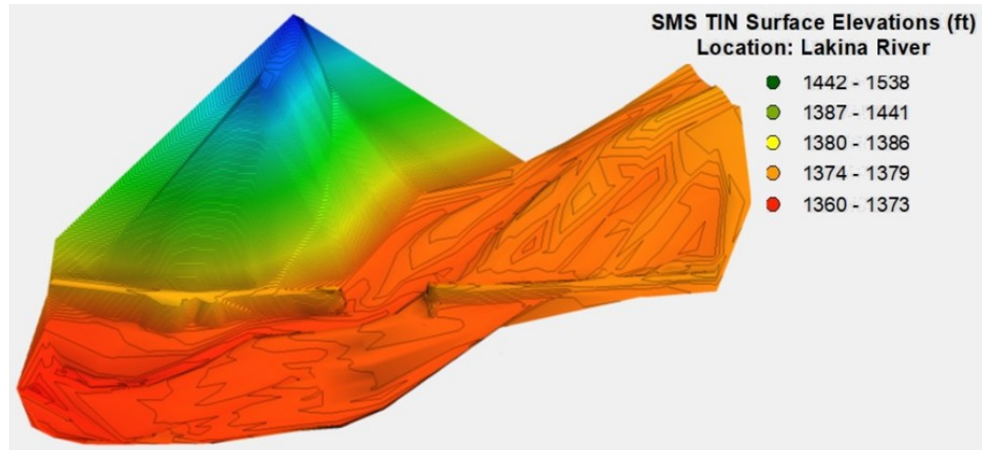


Developing Guidelines for Two-Dimensional Model Review and Acceptance



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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

To develop basic guidelines for two-dimensional (2D) model review and acceptance, we conducted an information search, and we compared the results of two models implemented by two modelers.

The information search consisted of a set of questions sent to five state departments of transportation. Of the three departments that responded, none has established criteria for 2D/3D hydraulic modeling.

In carrying out the hydraulic modeling efforts, we compared the results of the Sedimentation and River Hydraulics–2-Dimensional (SRH-2D) model and the Hydrologic Engineering Center River Analysis System 2-dimensional (HEC-RAS 2D) model. Two independent modelers ran simulations using both models. We compared water depth, velocity, and shear stress at two geographic settings: Lakina River and Quartz Creek in Alaska. Without calibration, it is impossible to know which of the two models is more accurate. Since the models were not calibrated due to the lack of basic field data (i.e., discharge, water surface elevation, and sediment characteristics), only the differences in the results were evaluated. The extent of the surveyed area and the density of the survey data for Quartz Creek were important limitations during the modeling scenarios; the survey data did not extend beyond the simulated flooding. We recommend that future surveys cover a larger area, especially when modeling low-gradient terrains.

The modelers selected different domain sizes and material properties, which were identified as sources of difference in the model results. Higher resolution base maps to better determine material property boundaries, surrounding roughness values, and site-specific channel material sizes would contribute greatly to the models' ability to improve simulation of the hydraulic conditions at a given geographic area.

Based on sensitivity analyses, HEC-RAS 2D was more susceptible to changes in material properties and produced slightly higher velocities. We recommend using the full dynamic wave equation (also referred to as the full momentum equation), unless the HEC-RAS 2D diffusion wave equation uses the smallest possible iteration time step. The diffusion wave equation would only be appropriate for straight channels with no flow contractions.

The developed guidelines consist of a questionnaire for reviewing 2D model results. A successful calibration is needed to accept a model. Models are comparable if they have been calibrated. The guidelines should provide the reviewer with an understanding of the modeling process and results.

We conducted a two-day hydraulic modeling training workshop for ADOT&PF hydraulic engineers in Fairbanks, Alaska. We supplied a workbook that explains the development of hydraulic models, starting from survey data and progressing through simulation execution. The workbook has two sections: SRH-2D and HEC-RAS 2D.

CHAPTER 1. INTRODUCTION

Hydraulic engineers working for consulting companies and/or state agencies have a number of tools at their disposal to perform design work. These tools include equations that can be solved explicitly (e.g., Manning's equation) or numerically (e.g., the backwater equation), and a series of numerical models with different levels of complexity (hydrodynamic; hydro-sedimentological; 1-, 2-, or 3-dimensional models).

While the use of numerical models has value, there are issues that should be addressed: the results generated by different models used should be compared, and to some extent, the results generated by different modelers should be assessed. Hydraulic engineers may use various free or commercially available modeling software programs. The lack of a standard approach in hydraulic modeling or lack of consistency in treatment of data adds a layer of complexity to the evaluation process of bridge design.

The Federal Highway Administration (FHWA) is promoting the use of two-dimensional (2D) models for bridge hydraulic simulations. The hydraulic engineers in the Alaska Department of Transportation and Public Facilities (ADOT&PF) intend to follow the FHWA's directions and develop expertise in two hydraulic models: the Sedimentation and River Hydraulics–2D model developed by the Bureau of Reclamation (USBR, 2017) and the River Analysis System 2D model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE, 2015).

This project included two phases:

- Phase 1 – Develop guidelines for 2D model review and acceptance.
- Phase 2 – Conduct a training workshop for ADOT&PF hydraulic engineers.

The details on Phase 1 are contained in this report. The details on Phase 2, which was completed March 1–2, 2017, are found in Appendix C.

CHAPTER 2. METHODOLOGY – PHASE 1

The specific objective of Phase 1 was to develop basic guidelines for 2D model review and acceptance. In developing the guidelines, we performed an information search and implemented the SRH-2D model and the HEC-RAS 2D model, comparing the model results. Neither model was calibrated due to the lack of basic field data (i.e., discharge, water surface elevation, and sediment characteristics). For this reason, it is impossible to know which model is more accurate. We have provided, therefore, only the differences between the model results.

2.1 Information Search

To assist in developing basic guidelines when reviewing 2D model results generated by other organizations, we sought the current knowledge and practices of five state DOTs, all of which were sent a list of questions. We obtained the names of states and contacts from S. Hogan at the Federal Highway Administration (FHWA), based on his knowledge that the contacts were actively working with 2D modeling. The questions sent to the five DOTs were provided by the ADOT&PF.

2.1.1 Questions Sent to State DOTs

The following questions, developed by the Statewide Hydraulic Engineer at ADOT&PF, were sent to five state DOTs:

1. Does your state have criteria for 2D/3D hydraulic model development, documentation, and/or acceptance? If so, please share. These might include:
 - Review check lists
 - Documentation standards/templates
 - Hydraulic site survey standards (for 2D models)
 - Model calibration information
 - Boundary control information
 - Sensitivity analyses
 - Error checks (e.g., continuity)
2. Has your state conducted comparisons between hydraulic models? If so, would you be willing to share your insights on these comparisons?
3. Has your state experienced shortcomings with 2D/3D modeling submittals (internal or from consultants)? If so, what are these?

2.1.2 State DOTs Contacted

The following state DOTs were contacted for this information search:

Montana DOT (MDT)
JR Taylor
Hydraulic Engineer
406-444-7636
jertaylor@mt.gov

Caltrans
Kevin Flora
Senior Hydraulic Engineer
916-799-1423
kevin.flora@dot.ca.gov

Colorado DOT (CDOT)
Brian Varrella
Hydraulic Engineer
970-350-2140
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Nebraska Department of Roads (NDOR)
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Oregon DOT (ODOT)
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Senior Hydraulic Engineer
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FOLTYN.Ed@odot.state.or.us

2.1.3 Responses Received

Of the five state DOTs contacted, only three responded: Montana, Oregon, and Colorado. Some of the responses are provided below.

