# Illinois Department of Transportation

Bureau of Bridges & Structures – Hydraulics Unit

Drainage Manual:

Appendix A

Interim Guide to 2-D Hydraulic Modeling

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## Table of Contents

# Appendix A Interim Guide to 2-D Hydraulic Modeling

## A–001 Introduction

This Interim Guide provides guidance for developing an Illinois Department of Transportation (IDOT) 2-Dimensional (2-D) Hydraulic Report and associated Waterway Information Table (WIT) using the U.S. Bureau of Reclamation's Sedimentation and River Hydraulics Model, SRH-2D, which is supported by the Federal Highway Administration (FHWA). The guide documents how to use the Model results to prepare Hydraulic Reports in accordance with IDOT Drainage Manual procedures and is intended to serve as a supplement. The Interim Guide assumes the user has basic knowledge of basic fluid mechanics in addition to 1-D and 2-D Hydraulics and is familiar with procedures described in the IDOT Drainage Manual. This guide does not cover design principles of drainage structures. Such topics are covered in detail in the Drainage Manual and companion documents such as the Bridge Manual and the Bureau of Design and Environment (BDE) Manual. This guide focuses on waterways that contain bridge crossings that are too complex to be modeled using conventional one-dimensional (1-D) Models such as the Hydrologic Engineering Center-River Modeling System (HEC-RAS). It describes data preparation, quality control and using the Model results to prepare exhibits and documentation for inclusion in 2-D Hydraulic Reports.

To use this guide, the user must have access to the Surface-Water Modeling System (SMS). SMS is a pre- and post-processor for SRH-2D. SMS provides a convenient interface for developing SRH-2D Model components and processing Model results. SMS was developed and maintained by Aquaveo. Information about SMS and licensing can be obtained from Aquaveo's website: http//www.aquaveo.com/.

For the purposes of this document, the meaning and references to the word 'Model' is as described in the Drainage Manual. Since this manual is devoted to the SRH-2D Model, the word "Model" means the representation of the drainage system or hydraulic structure using the SRH-2D program using SMS. SMS and SRH-2D are being continuously improved to address software glitches and to add new features. The information link given above should be consulted periodically to check for newer and updated versions of the software.

The procedures and associated tools have been developed by IDOT in coordination with Aquaveo and is specific to SMS Version 13.2.10, build date August 10, 2022.

## A–002 Available References and Training Materials

There are numerous manuals and guidelines that describe how to develop and perform a 2-D Model analysis. These documents cover theory and Model development. Documents that present the theory of 2-D Model development are applicable in most situations and do not depend on which software code is used to develop the Model. This manual however is specific to the SRH-2D code and the complimentary SMS platform. The following documents were used extensively as primary sources in preparing this Interim Guide.

**A–002.01 Key Reference Documents**

- The IDOT Drainage Manual 2011 is the main reference for policies, and general guidelines for preparing Hydraulic Reports. This manual does not discuss 2-D Modeling, however the procedures for preparation of Hydraulic Reports and contents are assumed to be applicable to the development of 2-D Models.

- The FHWA Two-Dimensional Hydraulic Modeling for Highways in the River Environment – Reference Document. This manual describes in detail the rational for selection  and development of 2-D Models. It includes a survey of 2-D Models in current use, including SRH-2D and a general theory of 2-D Model development.

- SMS Online sources:  SMS online manuals, the SMS graphical interface, and how-to guides. Online sources provide hands-on aids for creating, manipulating and files and Model elements are provided through a wiki portal that can be accessed through the help command in the interface. The help command provides a quick and convenient way to access the commands available on the interface.

**A–002.02 SRH Training Courses**

National Highway Institute (NHI) provides various on-site and on-line training courses on developing, diagnosing, and using SRH-2D results. These courses are obtained by registration on the NHI website at https://www.nhi.fhwa.dot.gov/course-search.

The following is a list of relevant courses currently offered:

- NHI 135095A – "SRH-2D Model Data Files, Diagnostics & Verifying 2D Model Results"

- NHI 135095B – "SRH-2D Model Terrain Development with Various Data Sources"

- NHI 135095 – "Two-Dimensional Modeling of Rivers and Highway Encroachments" (Instructor-Led)

- NHI 135095V – "Two-Dimensional Modeling of Rivers and Highway Encroachments" (Virtual Delivery)

**A–002.03 Online sources:  Tutorials**

The SMS Learning Center is accessed through https://www.aquaveo.com/software/sms-learning-tutorials. Step-by-step procedures and tutorials are presented in PDF formats. Data files for the worked examples can be downloaded. Topics covered include how to use the SMS interface, data manipulation, visualization, simulation, modeling bridges, culverts, and Model development. A sample of these tutorials is shown below in Figure A-1.  To get the most recent Tutorials in addition to documentation on the history of their advancement, use this link: https://www.xmswiki.com/wiki/SMS:Tutorial_History.
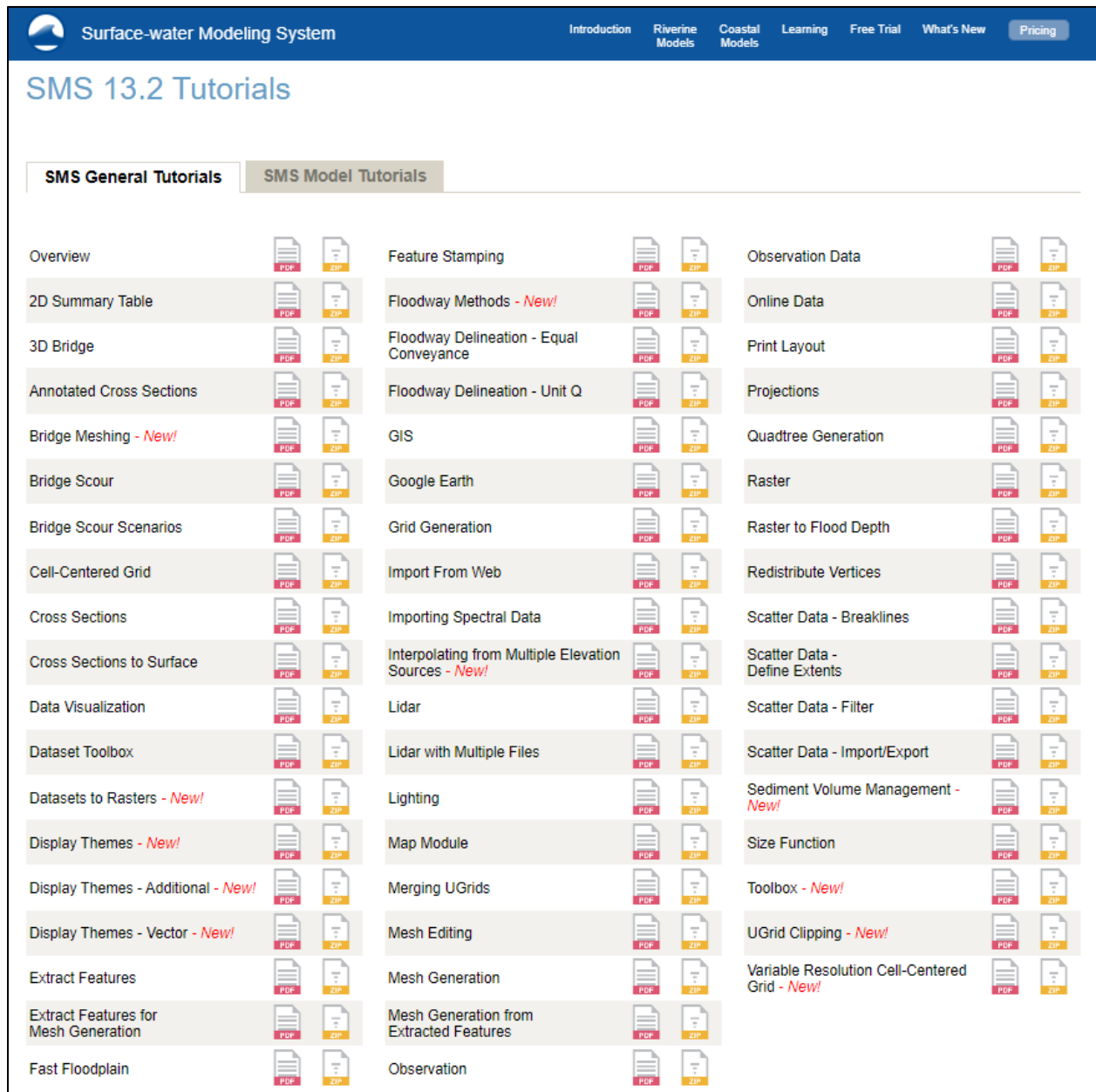
*Figure A-1: SMS Learning Center online tutorials*

**A–002.04 Online Sources:  Videos**

The how-to videos can be accessed at the Aquaveo Learning Center web page at https://www.aquaveo.com/software/sms-learning-videos. A sample of these videos is shown below in Figure A-2.
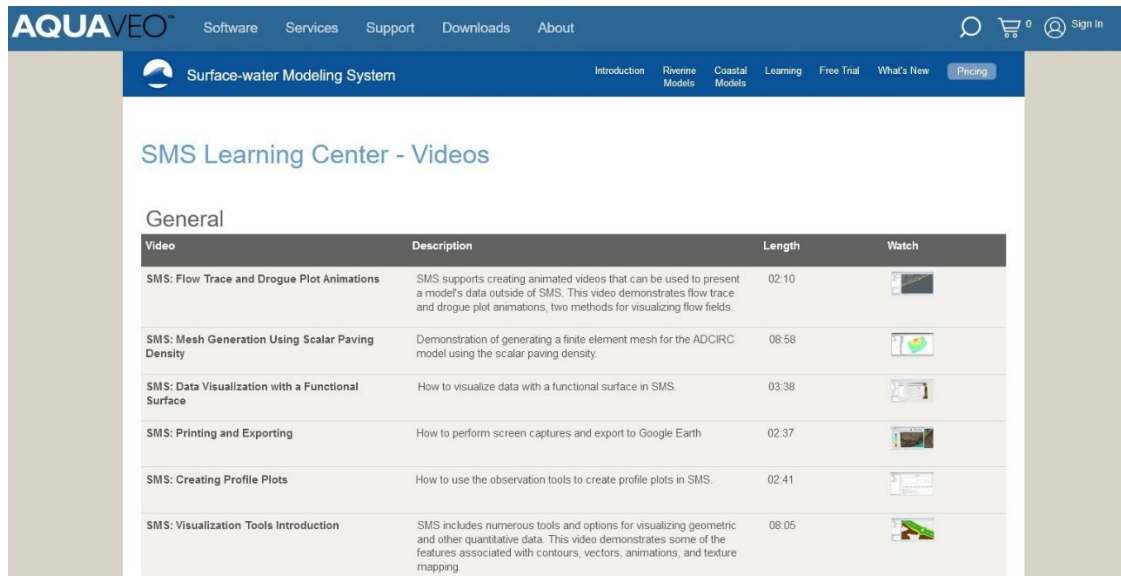
*Figure A-2: SMS Learning Center Videos Online Sources:  XMS Wiki*

Aquaveo's XMS wiki page provides the most comprehensive source for the SMS User's Manual, Summary of Bug Fixes, and What's New and Version Histories.  The SMS page can be accessed from https://www.xmswiki.com/wiki/SMS:SMS.  The SRH-2D main page provides access to technical papers and presentation with a focus on SRH-2D.  The Wiki page offers step by step workflows for SMS and SRH-2D at https://www.xmswiki.com/wiki/SMS:Workflows_Overview.

### A–002.05 FHWA Two-Dimensional Hydraulic Modeling User's Forum

The 2-D Hydraulics Modeling User's Forum is sponsored by FHWA's innovation initiative called Every Day Counts (EDC).  Bi-monthly presentations cover recent updates to SMS, SRH-2D, and summarize topics requested by the 2-D Modeling community.  Users can sign up for email alerts regarding upcoming User's Forum Webinars at https://public.govdelivery.com/accounts/USDOTFHWA/subscriber/new?topic_id=USDOTFHWA_97.

