elevation.
Min El	ft	Minimum overall section elevation.
Min El Prs	ft	Elevation at the bridge when pressure flow begins.
Min Error	ft	The minimum error, between the calculated and assumed water surfaces when balancing the energy equation.
Min El Weir Flow	ft	Elevation where weir flow begins.
Min Weir El	ft	Minimum elevation of a weir.
Momen. EG	ft	Energy grade elevation upstream of bridge for momentum method.
Momen. WS	ft	Water surface elevation upstream of bridge for momentum method.
Net Flux	cfs	Net inflow - outflow for a storage area.
Num Trials	#	Current number (or final number) of trials attempted before the energy equation is balanced.
Obs WS	ft	Observed water surface elevation.
Outflow	cfs	Net outflow into a storage area.
Perc Q Leaving		Percentage of flow leaving through a lateral weir.
Piping Flow	ft	Flow from piping weir failure.
Power Chan	lb/ft s	Total stream power in main channel (main channel shear stress times main channel average velocity). Used in Yang's and other sediment transport equations.
Power LOB	lb/ft s	Total stream power in left overbank (left overbank shear stress times left overbank average velocity). Used in Yang's and other sediment transport equations.

Power ROB	lb/ft s	Total stream power in right overbank (right overbank shear stress times right overbank average velocity). Used in Yang's and other sediment transport equations.
Power Total	lb/ft s	Total stream power (total cross section shear stress times total cross section average velocity). Used in Yang's and other sediment transport equations.
Prof Delta EG	ft	Difference in EG between current profile and EG for first profile.
Prof Delta WS	ft	Difference in WS between current profile and WS for first profile.
Profile	#	Profile number.
Prs O EG	ft	Energy grade elevation upstream of bridge for pressure only method.
Prs O WS	ft	Water surface elevation upstream of bridge for pressure only method.
Prs/Wr EG	ft	Energy grade elevation upstream of bridge for pressure and/or weir method.
Prs/Wr WS	ft	Water surface elevation upstream of bridge for pressure and/or weir method.
Pumping Head	ft	Pumping head for the pump station.
Q Barrel	cfs	Flow through one barrel in a culvert group.
Q Bridge	cfs	Flow through the bridge opening.
Q Channel	cfs	Flow in main channel.
Q Culv	cfs	Total flow in all culvert groups.
Q DS	cfs	Flow in cross section downstream of lateral weir.
Q Lat RC	cfs	Lateral rating curve flow.
Q Leaving Total	cfs	Total flow leaving in a lateral weir including all gates.
Q Left	cfs	Flow in left overbank.
Q Perc Chan	ft	Percent of flow in main overbank.
Q Perc L	ft	Percent of flow in left overbank.
Q Perc R	ft	Percent of flow in right overbank.
Q Pump Group	cfs	Pump group flow.
Q Pump Station	cfs	Total flow in all pump groups in a pump station.
Q Right	cfs	Flow in right overbank.
Q Total	cfs	Total flow in cross section.
Q US	cfs	Flow in cross section upstream of a lateral weir.
Q Weir	cfs	Flow over the weir.
R. Freeboard	ft	The freeboard in the main channel at the right bank (right bank elevation minus water surface elevation).
R. Levee Frbrd	ft	The freeboard before the right levee is over-topped.
Rght Sta Eff	ft	Furthest right station that still has effective flow.
ROB Elev	ft	The ground elevation at the right bank of the main channel.
SA Area	acres	Surface area of a storage area.
SA Chan	acres	Cumulative surface area for main channel from the bottom of the reach.
SA Left	acres	Cumulative surface area for left overbank from the bottom of the reach.
SA Min El	ft	Minimum elevation of a storage area.