Montana:

“We are currently in about the same position you are with the guidelines, trying to develop some basic guidelines for the use of 2D modeling. We actually haven’t even really breached the subject of 3D modeling yet.”

“With HEC-RAS 5.0 coming out and providing some limited 2D modeling capabilities at a VERY affordable price we are starting to get more and more consultants wanting to use HEC-RAS 5.0 to model bridge openings. Based on our current knowledge of HEC-RAS 5.0 in comparison to say SRH-2D we are still hesitant to accept HEC-RAS 5.0 models involving

bridge openings and scour analysis. What we have typically been doing to this point is asking for a 1-D HEC-RAS model as well that has been calibrated using the 2D HEC-RAS model.”

“As far as the use of other 2D models we have just started using SRH-2D in our Hydraulics office the last couple years and have yet to see much from consultants using some of the other 2D modelers.”

“So to answer your questions;

1. No, we currently do not have any set criteria in regards 2D/3D Hydraulic Modeling. We have done a couple models in house and have used varying degrees of survey, calibration, and boundary control information. We have yet to really develop any kind of documentation standards or checklists either.
2. We have done some basic comparisons between HEC-RAS 4.1 and SRH-2D and found that you can develop a fairly comparable 1D model from a 2D model and vice versa. Typically, I have been using a 2D model to calibrate 1D models that need to be submitted for floodplain permits.
3. We have not yet seen any real shortcomings with our internal submittals other than a lack of understanding from other disciplines who were not accustomed to seeing the bridge opening recommendation and report presented in 2D layout; i.e., 2D modeling creates a WSEL contour map vs. HEC-RAS and the set cross-sections with one WSEL across it.”

“As things progress over the next several months I will send you an update of any changes or developments that we may have come up with. I anticipate that the 2D modeling is something we should be seeing more and more of so we will need a way to handle these new types of submittals.”

Oregon:

“We are early in our usage of 2D models and are just starting to use SRH-2D. We have not developed any protocols at this time.”

Colorado:

“These questions are too specific to have helpful answers. We have standards of practice, but they are neither codified nor supported with ‘state’ guidance.”

2.1.4 Results of Information Search

None of the three state DOTs that responded to our request for information currently have criteria established for 2D/3D hydraulic modeling. The responses received indicate that the three state DOTs are in the beginning phases of developing their own guidelines for 2D modeling.

2.2 Model and Modeler Comparisons

2.2.1 Research Approach

Simulations from two models—SRH-2D and HEC-RAS 2D—were performed in two different morphological settings (straight vs. meandering stream channels) by Brett Wells, a recent University of Alaska master’s degree graduate, and Joel Homan, a Post-Doc at the University of Alaska Fairbanks. The goal of this task was to compare the similarities and differences between results obtained by two independent users. Additionally, Homan performed a sensitivity analysis of key parameters involved in each model. Specifically, basic model parameters were varied within their published range (i.e., the range reported in the literature), and results were compared across the models. All generated results were compiled and compared.

2.2.2 Numerical Models

2.2.2.1 Sedimentation and River Hydraulics – 2D Model

The Sedimentation and River Hydraulics–2-Dimensional (SRH-2D) model is a 2D hydraulic model for river systems that was developed at the Bureau of Reclamation (Aquaveo, 2017a; USBR, 2017). The SRH-2D model solves 2D depth-averaged Saint Venant equations: the continuity equation (also referred to as the law of conservation of mass) and the full momentum equation (also referred to as the dynamic wave equation). The modeling capability of SRH-2D is comparable to some existing 2D models, but SRH-2D has additional features. First, SRH-2D uses a flexible mesh that may contain arbitrarily shaped cells. In practice, the hybrid mesh of quadrilateral and triangular cells is recommended, though purely quadrilateral or triangular elements may be used. A hybrid mesh may achieve the best compromise between solution accuracy and computing demand. Second, SRH-2D adopts robust and stable numerical schemes with a seamless wetting/drying algorithm. The outcome is that few tuning parameters are needed to obtain the final solution (Aquaveo, 2017c).

We used the Surface-water Modeling System (SMS) with the SRH-2D model. The SMS is a complete program for building and simulating surface water models (Aquaveo, 2017a, 2017b). As a graphical user interface and analysis tool, SMS allows engineers and scientists to visualize, manipulate, analyze, and understand numerical data and associated measurements. Many of the tools in SMS are generic; they are designed to facilitate the establishment and operation of numerical models of rivers.

2.2.2.2 Hydrologic Engineering Center River Analysis System 2D Model

The Hydrologic Engineering Center River Analysis System (HEC-RAS) 2D model was developed with U.S. federal government resources by the U.S. Army Corps of Engineers and is, therefore, in the public domain (Brunner, 2015; USACE, 2017). The HEC cannot provide technical support to non-Corps users.

The HEC-RAS 2D model is designed to perform hydraulic calculations for a full network of natural and constructed channels; it also has the ability to perform 2D hydrodynamic routing within the unsteady-flow analysis portion of the model. Users can now perform 1D unsteady-flow modeling, 2D unsteady-flow modeling, as well as combined 1D and 2D unsteady-flow routing (Brunner, 2015).

The 2D unsteady-flow equation solver uses an implicit finite volume algorithm. The implicit solution algorithm allows for larger computational time steps than explicit methods. The wetting and drying scheme of 2D cells is robust. Two-dimensional flow areas can start completely dry and handle a sudden rush of water into the area. Additionally, the algorithm handles subcritical, supercritical, and mixed flow regimes (flow passing through critical depth, such as a hydraulic jump) (Brunner, 2015).

The software was designed to use unstructured computational meshes (Brunner, 2015; USACE, 2017), but can handle structured meshes. A structured mesh is treated the same as an unstructured mesh, except the software takes advantage of cells that are orthogonal to each other (which simplifies some of the computations required). This means that computational cells can be triangles, squares, rectangles, or even five- and six-sided elements (the model is limited to elements with up to eight sides). The mesh can be a mixture of cell shapes and sizes.

Mapping of the inundated area, as well as animations of the flooding, can be done inside of HEC-RAS 2D using the RAS Mapper features. The mapping of 2D flow areas is based on the detailed underlying terrain, which means that the wetted area is based on the details of the underlying terrain, not the computational mesh cell size. Computationally, cells can be partially wet or dry (this is how they are computed in the computational algorithm). Mapping of the results reflect those underlying terrain details, rather than being limited to showing a computational cell as either all wet or all dry.

2.2.3 Comparison of Numerical Models

Table 1 shows a comparison of the two models evaluated: SRH-2D and HEC-RAS 2D. Information for this comparison came from Aquaveo (2017b, 2017c), Brunner (2015), and USBR (2017).

Table 1: Main characteristics of SRH-2D and HEC-RAS 2D models.

	SRH-2D	HEC-RAS 2D
Cost	Free, \$, \$\$, \$\$\$, \$\$\$\$	Free
Information Resources	Excellent	Very Poor
Numerical Equations	St. Venant	St. Venant
Simulated States	Steady or Unsteady	Steady or Unsteady
Implicit Finite Volume	X	X
Mesh	Hybrid mesh of quadrilateral and triangular cells	Triangles, squares, rectangles, or even five and six-sided elements
Flow Regimes	Subcritical, Transcritical, & Supercritical	Subcritical, Transcritical, & Supercritical
Wetting-Drying	Robust and Seamless	Robust and Seamless
Solves for	Water Surface Elevation, Water Depth, Depth Averaged Velocity, Froude Number, Bed Shear Stress, Critical Sediment Diameter, Sediment Transport Capacity	Water Surface Elevation, Water Depth, Depth Averaged Velocity, Froude Number, Bed Shear Stress,
User Friendly	Very	Fair
Internal Hydraulic Structures	Fair	Poor

2.2.4 Implementation Sites and Data

2.2.4.1 Lakina River

The ADOT&PF replaced the bridge over the Lakina River (Figure 1) at Milepost 44, McCarthy Road, in Alaska (ADOT&PF, 2013; M.W. Knapp, personal communication, 2016–17). For the model simulation, we used the ground survey data collected by ADOT&PF for the bridge replacement project.