The Web Room for bi-monthly technical presentations can be accessed at any time and includes download links for past User's Forum Webinars and additional 2-D resources.  The web room can be accessed from https://connectdot.connectsolutions.com/modelingusersforum/

### A–002.06 Guidelines Specific to 2-D Application under Development

NCHRP panel 24-49 "Guidelines for Selection and Application of Manning's Roughness Values in 2-D Hydraulic Models" is currently in-progress and had an indefinite publication date.  When completed, this document should be utilized for guidance on selecting the appropriate Manning's roughness values.

### A–002.07 Technical Support for SMS and SRH-Model Development

In addition to the above sources, technical support is available through licensing agreements with Aquaveo.

*A–002.071 FHWA Bridge Scour Workshop*

The FHWA's Resource Center hosted a series of bridge scour workshops to DOTs nationwide in December of 2021.  This series included four recorded sessions on bridge scour using SRH-2D.  The videos and associated slides can be accessed through the links below.

*Workshop Summary Page*

https://www.fhwa.dot.gov/engineering/hydraulics/scourtech/scour_workshop/

*Workshop Slides*

https://www.fhwa.dot.gov/engineering/hydraulics/scourtech/scour_workshop/FHWA_Bridge_Scour_Workshop.pdf

## A–003 Background and Data Development

### A–003.01 Overview

Models require data that represents the physical river system. The quality of the data affects Model stability and the accuracy of results. The basic data requirements for a 2-D Model development are similar to those of 1-D Models. Both require hydrographic and structure geometry, hydraulic and flow data, boundary conditions data, roughness values, and Model parameters. The differences arise from the fact that the Model domain is now spatial rather than linear; therefore, the procedures that are applicable for a 1-D riverine systems are no longer applicable for 2-D Models. Terrain data for 2-D Modeling no longer represents 1-D cross-sections, instead the data represents 2-D cells. In contrast to 1-D Modeling, in which there are guidelines for assigning roughness values, there currently no consistent guidelines for assigning roughness values for 2-D Model domains. Improved guidelines are currently under development by the FHWA.

### A–003.02 Roughness Values

Friction factors are assigned to every element in the Model domain. As stated previously, FHWA is currently developing such procedures. In the meantime, Land Use types are used to assign hydraulic roughness coefficient throughout the domain. This is similar to what would be prepared for 1-D Models.  Land Use types can be obtained from geophysical databases maintained by local, state, and federal agencies.  Additional post processing and refinement of these datasets is needed when incorporating into the Model.  Some of these datasets can be directly accessed in SMS.  Generally speaking, these Land Use datasets can often be too pixelated to provide the appropriate level of detail.  Often it is more appropriate to digitize differing regions via using an aerial photo or pictures taken from a site visit.

The following is a listing of potential Land Use and roughness sources:

### A–003.03 National Datasets

- United Interagency Elevation Inventory.

- Data.gov > Comprehensive Geodata search:  Provides download links to all available U.S. Federal Agency datasets. Categories include elevation and derived

products, environment and conservation, agriculture, and farming, geological and geophysical, imagery and base maps, and inland water resources.

- USGS Earth Explorers:  Provides access to Landsat and other remote sensing satellite data. Requires users to create an account.

### A–003.04 Illinois Datasets

- Illinois Geospatial Data Clearinghouse:  Data provided through the University of Illinois at Urbana-Champaign's Prairie Research Institute. Includes climate, elevation, geology, hydrology, and imagery.

- Illinois Rivers Decision Support System:  Data provided by the Illinois State Water Survey to include online data, maps, downloadable GIS data, GIS animations/visualizations, and web mapping applications.

- Illinois County GIS Links:  This site provides a list of counties and links to each county's GIS website (if available). It is possible they have not updated all county links; searching for a county GIS website would also be beneficial.

- Illinois State Water Survey Data Resources:  Data provided through the University of Illinois' Illinois State Water Survey. Provides links to weather, agricultural, streamflow, drought, groundwater, wells, and atmosphere.

- National Hydrography Dataset:  Provides seamless digital data that can be queried and downloaded. Data can be extracted by sub-basin, county, congressional district, or by topographic map quad. Data can be extracted in blocks encompassing several adjacent reference areas.

- National Centers for Environmental Information (formerly National Geophysical Data Center):  Layers include Coastal Relief Models for central, western, and eastern Gulf of Mexico, Continental US, Hawaii, Puerto Rico, East Coast, Florida, Southern California, US Central Pacific Coast, US NW Pacific Coast, Bathymetric, Topographic data, DMSP OLS Daily Mosaics, DMSP GLOBE Version 1.0 Digital Elevation Data, 1999, Nighttime Lights of the World 2003, TerrainBase (Global 5-minute Digital Terrain Model), 1994.

- USGS Upper Midwest Environmental Sciences Center Data Library:  Provides maps, tools, and databases for the upper Midwest for various categories including bathymetry, navigation structure, land cover and Land Use data, long-term resource monitoring program data, maps, quadrangles, LiDAR datasets, elevation, discharge, and many others.

### A–003.05 Planning/Community Datasets

- Spatial Data Sets Available on the WRD NSDI Node:  A variety of water-based-datasets provided by the USGS.

**A–003.06 Terrain Data**

Terrain data is critical to developing an accurate SRH-2D Model. The quality of terrain data for 2-D has the same impact on Model accuracy as cross-sectional data in 1-D Models. The data must have the appropriate resolution to capture the hydraulic features that will affect the flow field. The hydraulic controls example in Figure A-3 illustrates common hydraulic features that need to be accurately defined when acquiring or evaluating terrain data. Such an evaluation must be included in the Model documentation. Common sources of terrain data include:

- Field surveys to obtain elevation data on structures and hard shots of critical features such as high spots and levees.

- Hydrographic surveys to obtain bathymetry data.

- Cross-section data from previous studies.

- LiDAR data available from the sources listed above, as well as municipalities, county agencies, and state and federal sources.

LiDAR and other elevation data are now readily available from the online sources listed in the beginning of this section. However, acquisition of stream bathymetry is necessary because LiDAR typically does not contain elevation data below the water surface.
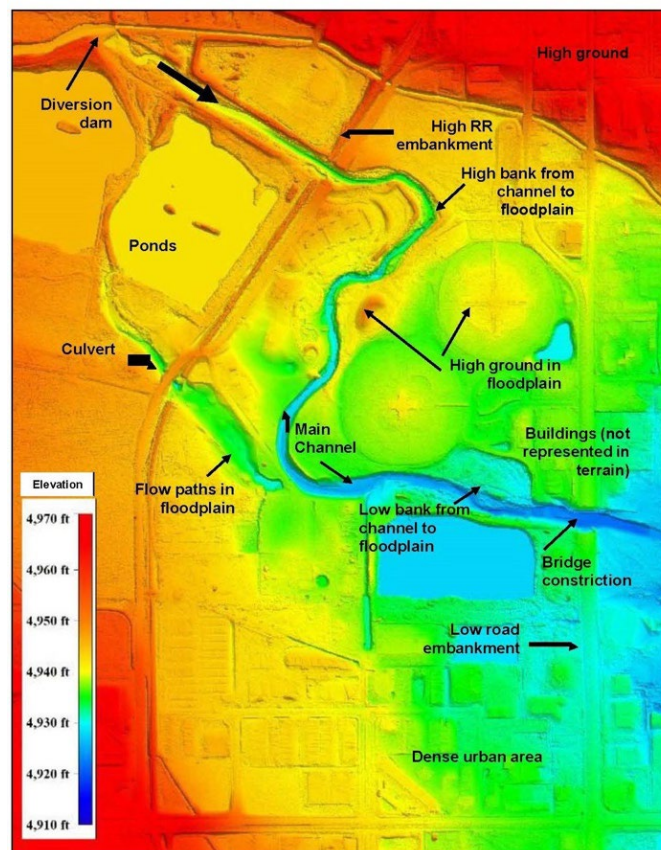


*Figure A-3: Hydraulic Controls Example*

The limits and location of data collection are dictated by the Model boundaries. Planning for data acquisition must make an allowance in estimating the Model limits to ensure adequate coverage of the Model domain.

In addition to establishing the spatial limits of terrain data collection, the Model boundary should be checked to identify features and structures that will impact conveyance and flow patterns. Figure A-3 illustrates the most common features. These may include berms, depressions, high ground, weirs, channel constrictions, high overbanks, culverts etc. It is important to identify these features early when planning for data collection because the creation of the computational mesh and the quality of the mesh greatly depend on proper resolution and representation of these physical features. Additional field shots may be appropriate to supplement terrain data.

### A–003.07 Data Processing and Quality Control

Data processing involves acquisition of the data by downloading from the source, merging, saving, checking the quality, checking the projection and other metadata, and filtering to reduce file sizes. SMS had the capabilities for processing LiDAR files for Model development. The NHI Course 135095 describes how to use SMS to process LiDAR data. A video from the class on importing LiDAR can be viewed at https://www.youtube.com/watch?v=agP9QzFDsMc.

Visualization of the data is an important quality assurance/quality control task which will provide great value when developing the mesh because anomalies in the data are easier to detect. SMS allows visualization of the data in 3-D. Suspect data usually show as spikes or spots above the terrain surface. Anomalies should be documented and included in the Model documentation.

The data process flow chart in Figure A-4 summarizes the steps taken to process raw data until they are ready to be used to generate a mesh in SMS.
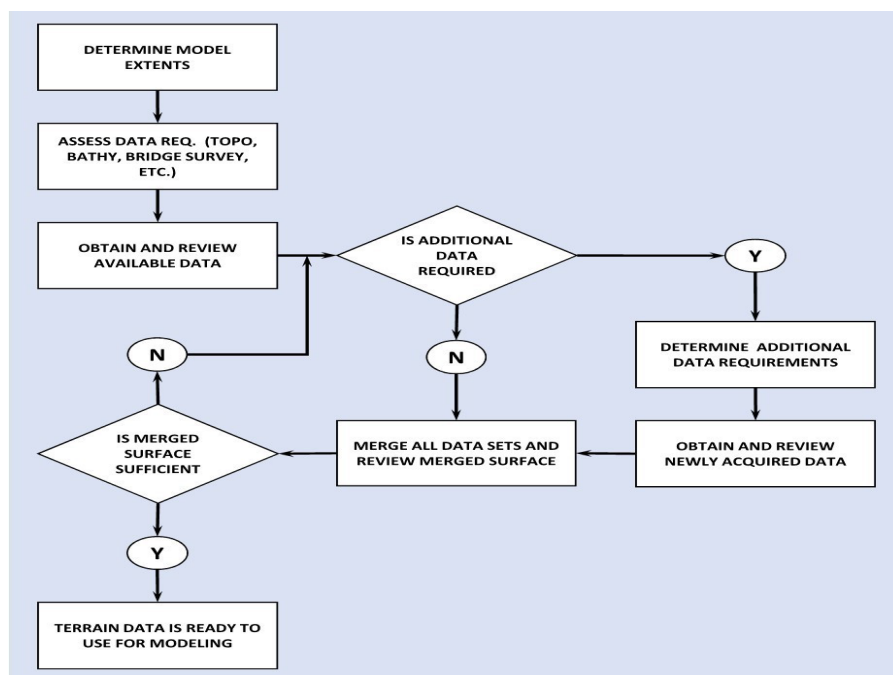


*Figure A-4: Data Process Flow Chart*

**A–004 Other IDOT 2-D Resources**

IDOT has developed additional training and resources on the subject of 2-D Modeling and related topics.  These documents have not been maintained. FHWA has provided similar training and references, which are maintained and are generally current with the continuing changes to the SMS interface.

IDOT also developed a Quick Check Model Guidebook and a set of examples in 2021. The Quick Check Model (QCM) concept was borrowed from the Colorado Department of Transportation (CDOT). The QCM is developed in SRH-2D. It uses a coarse meshing and a single roughness for the materials coverage, which can be later refined to produce the Design 2-D Model.  IDOT intends to use the QCM to identify approximate extent of the Modeling domain, flood levels and boundaries, estimated roadway overtopping conditions, survey extents and needs, other structures that may impact the design and evaluation, and potential flood receptors.  IDOT has developed a Quick Check Guidebook that provides step-by-step instruction as how to develop the QCM.  IDOT has developed a Quick Check Checklist that documents the QCM inputs and outputs.  Requests for these documents can be submitted to the BBS-Hydraulics Unit.