SA Right	acres	Cumulative surface area for right overbank from the bottom of the reach.
SA Total	acres	Cumulative surface area for entire cross section from the bottom of the reach.
SA Volume	acre-ft	Storage volume of a storage area.
Shear Chan	lb/sq ft	Shear stress in main channel ($\gamma R_{CH} S_f$).
Shear LOB	lb/sq ft	Shear stress in left overbank ($\gamma R_{LOB} S_f$).
Shear ROB	lb/sq ft	Shear stress in right overbank ($\gamma R_{ROB} S_f$).
Shear Total	lb/sq ft	Shear stress in total section ($\gamma R_T S_f$).
Spc Force PR	cu ft	Specific force prime. For mixed flow, the specific force at this cross section for the flow regime that does not control.
Specif Force	cu ft	The specific force for this cross section at the computed water surface elevation. $SF = A_T Y_{cent} + (Q^2)/(gA_{act})$
Sta W.S. Lft	ft	Left station where water intersects the ground.
Sta W.S. Rgt	ft	Right station where water intersects the ground.
Std Stp Case	#	Standard step method used to determine WSEL (1 = successful convergence, 2 = minimum error, 3 = resorted to critical depth).
Top W Act Chan	ft	Top width of the wetted channel, not including ineffective flow.
Top W Act Left	ft	Top width of the wetted left bank, not including ineffective flow.
Top W Act Right	ft	Top width of the wetted right bank, not including ineffective flow.
Top W Chnl	ft	Top width of the main channel. Does not include 'islands', but it does include ineffective flow.
Top W Left	ft	Top width of the left overbank. Does not include 'islands', but it does include ineffective flow.
Top W Right	ft	Top width of the right overbank. Does not include 'islands', but it does include ineffective flow.
Top Wdth Act	ft	Top width of the wetted cross section, not including ineffective flow.
Top Width	ft	Top width of the wetted cross section.
Total Gate Flow	cfs	Total flow through all of the gate groups of an inline/lateral weir.
Trvl Tme Avg	hrs	Cumulative travel time based on the average velocity of the entire cross section, per reach.
Trvl Tme Chl	hrs	Cumulative travel time based on the average velocity of the main channel, per reach.
Vel Chnl	ft/s	Average velocity of flow in main channel.
Vel Head	ft	Velocity head.
Vel Left	ft/s	Average velocity of flow in left overbank.
Vel Right	ft/s	Average velocity of flow in right overbank.
Vel Total	ft/s	Average velocity of flow in total cross section.
Vol Chan	acre-ft	Cumulative volume of water in the channel (including ineffective flow).
Vol Left	acre-ft	Cumulative volume of water in the left overbank (including ineffective flow).

Vol Right	acre-ft	Cumulative volume of water in the right overbank (including ineffective flow).
Volume	acre-ft	Cumulative volume of water in the direction of computations (including ineffective flow).
W.P. Channel	ft	Wetted perimeter of main channel.
W.P. Left	ft	Wetted perimeter of left overbank.
W.P. Right	ft	Wetted perimeter of right overbank.
W.P. Total	ft	Wetted perimeter of total cross section.
W.S. DS	ft	Water surface downstream of a bridge, culvert, or weir.
W.S. Elev	ft	Calculated water surface from energy equation.
WS Inlet	ft	WS at the inlet of a pump station.
WS Outlet	ft	WS at the outlet of a pump station.
W.S. Prime	ft	Water surface prime. For mixed flow, the water surface of the flow regime that does not control.
W.S. US.	ft	Water surface elevation upstream of bridge or culvert.
Weir Avg Depth	ft	The average depth of flow over the weir.
Weir Max Depth	ft	The maximum depth of flow over the weir.
Weir Sta DS	ft	Downstream station where weir flow ends.
Weir Sta Lft	ft	Station where flow starts on the left side of weir.
Weir Sta Rgt	ft	Station where flow ends on the right side of weir.
Weir Sta US	ft	Upstream station for weir flow starts.
Weir Submerg	-	The ratio of the downstream depth above the weir to the upstream depth above the weir.
Wr Flw Area	sq ft	Area of the flow going over the weir.
Wr Top Wdth	ft	Top width of water over the weir.
WS Air Entr.	ft	Water surface elevation accounting for air entrainment.
WSPRO EG	ft	Energy grade elevation upstream of bridge for the WSPRO method.
WSPRO WS	ft	Water surface elevation upstream of bridge for the WSPRO method.
Wtd. n Chnl	-	Conveyance weighted Manning's n for the main channel.
Wtd. n Left	-	Conveyance weighted Manning's n for the left overbank.
Wtd. n Right	-	Conveyance weighted Manning's n for the right overbank.
XS Delta EG	ft	Change in energy gradeline between current section and next one downstream.
XS Delta WS	ft	Change in water surface between current section and next one downstream.
Yarnell EG	ft	Energy grade elevation upstream of bridge for Yarnell method.
Yarnell WS	ft	Water surface elevation upstream of bridge for Yarnell method.

Sediment Transport Output Variables

Variable Name	Units	Description
Ch Invert El	ft	Minimum elevation of the main channel at each output time step.
Wsel	ft	Elevation of the water surface at each output time step.
Observed Data	ft	Observed elevation of main channel bed, entered by the user.
Invert Change	ft	Delta change in the minimum elevation of the main channel.
Mass Out: All	tons	Total sediment mass, for all grain size classes, going out of the sediment control volume, per individual computational time step.
Mass Out: Class 1-20	tons	Sediment mass leaving the sediment control volume per grain size fraction, per computational time step.
Mass In: All	tons	Total sediment mass, for all grain size classes, coming into the sediment control volume, per individual computational time step.
Mass In: Class 1-20	tons	Sediment mass entering the sediment control volume per grain size fraction, per computational time step
Flow	cfs	Total flow at the cross section for each output time step.
Velocity	ft/s	Average velocity of the movable portion of the bed at each time step.
Shear Stress	lb/sq ft	Average shear stress of the movable portion of the bed at each time step.
EG Slope	ft/ft	Slope of the energy gradeline at each output time step. This can be a point value at the cross section or an average value between cross sections.
Mass Bed Change Cum: All (tons)		Cumulative mass of the change in the bed elevation over time.
Mass Bed Change Cum: class 1-20 (tons)		Cumulative mass of the change in bed elevation over time, per grain size fraction (Bins 1 – 20). This only displays the size fraction bins that are being used.
Mass Bed Change: All	tons	Incremental total mass change in the bed for the current computational time step.
Mass Bed Change: Class 1–20 (tons)		Incremental mass change in the bed for the current time step, by individual grain size fraction.
Mass Out Cum: All	tons	Cumulative total sediment mass leaving the sediment control volume for a specific cross section, per individual computational time step.
Mass Out Cum: Class 1-20 (tons)		Cumulative sediment mass leaving the sediment control volume per grain size fraction, at a cross section, per computational time step.
Mass In Cum: All	tons	Cumulative total sediment mass entering the sediment control volume for a specific cross section, per individual computational time step.
Mass In Cum: Class 1-20 (tons)		Cumulative sediment mass entering the sediment control volume per grain size fraction, at a cross section, per computational time step.