The Lakina River originates from the Lakina Glacier and the southern flanks of Mt. Blackburn, and flows into the Chitina River (Wikipedia, 2017). Carving through geologically new mountains, the Lakina River is steep and narrow.



Figure 1: Lakina River (photo provided by M.W. Knapp, ADOT&PF).

2.2.4.2 Quartz Creek

The ADOT&PF is working on replacing the bridge over Quartz Creek (Figure 2) at Milepost 0.7, Quartz Creek Road, in Alaska (ADOT&PF, 2015; M.W. Knapp, personal communication, 2016–17). For the model simulation, we used the ground survey data collected by ADOT&PF for planning the bridge replacement.

Quartz Creek is a stream on the Kenai Peninsula that drains into Kenai Lake. Quartz Creek waters are typically slow, deep, and meandering, providing an example for the use of 2D modeling where the consideration of lateral flow is necessary.



Figure 2: Quartz Creek (photo provided by M.W. Knapp, ADOT&PF).

2.2.5 Background Data for Modeling Comparisons

The first step in using any numerical model is to gather available data, the information needed to perform a hydraulic analysis.

2.2.5.1 Elevation Data

Elevation (or geometry) is the most important data in 2D hydraulic modeling. Elevation data represent the surface over which water flows (riverbed, floodplain). A model requires a geometric representation (Aquaveo, 2017b; Brunner, 2015).

The elevation data used in our investigation and implementation of two numerical models were collected by the ADOT&PF. During ground-based surveys in fall 2013 (Lakina River) and spring 2015 (Quartz Creek), elevation data were obtained for the purpose of bridge replacement projects (ADOT&PF, 2013; ADOT&PF, 2015; M.W. Knapp, personal communication, 2016–17). Both the Lakina River and Quartz Creek surveys were collected in a U.S. Survey Feet local surface grid coordinate system developed by ADOT&PF.

Transformation parameters were used to convert the local coordinate systems into Alaska State Plan coordinate systems: Zone 4 for Lakina River and Zone 2 for Quartz Creek. The Lakina River surveys (Figure 3) were conducted within an approximately 26-acre area and consist of 2048 scatter points. The Quartz Creek surveys (Figure 4) were conducted within an approximately 38-acre area and include 4144 scatter points (ADOT&PF, 2013; ADOT&PF, 2015; M.W. Knapp, personal communication, 2016–17).

2.2.5.2 Hydraulic Conditions

Hydraulic data define the conditions that the model simulates (Aquaveo, 2017b; Brunner, 2015). The hydraulic data include flow rates, water levels, and hydraulic structures. These types of hydraulic data come from river gauges, flow meters, high-water marks, or other sources. Discharge estimates for the Lakina River (Table 2) were provided by ADOT&PF. Discharge values for Quartz Creek (Table 2) were estimated using U.S. Geological Survey (USGS) StreamStats, a tool for computing regional regression-based flood frequency estimates and associated prediction intervals for unregulated streams in Alaska and conterminous basins in Canada. The estimations are based on methods determined by the U.S. Geological Survey (USGS, 2017). The values entered into StreamStats are as follows (M.W. Knapp, personal communication, 2016–17):

- Drainage area (in square miles):~110 square miles
- Mean annual precipitation from the 1971–2000 PRISM data (in inches): ~46.5 inches
- Downstream boundary control, “normal depth” slope: 0.003

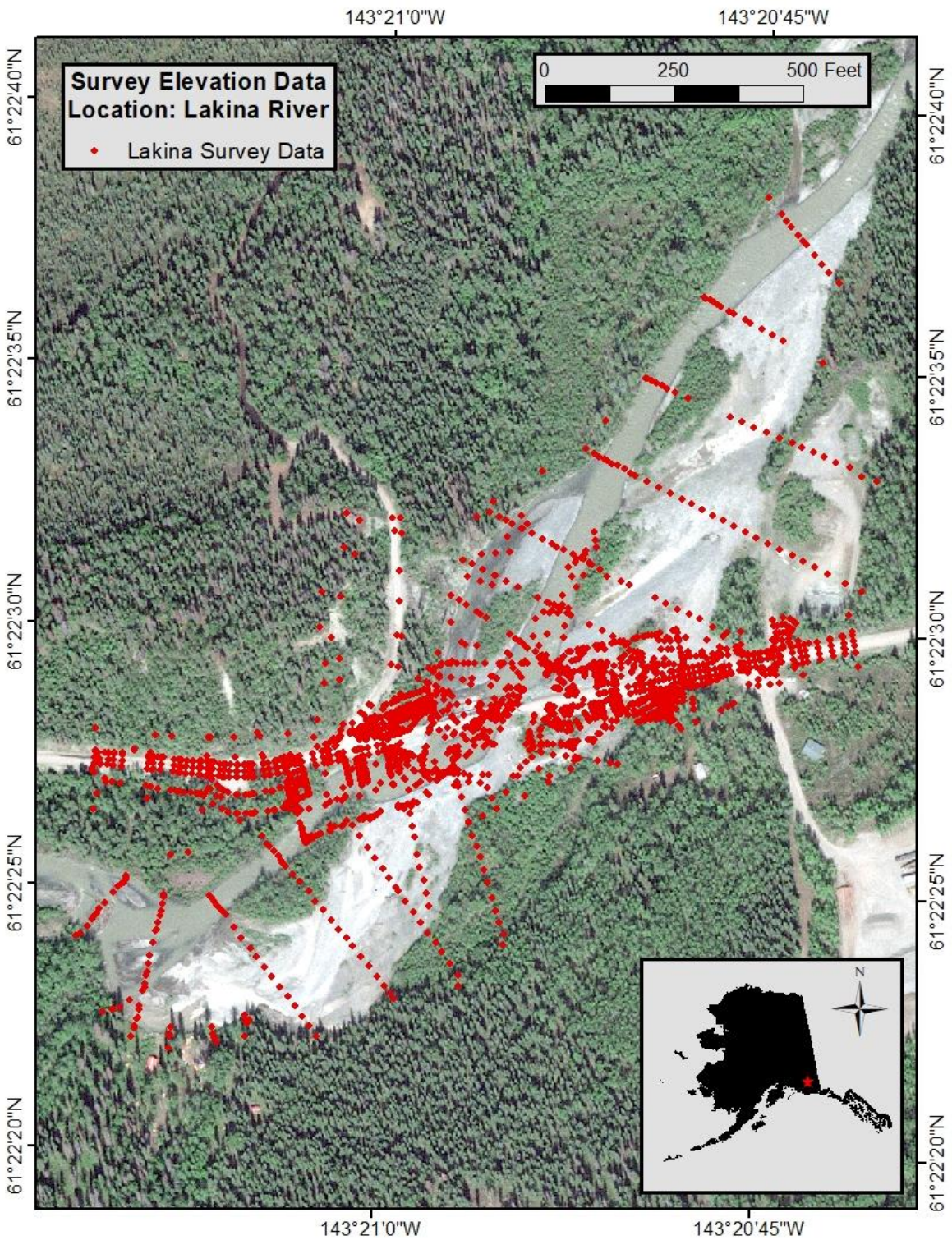


Figure 3: Lakina River image (provided by M.W. Knapp, ADOT&PF) and survey points.