**A–005 Standard 2-D Hydraulic Report Contents**

**A–005.01 Introduction**

Section 2-601.01 of the Drainage Manual describes information that should be included in Hydraulic Reports. This section describes the additional information that should be provided in parts 3(i) through 3(k) in regards to the hydraulic methodology of the existing, proposed, and natural conditions when the analyses are performed in 2-D.

**A–005.02 Model Domain**

A map showing the Model domain, boundary condition lines, and observation lines/points should be prepared. The Model domain must be a closed polygon and must contain all features that can affect conveyance or flow patterns through the study area within the Model domain. Location and type of boundary condition lines and observation lines/points should be identified.

**A–005.03 General Statistics**

The general statistics of the Model including the number of nodes, number of elements, and average mesh density should be documented. Average mesh density should be reported as the number of elements divided by the area of the domain, in acres.

**A–005.04 Mesh Quality**

Comparisons of the source terrain and the mesh elevations should be provided using the SMS observation coverages.  The comparison ensures that the mesh provides adequate density to capture the source terrain.  A focus should be placed on areas of the terrain with steep slopes, such as channel banks, where more elements may be required in the mesh to provide the appropriate detail of the underlying terrain.

**A–005.05 Model Calibration and Sensitivity**

When possible, all 2-D Models should be calibrated to observed data.  A summary of the calibration efforts utilized to support Model results should be provided in the Model approach section Hydraulic Report including a narrative of the calibration approach and tables or charts comparing the final adjusted parameters and the difference between predicted and observed data.

In the event there is not sufficient observed data for calibration of the Model, it is recommended that the user perform a sensitivity check of the Model to evaluate the influence of key input data on the design. The sensitivity of these variables should be documented in the model approach section of the Hydraulic Report.  The following are examples of sensitivity checks which assist in the validation of the modeling parameters:

- Run the Model using two discharges based on 80% and 120% of the upstream flows, i.e., 20% uncertainty.

- Check the sensitivity of water elevations (WSE) within the study area by varying the downstream WSE by about ±10% of the depth in the main channel. This check is particularly valuable if the downstream boundary condition is uncertain.  If this check indicates high sensitivity, the downstream boundary may need to be relocated further downstream.

- Check the sensitivity of the WSE at the project site to the Manning's *n* values in the channel and floodplain.

**A–005.06 Recommended 2-D Hydraulic Report Outline**

IDOT has prepared a recommended outline and associated exhibits to set some expectations for a 2-D Hydraulic Report, which would facilitate review and approval of the Models and associated documentation.  The following is a example outline for a 2D Hydraulic Report:

**1. Introduction**

**2. Data Collection**

   2.1 Record Drawings

   2.2 Field Survey

   2.3 USACE Data

   2.4 LiDAR Data

   2.5 FEMA Data

**3. Existing Site Description**

   3.1 Structure

   3.2 Navigation

### 4. Hydrology

4.1 StreamStats Discharges

4.2 Other Studies (FEMA, USACE)

4.3 Study Discharge Recommendations

### 5. Hydraulics

5.1 One-Dimensional (1-D) HEC-RAS Model

5.1.1 Existing Conditions

5.1.2 Natural Conditions

5.1.3 Proposed Conditions

5.1.4 Temporary Conditions

5.2 Two-Dimensional (2-D) Model

5.3 Results

5.3.1 One-Dimensional Model Results

5.3.2 Two-Dimensional Model Results

5.3.3 Flood Receptors

### 6. Scour

6.1 Long-Term Degradation

6.2 Scour (Contraction, Pier, Abutment, Total)

6.3 Scour Countermeasures

### 7. Ice / Debris Assessment

### 8. Conclusion & Recommendations

### 9. References

*A–005.061 List of 2-D Exhibits*

IDOT has prepared a list of 2-D exhibits, which should be included in the 2-D Hydraulic Report. The objective is to document that appropriate modeling procedures and methods have been used, all of which is intended to facilitate IDOT's review and approval.

- Boundary Conditions Map
  - Provide a map depicting locations of the Model boundary conditions, monitor lines, and monitor points. The boundary condition lines should be clearly labled with the boundary type.
  - Monitor lines and points should be labeled with the SMS line or node number, respectively.
  - The map should include the Model domain for reference.
- Observation Coverage Map
  - Provide a map depicting locations of any observation linework used for documenation of Hydraulic results.  The observation SMS *.map file should be submitted with the Hydraulic Report.  The observation map may be combined with the boundary condition map if all lines can be clearly identified.
- Mesh Spacing Map
  - A map shall be provided depicting the mesh density at key locations in the hydraulic Model.
  - The map should include documentation for the range of mesh densities in a particular reach.
- Polygon Mesh Map
  - A map depicting the polygon type used for generating the mesh should be inclued.
- Manning's Roughness Map
  - A map depicting the manning's roughness in the 2-D Model should be provided.
  - The roughness coefficients used in the Model should be clearly labeled on the map. Including the roughness value in the label is suggested, ie. "Farm Ground (0.035)".
  - If a landuse coverage was used in development of the manning's coverage, the source of the coverage should be provided.
- A summary of the simulation inputs should be provided and at a minimum include:
  - SMS File Name, Simulation Name, and Case Name
  - Simulation Start Time, End Time, total simulation length, and Timestep
  - Model Initial Condition
  - Discharge
  - View Simulation Plots for documening stability
- Unit Discharge Map
  - A map depicting unit discharge (q) is defined as the velocity multiplied by the flow depth (q=V*y) = **[Vel_Mag_ft_p_s]\*[Water_Depth_ft]** and can be developed using the Dataset Calculator Toolbox. The dataset and map should be provided for each Model profile.  The dataset shall be provided with the Model deliverables and the dataset name should be named according to the flow profile and dataset – ex. 100YR_q.
- Critical Velocity Index
  - A map depicting the critical velocity index (CVI) is defined as the velocity above which bed material of size D50 and smaller will be transporter.  The dataset and map should be provided for each Model profile.  The map can be developed using the Dataset Calculator Toolbox by entering the following equation: **[Vel_Mag_ft_p_s]/(11.17\*[Water_Depth_ft]^(1/6)\*D50^(1/3))**. The D50 value for sand can be assumed to be 0.2 mm (0.000656 ft).  The dataset shall be provided

with the Model deliverables and the dataset name should be named according to the flow profile and D50 – ex. 100YR_CVI_(0.2 mm Sand).  The datest contour options for the map should be set as follows:
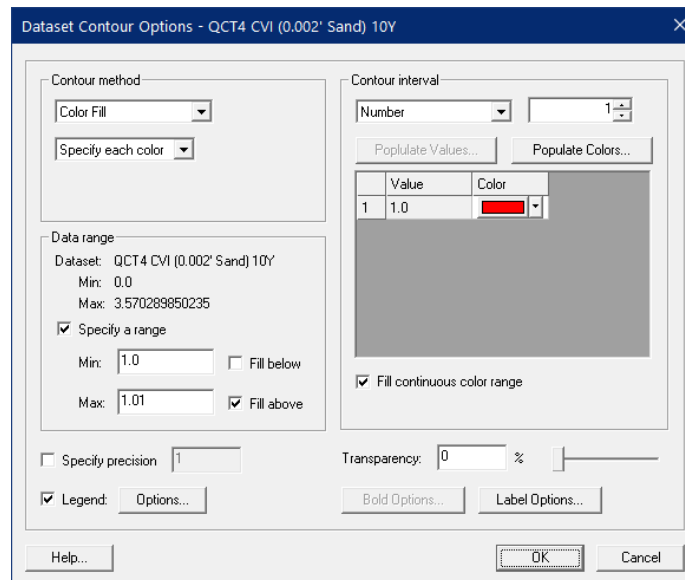


- Energy Slope
  - o A map and dataset depicting the engery slope (E Slope) shall be provided for each Model profile. The map can be developed using the Dataset Calculator Toolbox by entering the following equation: **[B_Stress_lb_p_ft2]/(62.4*[Water_Depth_ft])** The dataset shall be provided with the Model deliverables and the dataset name should be named according to the flow profile and dataset – ex. 100YR_E Slope.
- Stream Power
  - o A map and dataset depicting the Stream Power (P!) shall be provided for each Model profile. The map can be developed using the Dataset Calculator Toolbox by entering the following equation: **[B_Stress_lb_p_ft2]*[Vel_Mag_ft_p_s]** The dataset shall be provided with the model deliverables and the dataset name should be named according to the flow profile and dataset – ex. 100YR_P!.
- Shear Stress
  - o A map depicting the Shear Stress (τ) shall be provided for each Model profile. The datest contour options for the map should be set as follows:
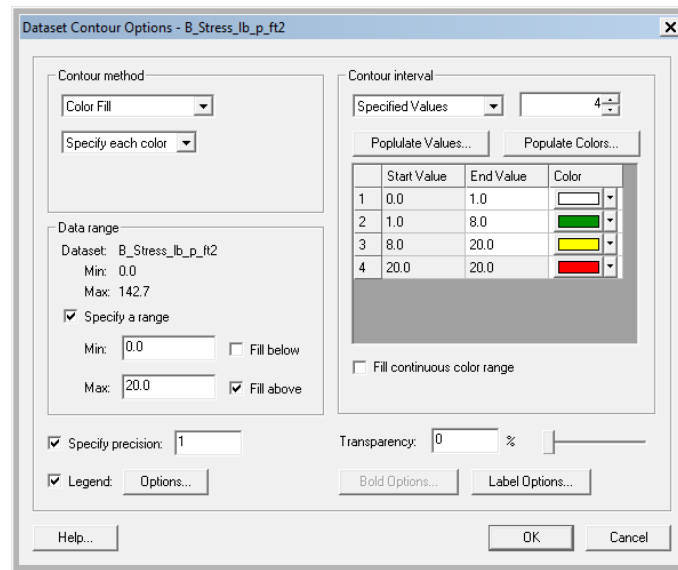
- Froude
  - A map depicting the Froude (Fr) shall be provided for each Model profile. The datest contour options for the map should be set as follows:
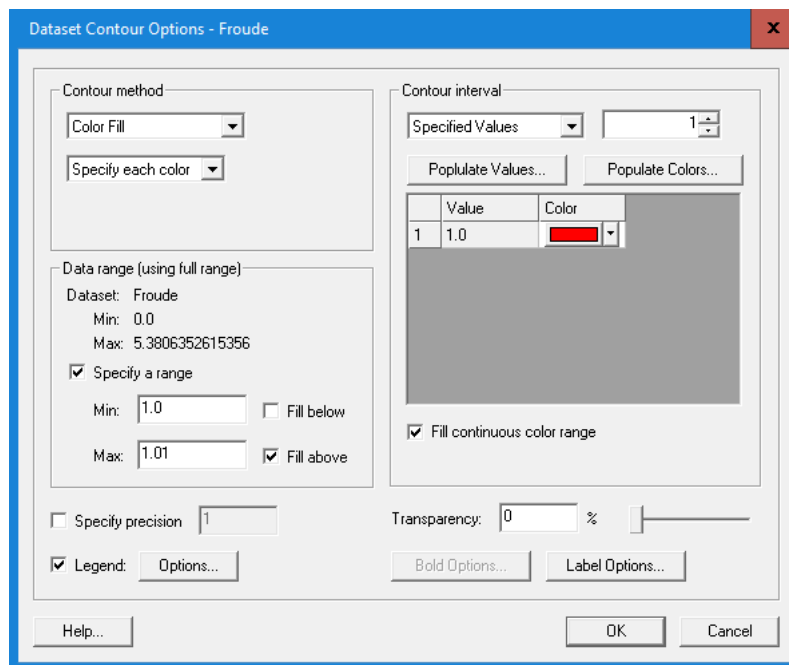


### A–005.07 Submittals and Coordination with IDOT

IDOT has prepared a list of potential coordination opportunities for submitting 2-D Model data and associated documentation for review and approval.  These submittals would provide key coordination opportunities with IDOT staff, which would reduce potential rework on projects and expedite reviews.  The expectation would be that the consultant would prepare and submit these items to IDOT for review and approval in sequential order.