Mass Capacity: All	tons/day	Transport capacity in total mass at the current computational time step.
Mass Capacity: Class 1-20 (tons/day)		Transport capacity in mass, by grain size fraction, at the current computational time step.
Mean Eff Ch Invert	ft	Average channel invert elevation computed by subtracting the effective depth of the main channel from the water surface elevation.
Mean Eff Ch Invert Change (ft)		Change in the average channel invert elevation, which is computed by subtracting the effective depth of the main channel from the water surface elevation.
Long. Cum Mass change (tons)		Total change in bed mass, cumulative in space and time. Spatial accumulation is from the current cross section to the upstream end of the river reach in which this cross section resides.
d50 Cover	mm	d50 of the cover layer at the end of the computational increment. Used in the Exner 5 bed sorting and armoring routine.
d50 Subsurface	mm	d50 of the surface layer material at the end of the computational time step. Used in the Exner 5 bed sorting and armoring routine.
d50 Active	mm	d50 of the active layer of the simple active layer bed sorting and armoring routine.
d50 Inactive	mm	d50 of the inactive layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine.
Cover Thickness	ft	Thickness of the cover layer at the end of each computational time step. Used in the Exner 5 bed sorting and armoring routine.
Subsurface Thickness	ft	Thickness of the surface layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine.
Active Thickness	ft	Thickness of the active layer at the start of each computational time step. Used in the simple active layer bed sorting and armoring routine.
Mass Cover: All	tons	Total tons of material in the cover layer at the end of each computational time step. Used in the Exner 5 bed sorting and armoring routine.
Mass Cover: Class 1-20 (tons)		Tons of material in the cover later at the end of each computational time step, by individual grain size fraction. Used in the Exner 5 bed sorting and armoring routine.
Mass Subsurface: All	tons	Total tons of material in the surface layer at the end of each computational time step.
Mass Subsurface: Class 1-20 (tons)		Tons of material in the surface layer at the end of each computational time step, by individual grain size fraction.
Mass Inactive: All	tons	Total tons of material in the inactive layer at the end of each computational time increment.
Mass Inactive: Class 1-20 (tons)		Tons of material in the inactive layer at the end of each computational increment, by individual grain size fraction.

Armor Reduction: All	(fraction)	Fraction that the total sediment transport capacity is reduce to, based on the concepts of a cover layer computation.
Armor Reduction: Class 1-20	(fraction)	Fraction for each individual grain size, that the transport capacity is reduce to, based on the concepts of a cover layer computation.
Sediment Discharge	tons/day	Total sediment discharge in tons/day going out of the sediment control volume for a specific cross section, per individual computational time step.
Sediment Concentration	(mg/l)	Total sediment concentration in mg/liter going out of the sediment control volume at the end of the computational time step.
Eff Depth	ft	Effective depth of the water in the mobile portion of the cross section, at the end of the computational time step.
Eff Width	ft	Effective width of the water in the mobile portion of the cross section, at the end of the computational time step.
Ch Manning n	-	Main channel manning's n value.
Ch Froude Num	-	Main channel Froude number at the end of the current computational time step.
Shear Velocity u*	ft/s	Shear velocity. Used in Shields diagram and several sediment transport potential equations.
d90 Cover	mm	d90 of the cover layer at the end of the computational increment. Used in the Exner 5 bed sorting and armoring routine.
d90 Subsurface	mm	d90 of the surface layer material at the end of the computational time step. Used in the Exner 5 bed sorting and armoring routine.
d90 Active	mm	d90 of the active layer of the simple active layer bed sorting and armoring routine.
d90 Inactive	mm	d90 of the inactive layer at the end of each computational time step. Used in the Exner 5 and simple active layer bed sorting and armoring routine.
Dredge Vol Cum	ft3	Total volume of sediment removed from each cross section by the dredging routines.