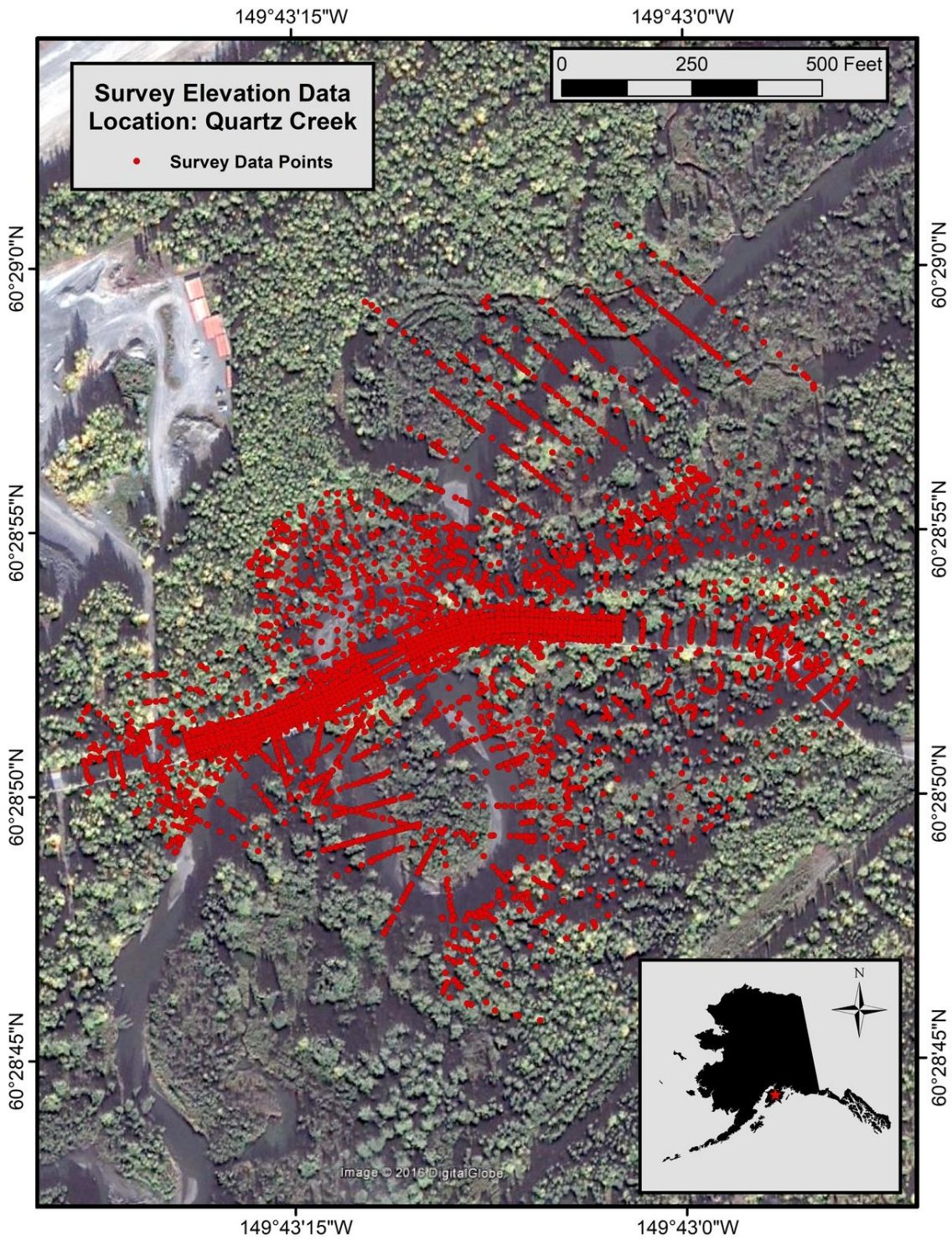


Figure 4: Quartz Creek image (from Google Earth) and survey points.

Table 2: Discharge for 2-, 10-, 50-, 100-, and 500-year flood events for the Lakina River and Quartz Creek (M.W. Knapp, personal communication, 2016–17, and USGS, 2017).

Flood Frequency	Lakina River (cfs)	Quartz Creek (cfs)
Q2	1285	2440
Q10	2540	4240
Q50	3840	5930
Q100	4430	6690
Q500	5880	8460

2.2.5.3 Base Map Data

Base map data simplify development of the numerical model domain and help with understanding the study area. Base map data include aerial imagery or topographical maps that are not essential for the model to run, but make the model more intuitive and provide spatial reference information for the site being modeled (Aquaveo, 2017b; Brunner, 2015). The Lakina River aerial image in Figure 3, provided by M.W. Knapp at ADOT&PF, and the Quartz Creek image in Figure 4, which we extracted from Google Earth, have been used as the background for several figures in this report. Neither the Lakina River image nor the Quartz Creek image was geo-referenced to a standard coordinate system, so each needed to be registered using a three-point registration method.

2.2.5.4 Digital Elevation Model

A digital elevation model (DEM) is a representation of surface terrain and can be characterized as a raster (a grid of squares) or as a vector-based triangular irregular network (TIN) (Aquaveo, 2017b; Brunner, 2015). “The TIN DEM dataset is referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM” (Wikipedia, 2017b). As mentioned, elevation (or geometry) is the most important data input when working with a 2D hydraulic model; a DEM is how a 2D hydraulic model makes use of the elevation data.

A TIN DEM is used by the SMS graphical user interface when building SRH-2D models (Aquaveo, 2017b, 2017c). The SMS program has the internal capability to develop a TIN that is based on imported scatter data (Figure 5). The HEC-RAS 2D, however, requires a Raster DEM, which involves the following intermediate sets to compute (Brunner, 2015; USACE, 2017):

- (1) HEC-RAS 2D currently does not have the capability to create a raster from elevation scatter data, so the survey points were imported into ArcGIS. Utilizing GIS geo-processing tools, a TIN surface was initially created using the “Create TIN” tool.

- (2) Subsequently, the TIN was converted to a raster using the “TIN to Raster” geoprocessing tool.
- (3) The computed Raster DEM was then exported from ArcGIS and imported into HEC-RAS 2D.

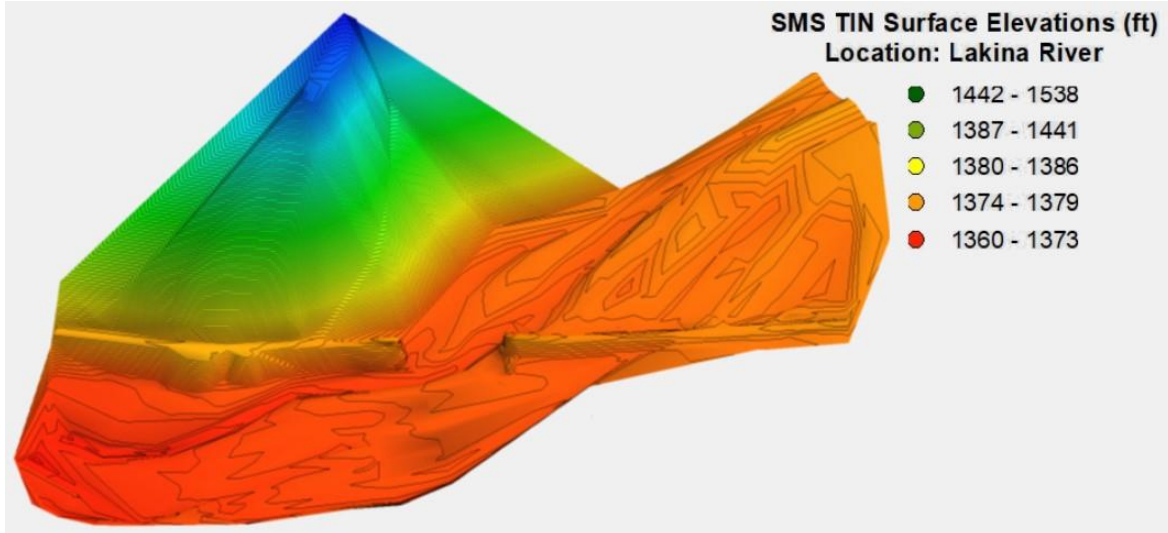


Figure 5: SMS TIN surface for the Lakina River. Terrain based on scatter survey data.