The following coordination points are to be included at the discretion of the District Hydraulic Engineer and should be coordinated in advance.

1. Model domain.
2. Survey request and requirements.
3. Model mesh (natural, existing, and proposed).
4. Final modeling surfaces.
5. 2-D Created Head and draft Waterway Information Table.
6. 2-D scour results.
7. Draft Hydraulic Report.
8. Final Hydraulic Report.

## A–006 Scour Calculation Guidance using SRH-2D

### A–006.01 Introduction

The objective of this chapter is to provide guidelines for documenting scour calculations using 2-D Hydraulic results and tools provided in SMS and SRH-2D.  See Drainage Manual Chapter 10 for general guidance on scour requirements.

A detailed tutorial for completing an SRH-2D scour analysis can be found on Aquaveo's website at SMS 13.1 Tutorials | Aquaveo.com.  The tutorials are titled "Bridge Scour and Bridge Scour Scenarios."

Aquaveo, in collaboration with FHWA and USBR, regularly update the tools included in SMS and SRH-2D.  Regular review of updated SRH-2D guidance and available scour tutorials is encouraged to ensure the engineer is familiar with the latest 2-D scour guidance.  The Drainage Manual may reference tools or example Model windows that are outdated.  In these instances, the Hydraulic Report should provide sufficient detail to meet the intent of the documentation requested herein.

The FHWA has developed a Bridge Scour Workshop introducing users to general requirements for computing scour including use of the 2-D Bridge Scour Tools.  Recordings of the workshop can be found online at the following website:
https://www.fhwa.dot.gov/engineering/hydraulics/scourtech/scour_workshop/.

### A–006.02 SMS Scour Observation Arcs

A map depicting the locations of the scour linework shall be submitted with the Hydraulic Report for IDOT review. The map shall include locations of the contracted section, approach section, channel centerline, bank lines, abutment toe, and piers as shown in Figure A-5.  A brief description of why the locations were chosen shall be provided.
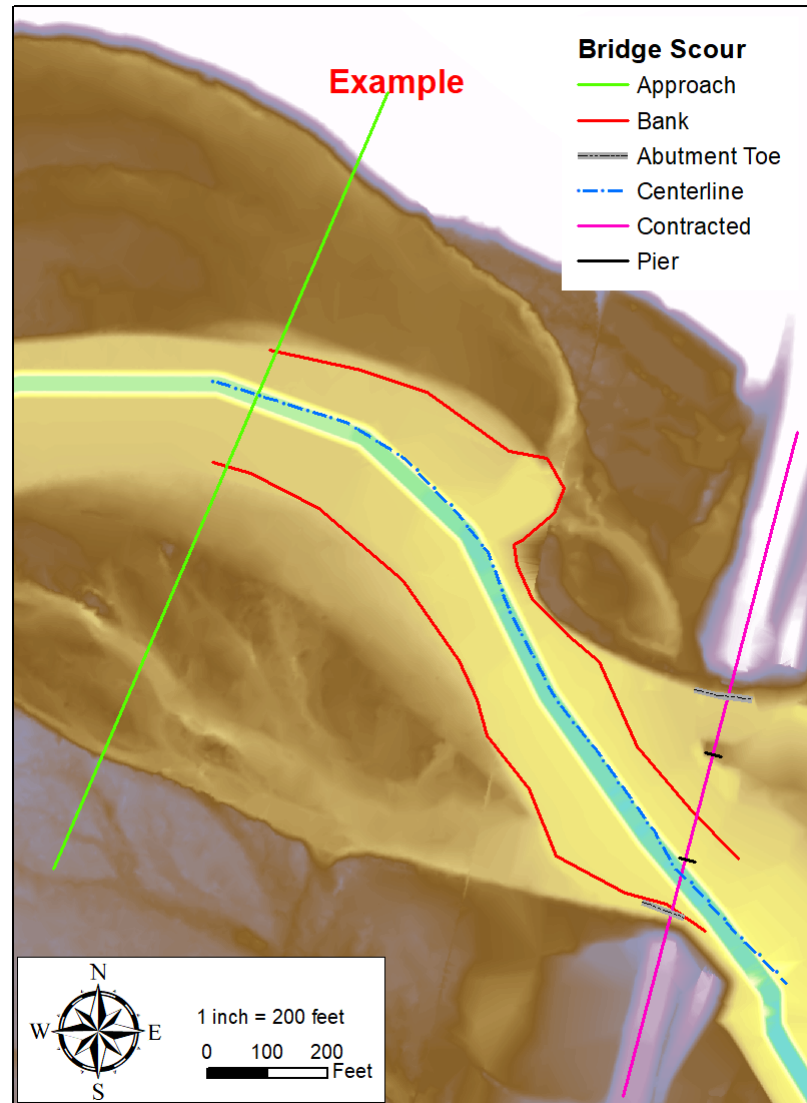
*Figure A-5:  SMS Bridge Scour Tool Linework*

- Contraction Section – The contracted section shall be located at the maximum hydraulic contraction within the bridge limits.  The arc must be drawn left to right looking downstream.
- Approach Section – The approach section shall be located sufficiently far upstream that flow is fully expanded.  The arc must be drawn left to right looking downstream.  A figure depicting the location of the velocity vectors compared to the approach section shall be provided with the Hydraulic Report to document that flow has fully expanded.  Figure A-6 provides an example map for documentation of the approach and contracted sections.
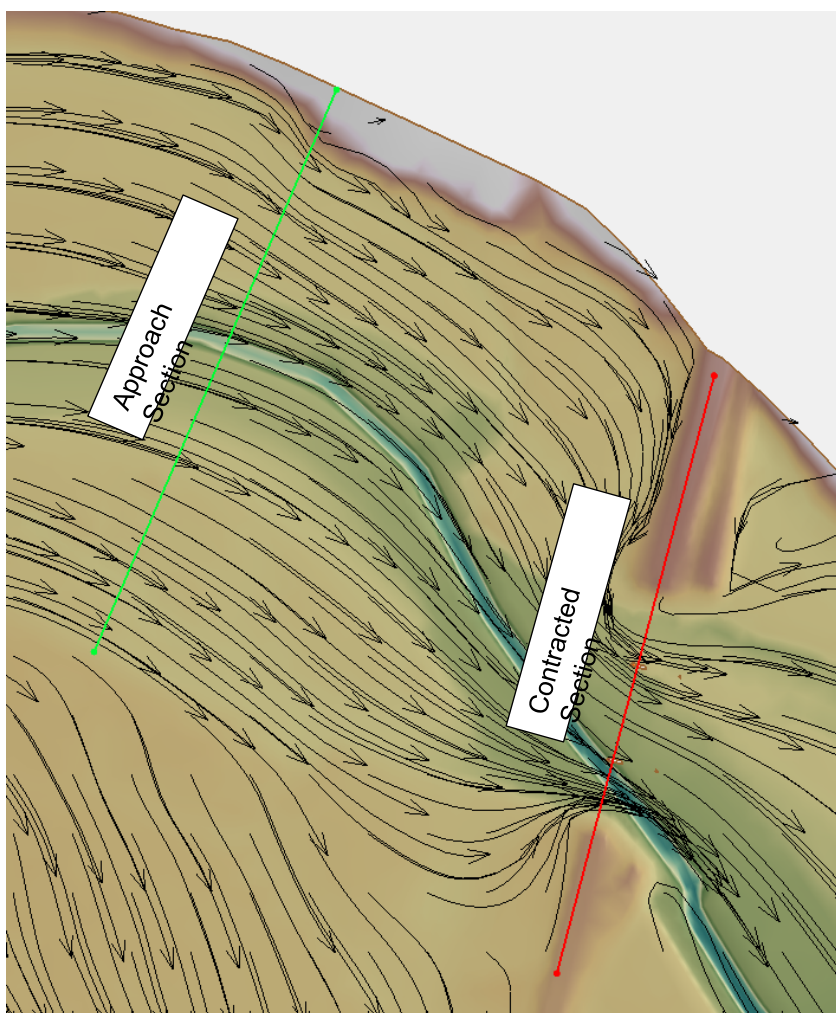
*Figure A-6:  Approach and Contracted Section Documentation*

- Channel Centerline – The centerline arc shall be drawn from upstream to downstream along the channel thalweg.
- Bank Lines – Bank lines must cross the expanded section and the contracted section. The lines do not need to cover the entire modeled reach and only need to travel a short distance upstream and downstream.
- Abutment Toe – The abutment toe shall be drawn along the toe of the abutment and must cross the contracted section.  The appropriate abutment type shall be selected and documentation of the selected type shall be provided in the Hydraulic Report.
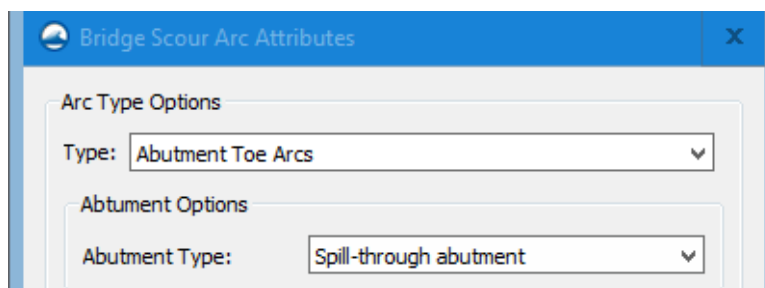
- Piers – The pier arc shall be located within the hole in the mesh representing the pier(s) and drawn from the upstream face to the downstream face along the pier center. The approved hydraulic mesh shall have sufficient definition around the bridge piers that flow direction and peak velocities are adequately captured. A summary of the Pier Arc Attributes should be provided in the Hydraulic Report as shown in Figure A-7. A brief explanation of the bed condition shall be provided in the Hydraulic Report. Generally, the "Reference for scour hole" shall assume the Main Channel (thalweg) in anticipation of the channel thalweg's ability to migrate according to FHWA guidance provided in HEC-18. **Pier foundations on floodplains should be designed to the same elevation as pier foundations in the stream channel if there is likelihood that the channel will shift its location over the life of the bridge.** The scour hole reference and hydraulic variable may be set to local streambed if the piers are sufficiently set back from the main channel. A map depicting the setback of the piers shall be provided in the Hydraulic Report. Generally, it is recommended that the user allow SMS to compute the pier flow angle of attack. A local angle of attack override may be allowed in special cases. A map depicting the computed attack angle from SMS and the override attack angle shall be provided in the Hydraulic Report.
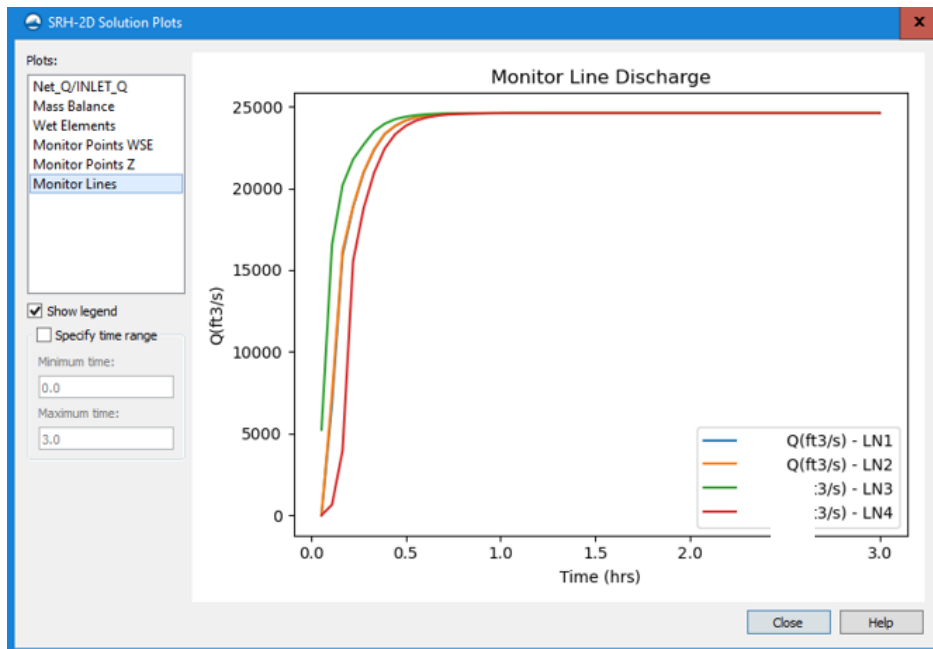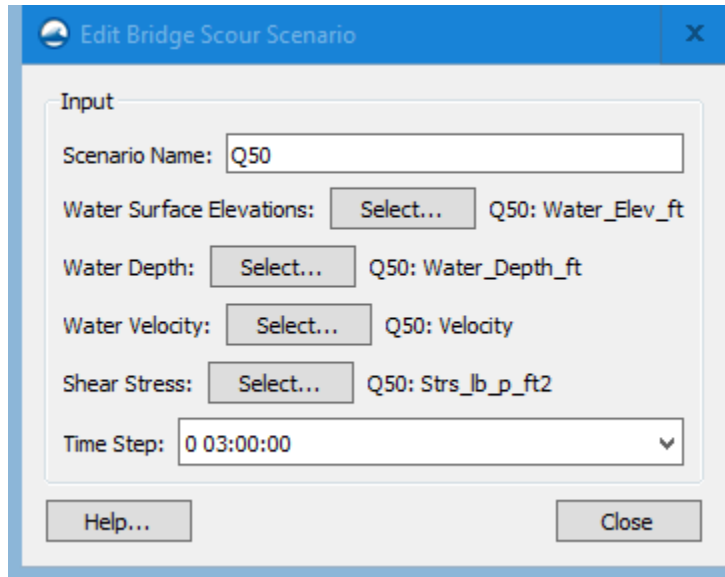


*Figure A-7:  Pier Arc Attributes*

### A–006.03 Bridge Scour Properties

*A–006.031 Scenario*

Users shall provide a summary of scour scenario inputs including the time step selected for analysis.  The selected timestep shall be compared to the Model output summary to show that the simulation is stable and has reached equilibrium.

*A–006.032 Default Options*

Divergence from bridge scour default options shall be documented in the Hydraulic Report.
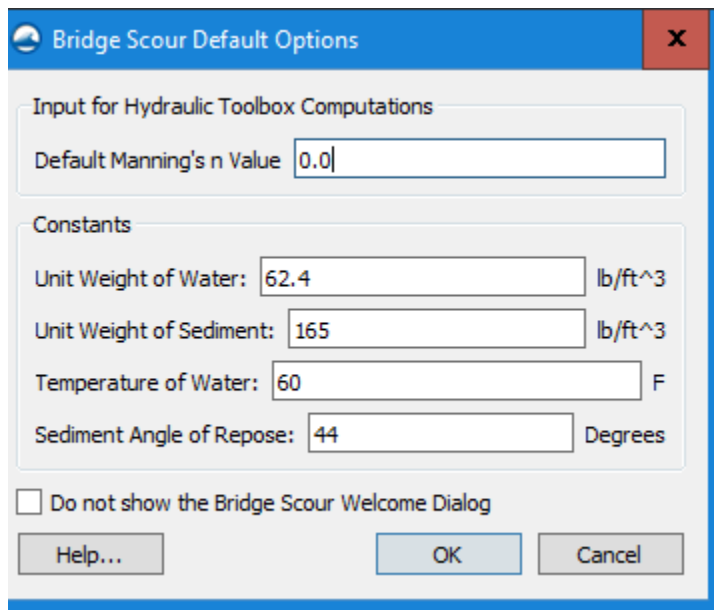


*A–006.033 Soil Gradation*

The soil gradation shall be defined based on best available boring information.  If detailed boring information is not available, the user shall assume sandy soil with a gradation that provides the most conservative exponent for the mode of bed material transport.  A summary table of the bridge scour soil gradation shall be provided in the Hydraulic Report.  Borings are required but may not be available at the time of the scour is computed; therefore, $d_{50}$ = 0.2mm (0.000656 ft.) per HEC-18.  The project Geotechnical Engineer will make adjustments based on the soil borings once available.
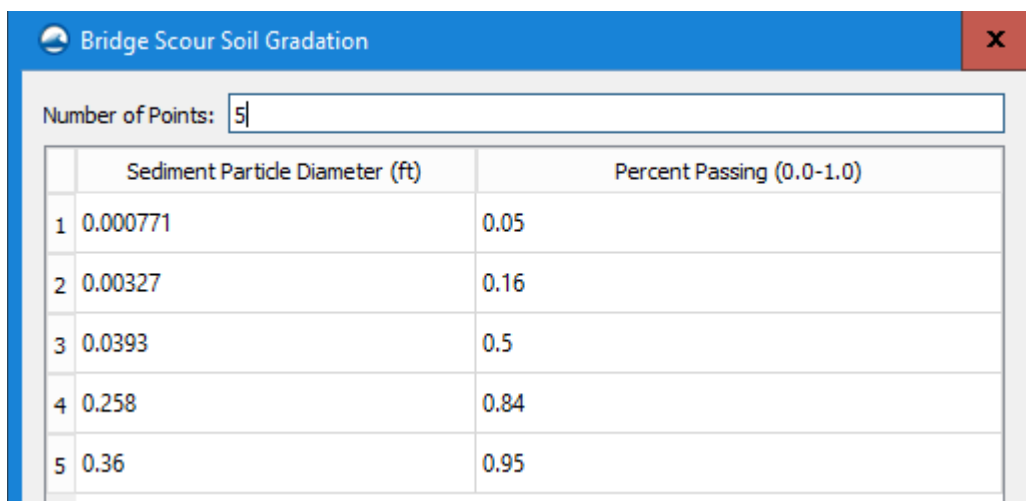
*A–006.034 Pier Scour – Local Approach Arc*

The pier scour tool generates a local approach arc based on the specified upstream offset for pier hydraulics. The objective is to find a point just upstream of the piers, where the local flow direction and magnitude has not yet been influenced by the pier itself. By default (enter an offset width of 0.0), SMS uses the length of the longest pier, and creates an arc that is a copy of the contracted arc offset that distance upstream. SMS performs a stream-trace upstream from each pier to intersect to this local approach arc. These locations are used to compute the local velocity and depth for each pier. This arc is also analyzed to determine the point of highest unit discharge. The velocity and depth at this location is used for the pier scour analysis of any piers set to a scour reference of "Thalweg". Results shall be reviewed to determine if one max pier length is adequate. The user shall document the specified offset and provide an image depicting an approximation of the SMS approach arc overlayed on a computed dataset for Unit Discharge. An example is provided in Figure A-8. Unit Discharge is defined as the velocity multiplied by the flow depth (q=V*y) and can be developed using the Dataset Calculator.
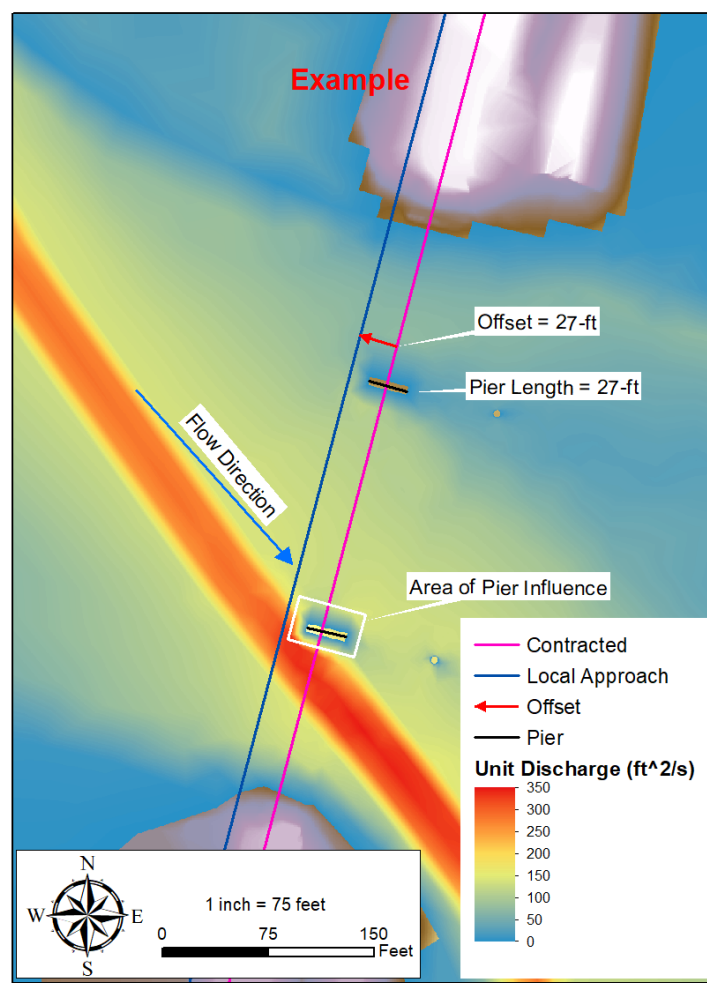


*Figure A-8: Pier Scour Local Approach Arc and Unit Discharge*

*A–006.035 Pressure Flow*

If pressure flow scour is anticipated, users shall document selection of the bridge deck for computations.

*A–006.036 Abutment Scour*

Users shall document the National Cooperative Highway Research Program (NCHRP) method for abutment scour condition and provide exhibits documenting the abutment setback to validate the choice of either main channel or overbank.

NCHRP Abutment Scour Condition

Left Abutment: Scour Condition a (Main Channel) ⌄   Right Abutment: Scour Condition a (Main Channel) ⌄
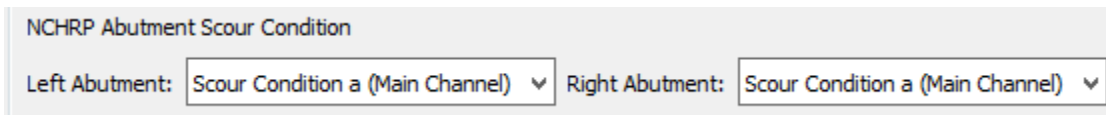
*A–006.037 Scour Tool Output*

All SRH-2D output files and SMS scour linework shall be provided to IDOT for review. Using the view values tool, the users shall provide a printout of the hydraulic parameters exported to the hydraulic toolbox. Figure A-9 is an example printout of the parameters from the scour tool.

```
APPROACH SECTION HYDRAULIC PARAMETERS:


Entire approach cross section:

Energy grade line slope at the approach section (ft/ft)        0.0032779
Total flow in the approach section (cfs)                       34876
Total flow area of the approach section (ft^2)                 10769.3
Total wetted perimeter of the approach section (ft)            1446.09


Main channel (approach):

Approach section left bank station (ft)                        842.3
Approach section right bank station (ft)                       1132.39
Approach section main channel width (ft)                       290.093
Approach section main channel flow (cfs)                       28578.3
Approach section main channel flow area (ft^2)                 4772.64
Approach section main channel wetted perimeter (ft)            298.233
Approach section main channel hydraulic radius (ft)            16.0031
Approach section main channel hydraulic depth (ft)             16.4521
   (used for average depth upstream of contraction)
Approach section main channel maximum depth (ft)               30.512
Approach section main channel unit discharge (cfs/ft)          98.5141
Approach section main channel average velocity (ft/s)          5.98794

Approach section critical velocity (ft/s)                      4.81316


Left overbank (approach; Used for overbank contraction scour calculations):

Left overbank station (ft):               842.3
Left overbank average flow depth (ft):                         3.32154
Left overbank average velocity (ft/s):                         4.41515
Left overbank flow width (ft):                                 691.01
Left overbank flow (cfs):                                      10133.7
Left overbank unit discharge (cfs/ft):                         14.6651


Right overbank (approach; Used for overbank contraction scour calculations):

Right overbank station (ft):              1132.39
Right overbank average flow depth (ft):                        8.62509
Right overbank average velocity (ft/s):                        5.64909
Right overbank flow width (ft):                                453.877
Right overbank flow (cfs):                                     22114.6
Right overbank unit discharge (cfs/ft):                        48.7239
```

*Figure A-9 Example Scour Tool Printout*

**A–006.04 Hydraulic Toolbox**

SMS leverages the FHWA Hydraulic Toolbox to compute scour based on the values extracted by SMS. The hydraulic toolbox file exported from SMS shall be provided to IDOT.  Users shall ensure that the latest version of SMS has been downloaded, which includes the most up to date version of the Hydraulic Toolbox.