2.2.5.5 Land Use Data – Material Properties

Material properties for most 2D hydraulic models are specified for various material zones defined by polygons, which delineate regions of varying material roughness (Aquaveo, 2017b, 2017c; Brunner, 2015; USACE, 2017). Material properties or roughness values help determine energy loss as water flows over a given area. The primary roughness property is the Manning’s n value. Both models in this investigation used the Manning’s roughness coefficient in the Manning’s formula to assist in calculating flow in open channels. Numerous Manning’s roughness coefficients (n) represent common surface materials. In general, sediments with more pronounced soil (cobbles vs. sand), local surface features (small ridges), and denser vegetation have higher resistance to flow and are represented by larger Manning’s n values (Henderson, 1966).

For this investigation, the material zone polygons were manually defined using aerial imagery as a guide (Figure 6–Figure 9). The modelers, Homan and Wells, chose their own material properties for the two study areas. However, to eliminate model differences between SRH-2D and HEC-RAS 2D, each modeler’s material polygons were used in both models.

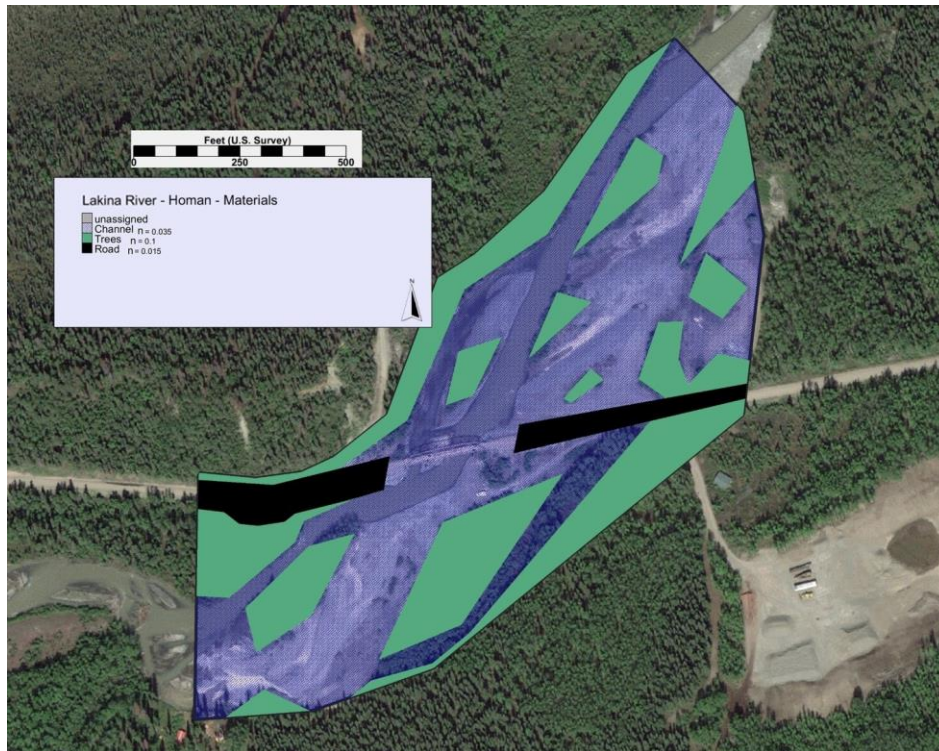


Figure 6: Lakina River material zones defined by Homan (background image provided by M.W. Knapp, ADOT&PF).

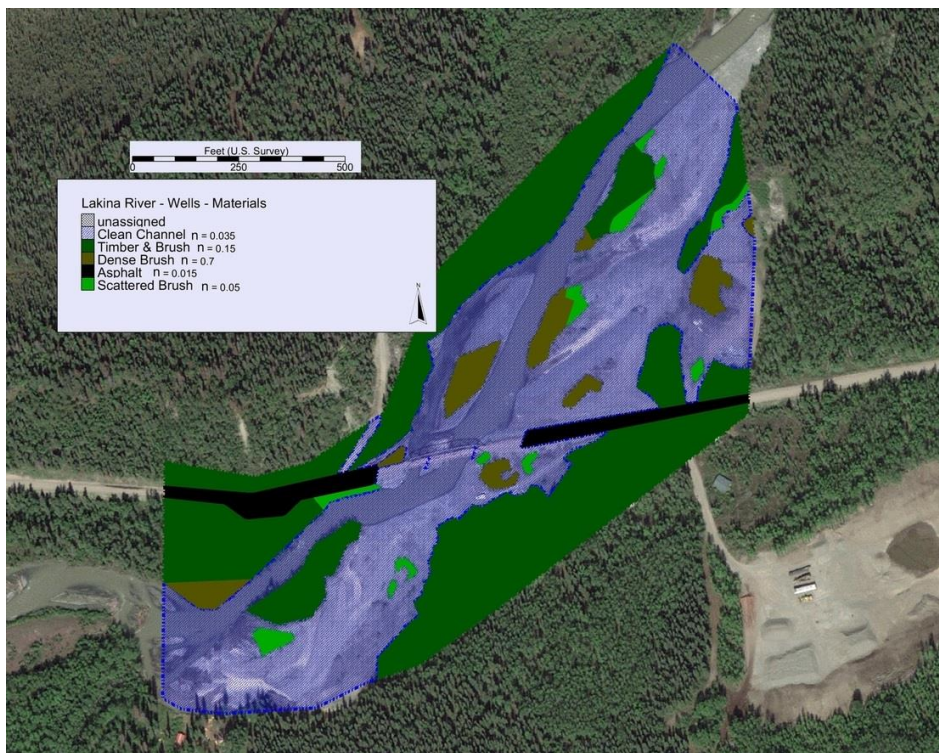


Figure 7: Lakina River material zones defined by Wells (background image provided by M.W. Knapp, ADOT&PF).