Results of the Hydraulic Toolbox shall be provided along with plots of computed scour.  Results of the scour analysis shall be summarized in the Hydraulic Report according to guidance provided in Chapter 10 of the Drainage Manual.

*A–006.041 Hydraulic Toolbox Exceptions*

The SMS scour analysis tool and Hydraulic Toolbox are appropriate for most scour analysis; however, unique cases may occur that require special consideration of scour parameters selected by SMS or even use of external tools for computing scour.  **Engineering judgment is essential to determining the scour potential at a given site.**  An example includes multiple parallel bridges with offset piers or a severe angle of attack like what is shown in Figure A-10.
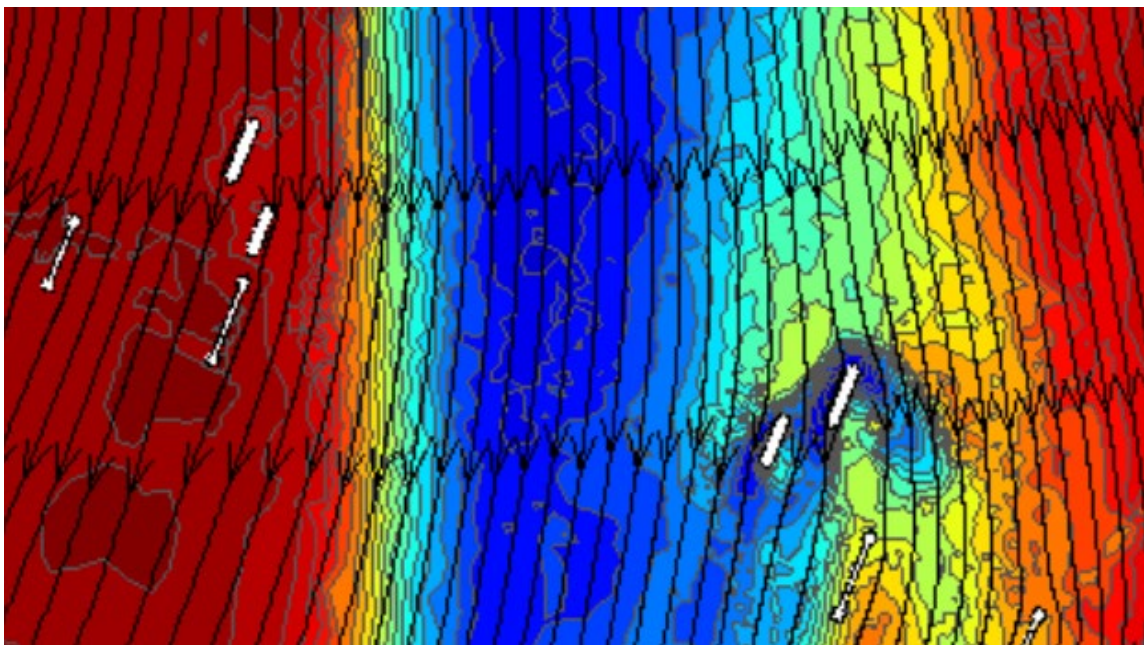


*Figure A-10 Example of a Unique Scour Case*

In special cases users may override the values exported to the Hydraulic Toolbox.  Any inputs that are user specified shall be well documented and early coordination with appropriate District staff is recommended if the engineer anticipates the potential for significant impacts to the design of the structure.  Additional correspondence with the IDOT Central Office may be requested by District staff if additional engineering discussion and guidance is needed.  The Hydraulic Report should specify the specific Model node where values were extracted, or the location of observation lines used to extract Model values.

The SMS view values tool allows users to view the scour parameters extracted from SMS. User's may export the SMS scour parameters to an alternative scour calculator including use of hand calculations and spreadsheets. Results from use of alternative methods shall be compared to results from the Hydraulic Toolbox and documented in the Hydraulic Report. An explanation shall be provided for any discrepancies between the toolbox and alternative methods.

The criteria outlined in this section represents the minimum requirements for documentation and reporting on 2-D Scour Analysis. Additional documentation may be provided at the user's discretion. All scour calculations shall be performed in accordance with guidance provided in Chapter 10 of the Drainage Manual and HEC-18.

### A–007 2-D Waterway Information Table Procedure & Recommendations

### A–007.01 Introduction

The following summarizes the approach that should be taken to develop and IDOT Waterway Information Table (WIT) from 2-D Hydraulic Model results. The process of documenting some of the WIT data remains unchanged from the typical 1-D Model process. Other procedures, specifically related to water surface elevations and created head, should be documented as outlined below. See the Raster Generation section for additional details on calculating created head. This procedure and associated tools have been developed by IDOT in coordination with Aquaveo and is specific to SMS Version 13.2.10.

1) **Flood Frequencies/Discharges** – The guidelines outlined in the Drainage Manual should be referenced to determine which frequencies to include in the WIT.

2) **Waterway Opening** – The waterway opening should be measured below the natural water surface elevation established in the WIT for each profile per the Drainage Manual. A uniform water surface elevation should be assumed for this measurement rather than a variable water surface produced by the 2-D Model.

3) **Natural HWE** – The natural water surface elevations should be established for each frequency by recording the maximum water surface elevation along an observation line of the natural conditions dataset at the upstream bridge face from edge-of-floodplain to edge-of-floodplain. Location of the observation line should be documented in an exhibit along with the location of the peak water surface elevation.

4) **Created Head** – Created Head values should be established as the maximum depth above natural conditions within the generated cross sections in the area upstream of the study structure embankment (See Calculating Created Head). Documentation of the location of the greatest created head should be provided.

   - *Notes: There may be situations where modeling noise or geometric oddities produce unexpected results, such as localized water surface increases, outside of the area of interest for the study bridge. In such situations, the modeler can choose to establish a created head area coverage polygon and utilize the maximum created head within this limit. The created head coverage should define the area of interest where created head is being generated by the study structure. The coverage polygon should be limited to the area*

*upstream of the embankment and, at a minimum, it should include the channel and overbank areas between the bridge abutments from the centerline of the embankment to the upstream boundary of the Model domain. If an alternate approach is utilized in lieu of taking the maximum created head within the Model domain, coordination with IDOT should occur for concurrence on the established created head for the project and documentation of the process should be provided.*

5) **Headwater Elevation –** Headwater Elevation should continue to be established by adding the maximum created head to the established natural water surface elevation at the bridge face for each profile per the Drainage Manual.

6) **10-Year Velocity –** The existing and proposed 10-year velocities should continue to be established by dividing the 10-year discharge by the 10-year waterway opening for each condition per the Drainage Manual.

### A–007.02 Calculating Created Head

The following steps should be taken to develop cross sections of the simulation results for use in developing the WIT.  Cross sections will be generated using WSE contour lines at specified WSE intervals, which may vary depending on location. This procedure and associated tools have been developed by IDOT in coordination with Aquaveo and is specific to SMS Version 13.2.

1) In the Display Options, turn on 2D mesh contours in the **2D Mesh** tab. In the **Contours** tab, set the contour method to ==Color Fill and Linear== and select **Specified Interval** for the contour interval. Once the contour interval is selected, hit OK.
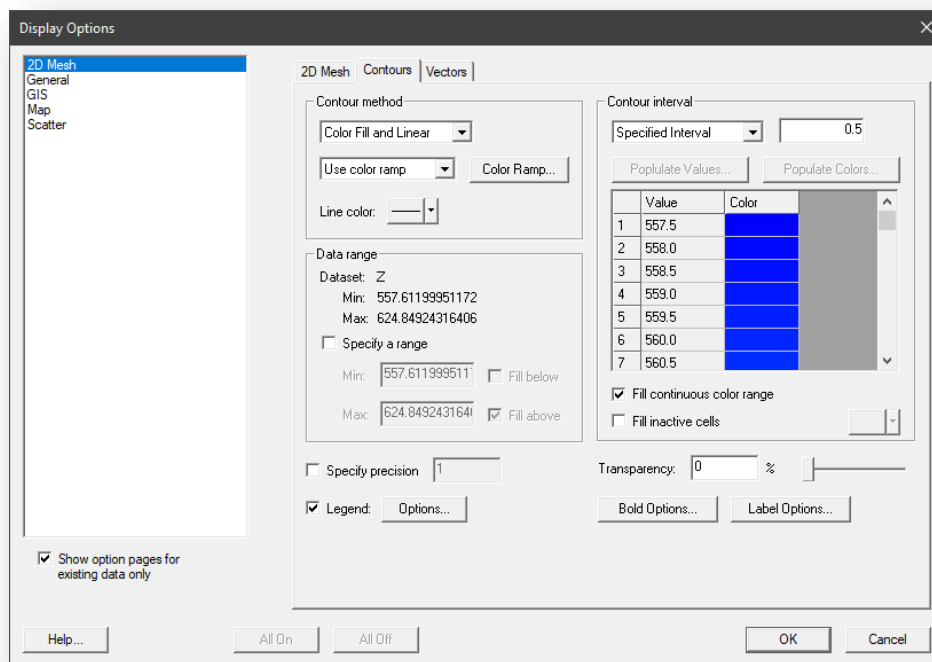
a. **Optional:** For nice, even contour intervals, check **Specify a range** and round the Min elevation down to the nearest tenth of a foot. This will provide a nice starting point for the contour intervals.

b. To eliminate the down stream contour lines, edit the WSE data range so that only upstream cross sections are displayed. Contour lines can also be manually deleted later in the process.

c. To view contour labels, select **Label Options** and check **Automatic labels**. In the drop-down menu, select **One label per contour**.
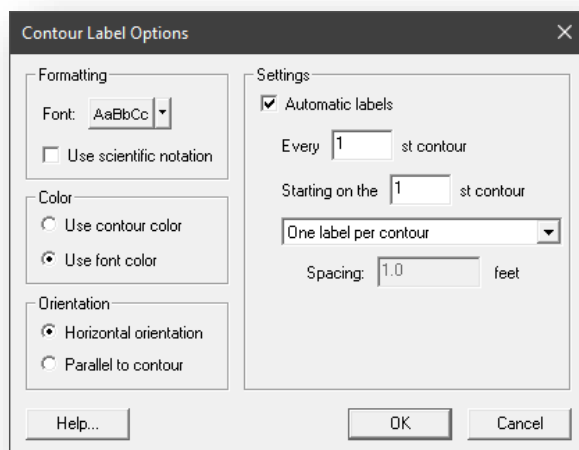