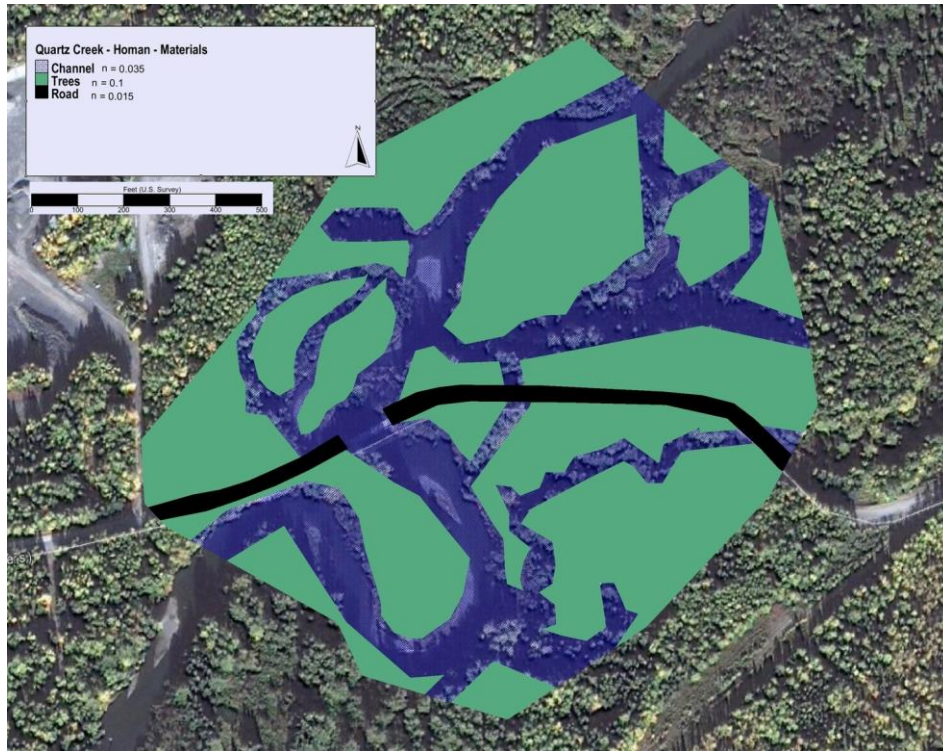


Figure 8: Quartz Creek material zones defined by Homan (background image from Google Maps).

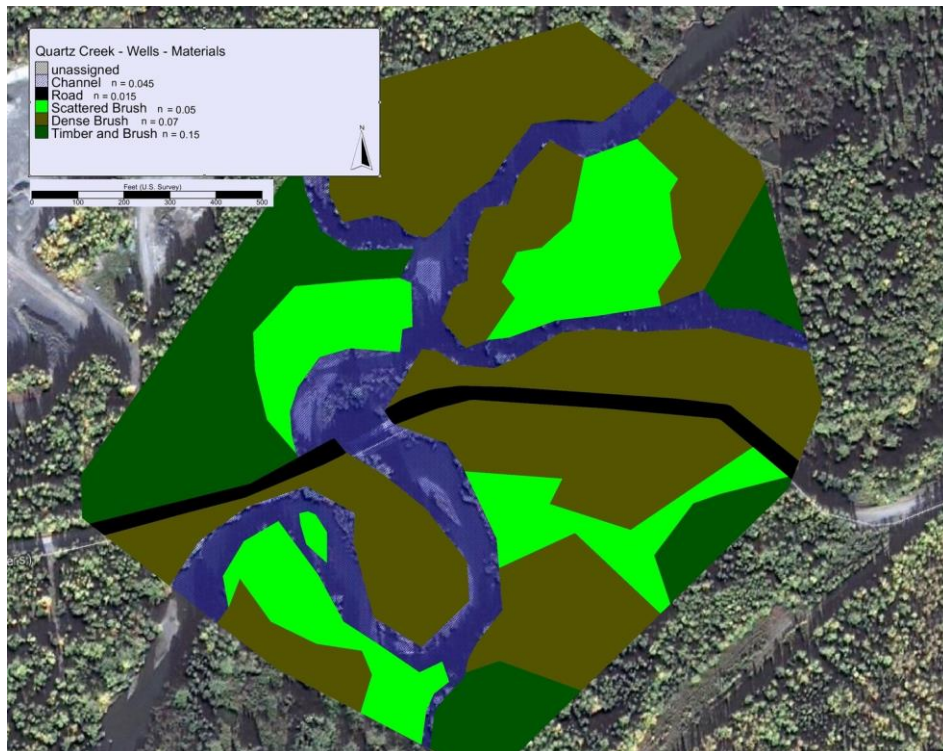


Figure 9: Quartz Creek material zones defined by Wells (background image from Google Maps).

2.2.5.6 Model Domain

The model domain defines the outer boundary of the model extent and must reside completely within the digital elevation model (DEM) (Aquaveo, 2017b, 2017c; Brunner, 2015; USACE, 2017). As a rule of thumb, the area of modeling interest should be in the center of the domain, and the boundary should extend upstream and downstream of the area of interest approximately three floodplain widths. This rule of thumb is ideal, but is generally restricted to the extent of available surface elevation data. For this research, the modelers individually specified the model domains for each model, based on the extent of the DEMs (Figure 10 and Figure 11).

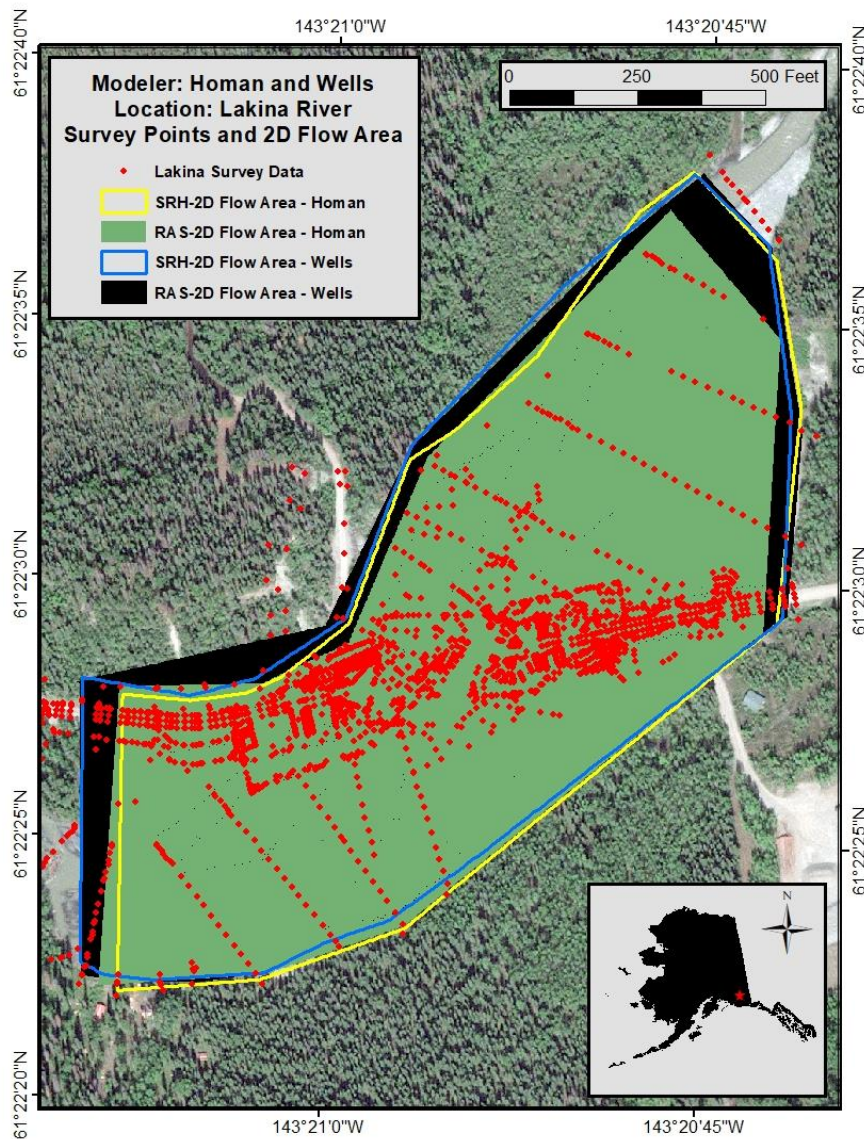


Figure 10: Lakina River survey points and model domain (2D flow areas) for both models (SRH-2D and HEC-RAS 2D) and both modelers (Homan and Wells).