2) Next, export the contour lines into a shape file. With the desired WSE contours **active**, right click on the corresponding mesh, and select **Export**. Give the shape file a name and make sure the save type is set to **Contours to Line Shapefile (*.shp)**.
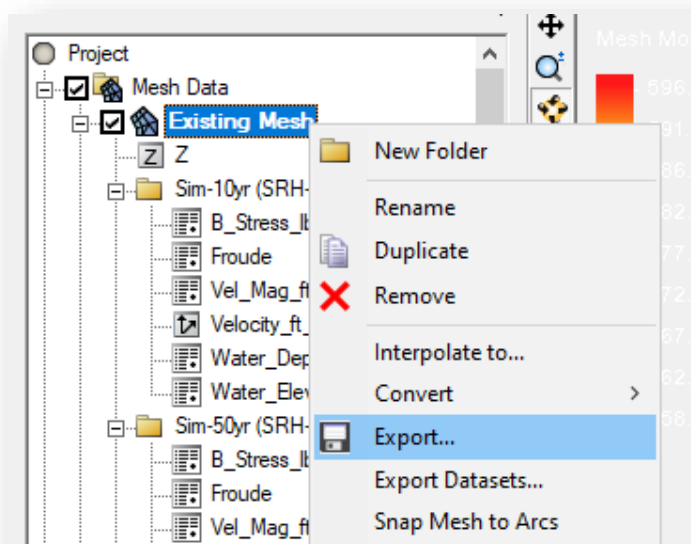
a. A shapefile will be created but will need to be brought into the project. The shapefile can be found in the same location as the project file. Simply drag and drop the new shapefile into the SMS Project Explorer. The shapefile will appear under GIS Data.
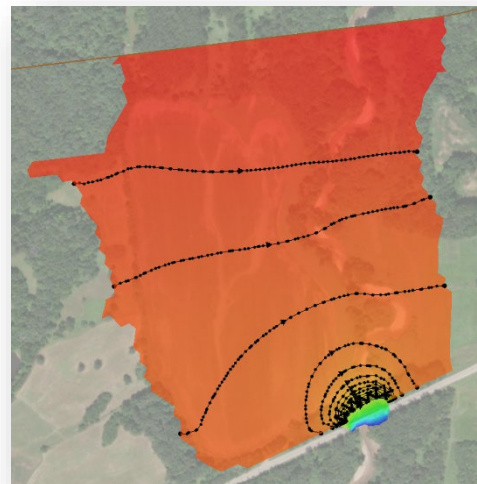


b. Next, create a **1D-Hyd Cross Sections** coverage by right clicking on **Map Data** and then selecting **New Coverage**. This is where will store our contour lines. A centerline error message will appear but proceed anyway. A centerline coverage will be created once the cross sections are generated.

3) Convert the shape file into feature objects by right clicking on the shapefile and selecting **Convert**, **Shapes -> Feature Objects**.
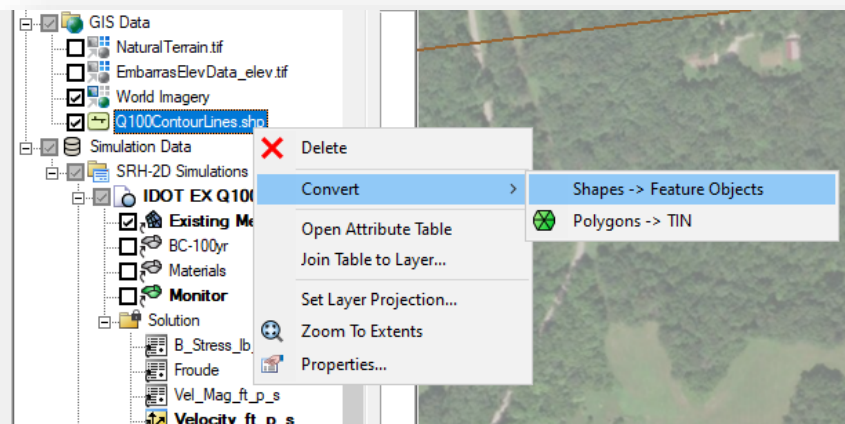
a. The GIS Wizard will appear. In the drop down menu in Step 1, select the cross section coverage created earlier and hit **Next**. Leave step 2 how it is and select **Finish**.
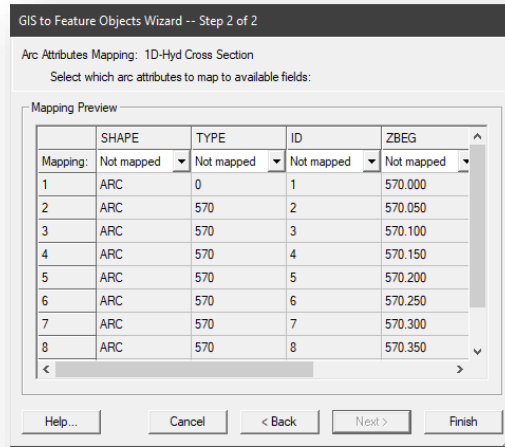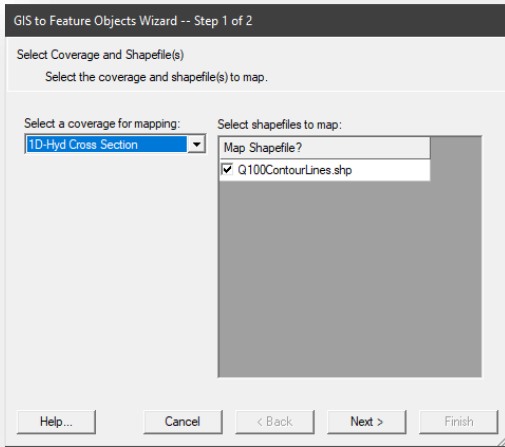


b. Using the **Select Feature Arc** tool, delete unnecessary contour lines.
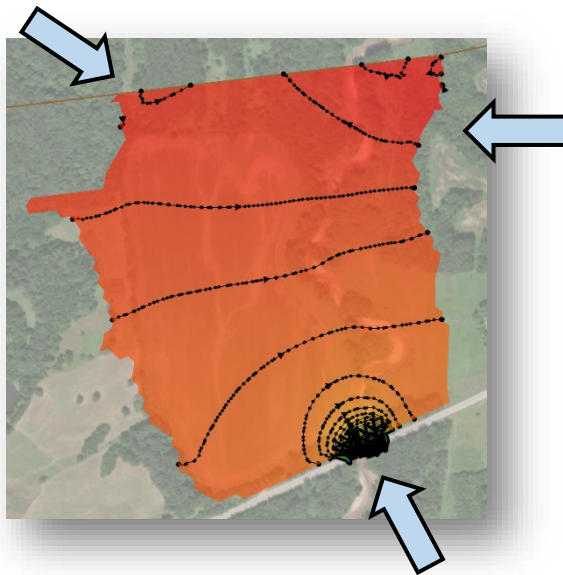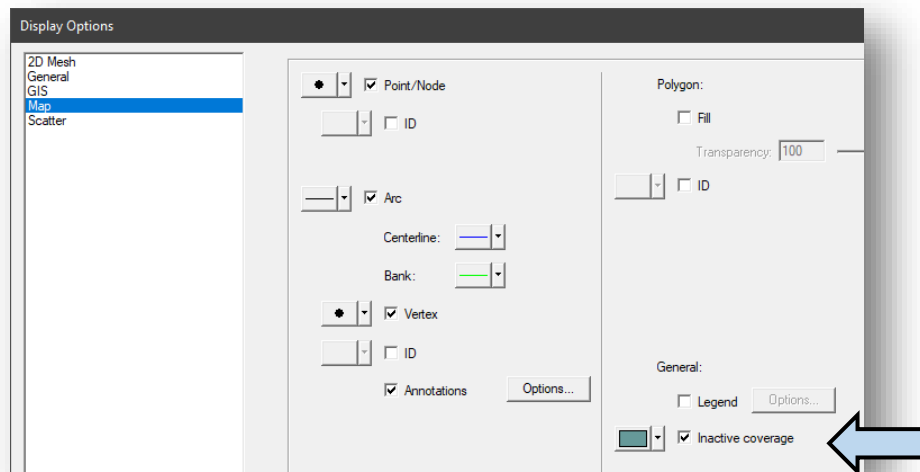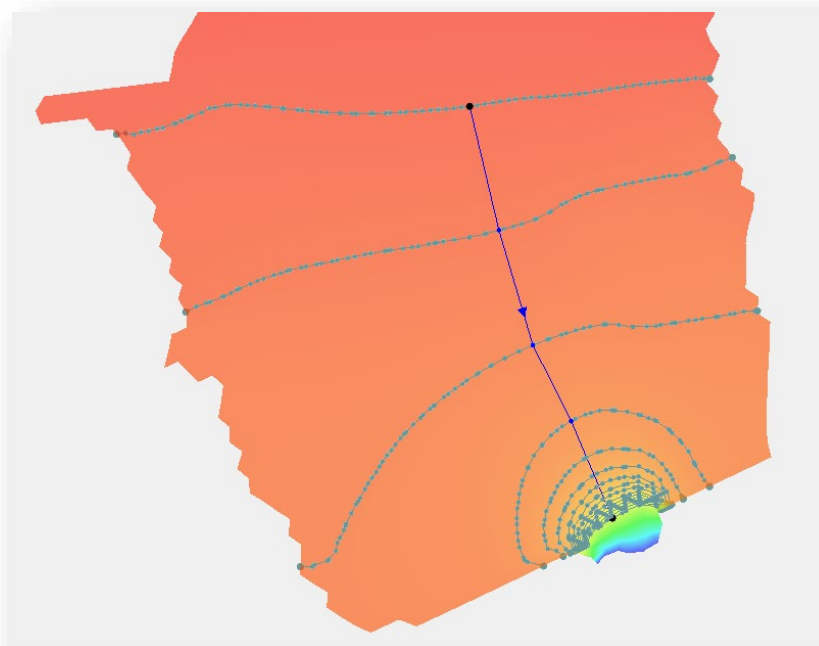
4) Create a **1D-Hyd Centerline** coverage by right clicking on **Map Data** and selecting **New Coverage**. To assist in the centerline generation, turn on the inactive coverage in the Map display options.



a. With the cross section coverage showing as inactive, use the cross section vertices to create a centerline. It is important to snap to the first and last cross sections going from **upstream to downstream**. Every cross section in between does not need to be snapped to but is recommended when possible. Wherever the cross section intersects the centerline will be considered that cross section's station, with the most downstream cross section considered station 0.



**Note:** Centerline does not need to align with channel but should follow the midpoint of the cross sections.

5) Now that the centerline coverage created, it must be assigned to the cross section coverage. Right click on the **1D-Hyd Cross Sections** coverage and select **Assign centerline overage**. Select the centerline coverage just created.
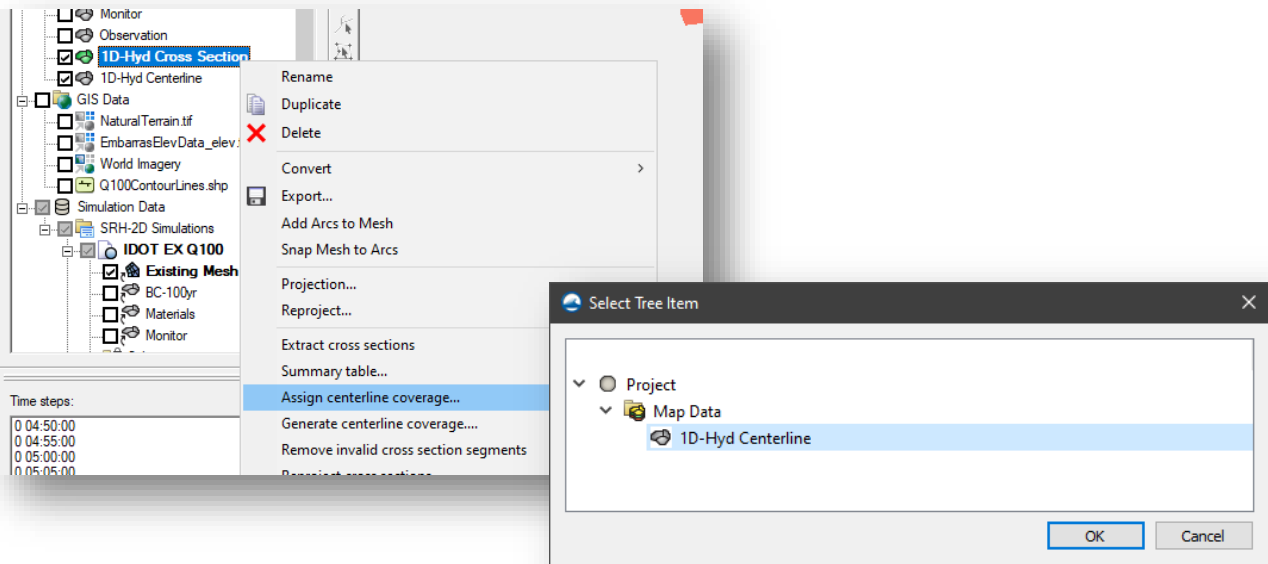


6) Generate summary tables by right clicking the cross section coverage and selecting **Summary table** (Shown in image above). The table will appear empty but will populate after a **Data source** is selected. Once the datasets are selected, hit **Generate table…**
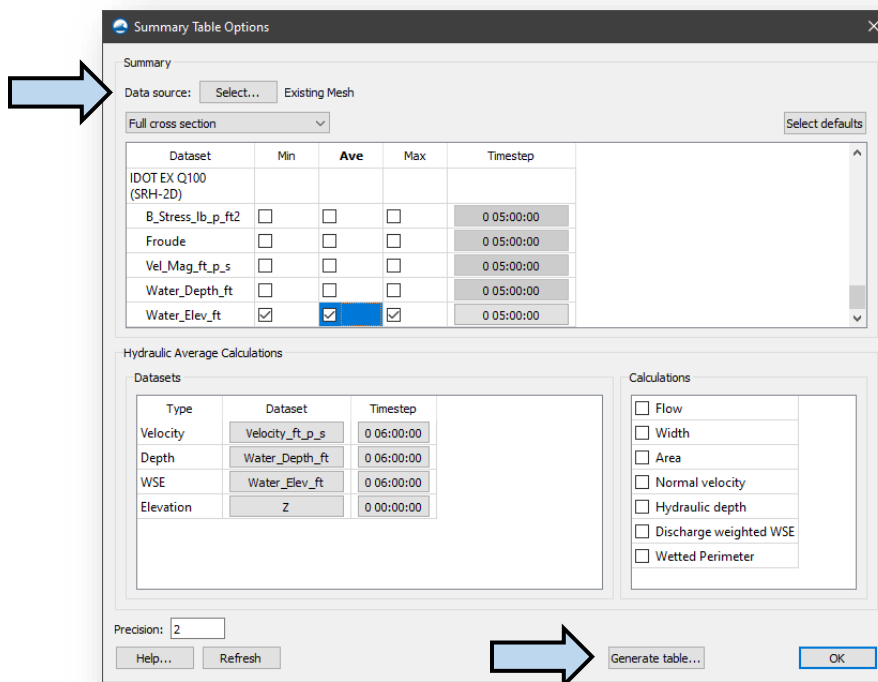
a.  The following table will populate. From here, hit **Copy to clipboard** and paste the results in a spreadsheet.

**Summary Table**

Summary

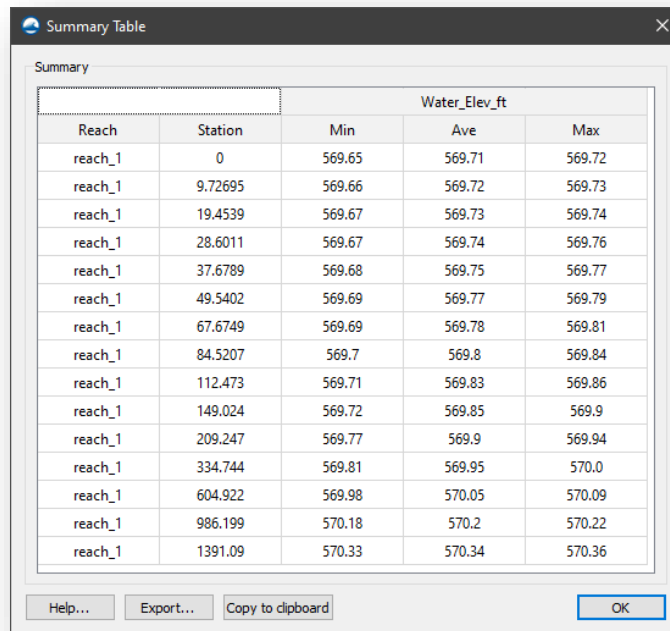| | | | Water_Elev_ft | |
| Reach | Station | Min | Ave | Max |
| --- | --- | --- | --- | --- |
| reach_1 | 0 | 571.8 | 571.8 | 571.8 |
| reach_1 | 9.72695 | 571.85 | 571.85 | 571.85 |
| reach_1 | 19.4539 | 571.9 | 571.9 | 571.9 |
| reach_1 | 28.6011 | 571.95 | 571.95 | 571.95 |
| reach_1 | 37.6789 | 572.0 | 572.0 | 572.0 |
| reach_1 | 49.5402 | 572.05 | 572.05 | 572.05 |
| reach_1 | 67.6749 | 572.1 | 572.1 | 572.1 |
| reach_1 | 84.5207 | 572.15 | 572.15 | 572.15 |
| reach_1 | 112.473 | 572.2 | 572.2 | 572.2 |
| reach_1 | 149.024 | 572.25 | 572.25 | 572.25 |
| reach_1 | 209.247 | 572.3 | 572.3 | 572.3 |
| reach_1 | 334.744 | 572.35 | 572.35 | 572.35 |
| reach_1 | 604.922 | 572.4 | 572.4 | 572.4 |
| reach_1 | 986.199 | 572.45 | 572.45 | 572.45 |
| reach_1 | 1391.09 | 572.5 | 572.5 | 572.5 |

Help...    Export...    Copy to clipboard    OK

b.  Repeat this process for the Natural Q100 by changing the **Data source** in the **Summary Table Options**. Select the Natural Mesh and Q100 WSE.

**Summary Table**

Summary

| | | | Water_Elev_ft | |
| Reach | Station | Min | Ave | Max |
| --- | --- | --- | --- | --- |
| reach_1 | 0 | 569.65 | 569.71 | 569.72 |
| reach_1 | 9.72695 | 569.66 | 569.72 | 569.73 |
| reach_1 | 19.4539 | 569.67 | 569.73 | 569.74 |
| reach_1 | 28.6011 | 569.67 | 569.74 | 569.76 |
| reach_1 | 37.6789 | 569.68 | 569.75 | 569.77 |
| reach_1 | 49.5402 | 569.69 | 569.77 | 569.79 |
| reach_1 | 67.6749 | 569.69 | 569.78 | 569.81 |
| reach_1 | 84.5207 | 569.7 | 569.8 | 569.84 |
| reach_1 | 112.473 | 569.71 | 569.83 | 569.86 |
| reach_1 | 149.024 | 569.72 | 569.85 | 569.9 |
| reach_1 | 209.247 | 569.77 | 569.9 | 569.94 |
| reach_1 | 334.744 | 569.81 | 569.95 | 570.0 |
| reach_1 | 604.922 | 569.98 | 570.05 | 570.09 |
| reach_1 | 986.199 | 570.18 | 570.2 | 570.22 |
| reach_1 | 1391.09 | 570.33 | 570.34 | 570.36 |

Help...    Export...    Copy to clipboard    OK

| Existing | Water Elevation (ft) | | | Natural | Water Elevation (ft) | | | Cr. Head |
|---|---|---|---|---|---|---|---|---|
| Station | Min | Ave | Max | Station | Min | Ave | Max | |
| 0 | 571.8 | 571.8 | 571.8 | 0 | 569.65 | 569.71 | 569.72 | 2.09 |
| 9.72695 | 571.85 | 571.85 | 571.85 | 9.72695 | 569.66 | 569.72 | 569.73 | 2.13 |
| 19.4539 | 571.9 | 571.9 | 571.9 | 19.4539 | 569.67 | 569.73 | 569.74 | 2.17 |
| 28.6011 | 571.95 | 571.95 | 571.95 | 28.6011 | 569.67 | 569.74 | 569.76 | 2.21 |
| 37.6789 | 572 | 572 | 572 | 37.6789 | 569.68 | 569.75 | 569.77 | 2.25 |
| 49.5402 | 572.05 | 572.05 | 572.05 | 49.5402 | 569.69 | 569.77 | 569.79 | 2.28 |
| 67.6749 | 572.1 | 572.1 | 572.1 | 67.6749 | 569.69 | 569.78 | 569.81 | 2.32 |
| 84.5207 | 572.15 | 572.15 | 572.15 | 84.5207 | 569.7 | 569.8 | 569.84 | 2.35 |
| 112.473 | 572.2 | 572.2 | 572.2 | 112.473 | 569.71 | 569.83 | 569.86 | 2.37 |
| 149.024 | 572.25 | 572.25 | 572.25 | 149.024 | 569.72 | 569.85 | 569.9 | 2.4 |
| 209.247 | 572.3 | 572.3 | 572.3 | 209.247 | 569.77 | 569.9 | 569.94 | 2.4 |
| 334.744 | 572.35 | 572.35 | 572.35 | 334.744 | 569.81 | 569.95 | 570 | 2.4 |
| 604.922 | 572.4 | 572.4 | 572.4 | 604.922 | 569.98 | 570.05 | 570.09 | 2.35 |
| 986.199 | 572.45 | 572.45 | 572.45 | 986.199 | 570.18 | 570.2 | 570.22 | 2.25 |
| 1391.09 | 572.5 | 572.5 | 572.5 | 1391.09 | 570.33 | 570.34 | 570.36 | 2.16 |

**Note:** Notice the Min, Ave, and max are the same for the existing summary table. This is because the Existing Q100 contour lines were used to generate the cross sections.
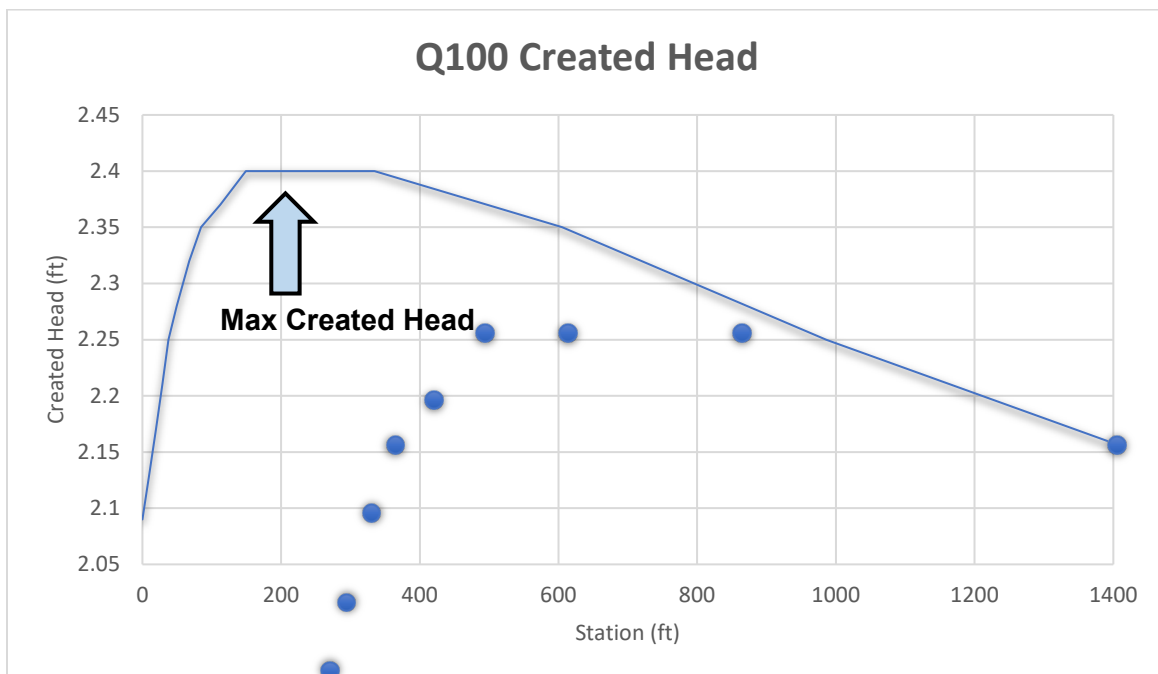
### A–008 List of References, Figures, Tables and Equations

### A–008.01 Table of Figures