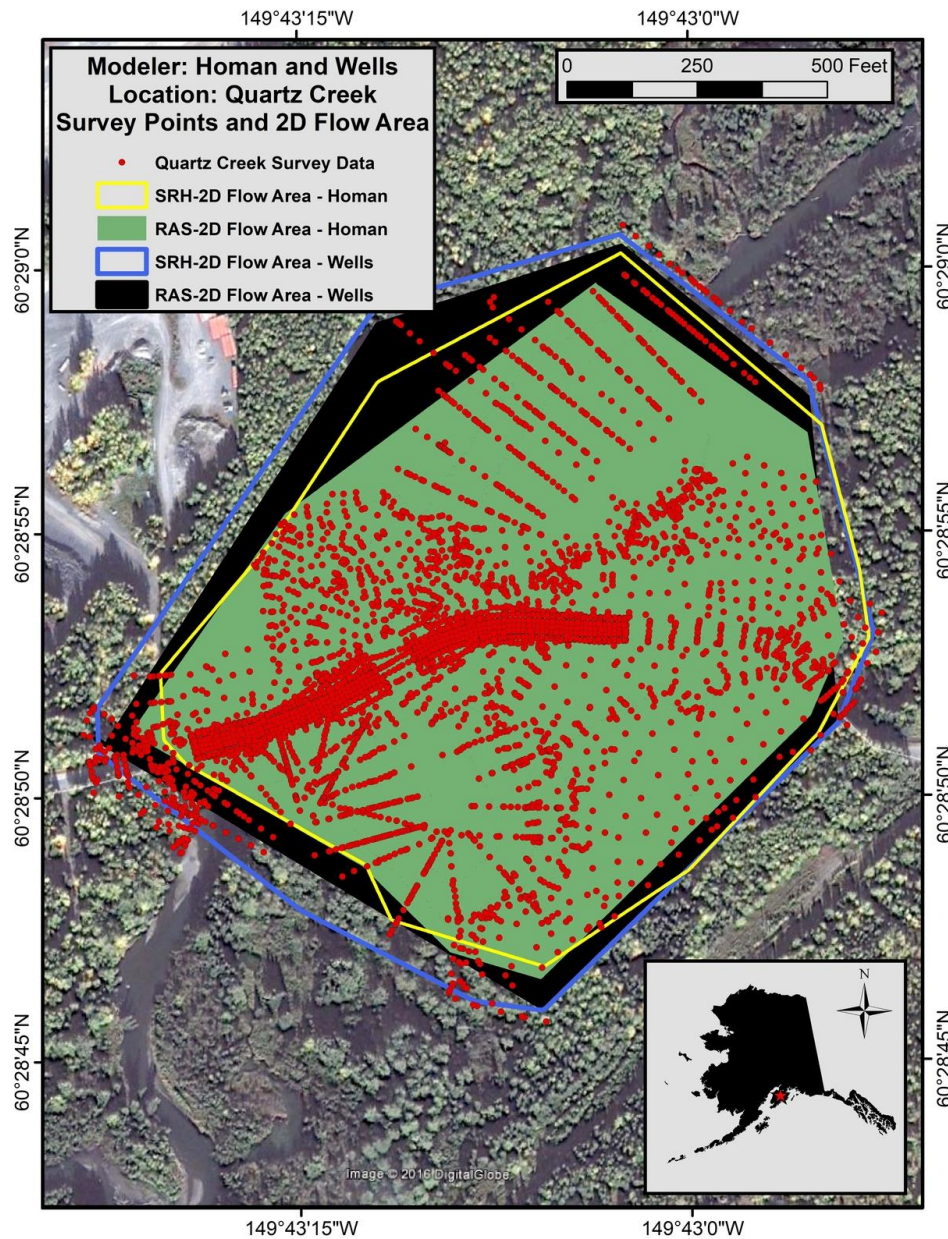


Figure 11: Quartz Creek survey points and model domain (2D flow areas) for both models (SRH-2D and HEC-RAS 2D) and modelers (Homan and Wells).

The size and shape of each domain varied slightly, as the modelers used personal judgment of the terrain and available data to create the boundaries. In all cases, the domains outlined by Homan were smaller in area. In Table 3, the “Diff of Max” column represents the domain size differences compared with the maximum domain created, regardless of the modeler; the “Model Diff per Modeler” column represents the differences between model domains created by an individual modeler; and the “Modeler Diff per Model” column represents the domain size differences between modelers for the individual models.

Table 3: Model domain sizes for each study area, model, and modeler.

Lakina River Domain Sizes					
Model	Modeler	Acres	Diff of Max	Model Diff per Modeler	Modeler Diff per Model
SRH	Homan	24	-8%	0%	-4%
	Wells	25	-4%	-4%	0%
RAS	Homan	23	-13%	-5%	-13%
	Wells	26	0%	0%	0%
Quartz Creek Domain Sizes					
Model	Modeler	Acres	Diff of Max	Model Diff per Modeler	Modeler Diff per Model
SRH	Homan	31	-18%	0%	-18%
	Wells	38	0%	0%	0%
RAS	Homan	29	-25%	-9%	-17%
	Wells	34	-10%	-10%	0%

2.2.6 Mesh Development and Computation Time Step

The most significant component of any numerical hydraulic model is an accurate representation of the geometric shape over which the water flows (Aquaveo, 2017b, 2017c; Brunner, 2015; USACE, 2017). To represent geometric shapes, numeric models use a collection of facets called *elements* connected over a domain in what is referred to as a mesh or an unstructured grid. The mesh is the computational basis for calculations, and the density of elements in a mesh affects the numeric stability of a model when performing computations.

Traditionally, the most time-consuming component of using a multi-dimensional hydrodynamic numerical model has been the generation of unstructured grids (meshes). This effort has given models that are based on Cartesian grids (structured grids) a decided simplifying advantage. Digitizing node points and connecting them into elements, while seemingly not a complicated process, becomes overwhelming when considering the number of nodes and elements that compose a numeric simulation (thousands to even millions).

Assigning an appropriate mesh cell size (or sizes) and computation time step (ΔT) is very important to getting accurate answers with 2D flow areas (Aquaveo, 2017b, 2017c; Brunner, 2015; USACE, 2017). The first step is to develop a computational mesh that has cell sizes that are appropriate for modeling both the terrain and the water flowing over the terrain. Many 2D flow models use a single elevation for each cell and cell face (grid-based models). Finite element models commonly (not always) use triangles (three elevations and a planar surface to represent each triangle) to represent the land surface, while each face has two elevations and a straight line between them.

It is important to understand the way computational mesh represents the underlying terrain in order to make a good decision about the number and size of cells that are necessary to model the terrain and the event accurately. Nodes define specific (x, y, z) locations in the

numerical representation of reality. A sufficient number of nodes must be created to adequately represent all features that exist in the physical site being modeled. The positioning of nodes is key because the positions define the location of the site features and the shape of the elements. All simulated flow must pass through one or more elements. The shape, size, and orientation of the element affect numerical stability and model accuracy. For the flow scenarios to be modeled, the mesh network being developed must include all the area that potentially will become wet.

2.2.6.1 SMS Mesh Development

After the lateral extent (mesh domain) has been defined, the Surface-water Modeling System (SMS) uses automated meshing tools to simplify the process of generating meshes (Aquaveo, 2017b, 2017c). SMS uses a finite element method, described above, to represent the land surface. SMS uses an unstructured mesh, which has the ability to vary the resolution of the grid. This ability makes it possible to capture small features that are hydraulically significant without requiring high resolution throughout the domain. Large elements can be used in areas where little is changing with respect to the geometry and the solution. Smaller elements can be specified in areas of interest or in areas of changing topography or flow conditions.

In SMS, the 2D mesh-developing process starts with an imported survey scatter set to interpolate node elevations (Aquaveo, 2017b, 2017c). Vertex spacing to control element sizing must be specified, along with the polygon types and the corresponding material coverage. With the completion of these steps, the entire model can be converted to a mesh (Figure 12). This capability has the advantage that the mesh resolution, material properties, or elevations can be changed easily by simply changing the model attributes and regenerating the mesh.

2.2.6.2 HEC-RAS 2D Mesh Development

HEC-RAS 2D modeling techniques are different from SRH-2D modeling techniques. Cells in HEC-RAS 2D can have up to eight sides (Brunner, 2015; USACE, 2017). Each cell is not a simple plane, but a detailed elevation volume/area relationship that represents the details of the underlying terrain. HEC-RAS 2D cell faces are detailed cross sections that are processed into detailed elevation versus area, wetted perimeter, and roughness. This approach allows the modeler to use larger cell sizes with HEC-RAS 2D, and still accurately represent the underlying terrain.

The key to making a good computational mesh in HEC-RAS 2D is to ensure that the faces of the cells capture the high point of barriers to the flow (Brunner, 2015; USACE, 2017). The water surface slope must be considered also. A single water surface elevation is computed in the center of each cell, so the larger the cell size, the farther apart the computed values of the water surface. Thus, the slope of the water surface is averaged over longer distances (in two dimensions). If the water surface slope varies rapidly, smaller cell sizes must be used in

that area to capture the changing water surface and its slope. HEC-RAS 2D allows the user to vary the cell size and shape at all locations in the model. As with SMS, HEC-RAS 2D computational meshes are unstructured and can be developed with varying sizes within the domain. Although the HEC-RAS 2D meshes are considered unstructured, the grid is generally structured, except around breaklines and boundary walls.

As explained at the HEC-RAS 2D website (USACE, 2017) and in the HEC-RAS 2D user manual (Brunner, 2015), key factors for developing good computational mesh with HEC-RAS 2D are as follows:

- Make sure that the cell sizes, shapes, and orientations adequately describe the terrain.
- Use breaklines along the crest of topographically high ground features to align cell faces so the terrain is properly represented in the mesh.
- Make sure that the cell size is adequate to describe the water surface slope and changes in the water surface slope.

As mentioned in the report section, Digital Elevation Model (Section 2.2.5.4), the HEC-RAS 2D model requires a Raster DEM to represent the underlying terrain. Within the 2D area (mesh domain), the mesh parameters can be set; these include the underlying terrain, materials coverage, and defined grid cell size (both width, ΔX , and height, ΔY). The HEC-RAS 2D model builds a structured mesh of constant cell size (Figure 12). The exception to this is around the perimeter of the mesh domain and breaklines; here, HEC-RAS 2D automatically creates irregularly shaped cells to fit the edges.

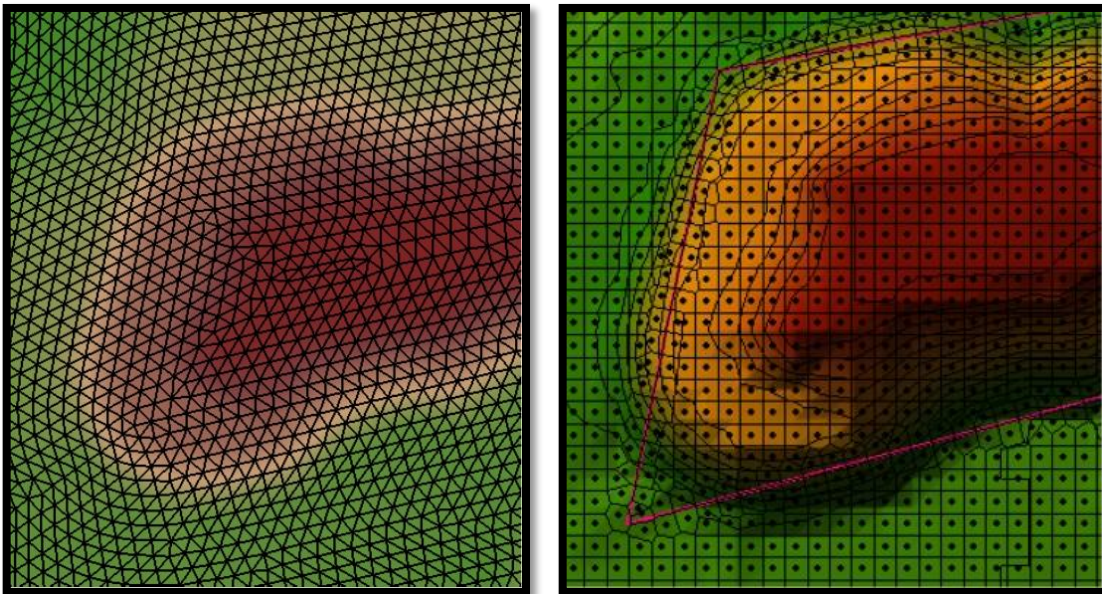


Figure 12: Two-dimensional meshes for SMS (left) and HEC-RAS 2D (right) at the end of the Lakina River road abutment. SMS uses finite element unstructured triangles to represent the land surface; HEC-RAS 2D uses mostly a structured grid of cells. Red lines in the HEC-RAS 2D mesh (right) are breaklines to force cell face alignment.

2.2.6.3 Mesh Parameters

Using the background data presented above, each modeler developed meshes for the two study areas (Lakina River and Quartz Creek) using both models (SRH-2D with SMS and HEC-RAS 2D). The mesh parameters, which were user defined, were material properties, model domain, and mesh grid spacing.

2.2.6.4 Computation Time Step

Once a good computational mesh is developed, the user must select an appropriate computational time step that works well with the mesh and the event being modeled. Selecting an adequate time step is a function of the cell size and the velocity of flow moving through those cells (Aquaveo, 2017a; USACE, 2017). During each iterative time step, the models compute the water levels and velocities at each computation point in the domain. If the time step is too large, the numerical derivatives in the solver will not be appropriate to capture the nonlinear behavior of the fluid, driven by high acceleration terms. If the time step is too small, the computation time can be excessively long.

Both models solve the 2D Saint Venant equations (often referred to as shallow water equations) (Aquaveo, 2017a; USACE, 2017). Model simulations with HEC-RAS 2D can be done using the Saint Venant equations or using a simplified version of the momentum equation, the diffusion wave equation.

To maintain consistency between the modelers, both used the 2D Saint Venant equations with a computation time step of 1 second. This consistency allowed for greater comparison of the models and the modelers.

2.2.6.5 Boundary Conditions

A boundary condition is a section of the channel where the depth of flow is known at a given flow rate (Aquaveo, 2017a; USACE, 2017). For unsteady flows, a user is required to enter boundary conditions at all of the external boundaries of the system, as well as at any desired internal locations, and set the initial flow and storage area conditions in the system at the beginning of the simulation period. In other words, boundary conditions are where flow enters and exits the domain, and are related to how much water exchange there is at a given time.

2.2.6.5.1 Initial Flow and Internal Boundary Conditions

Initial flow is the flow that enters the study domain and is then modeled downstream (Aquaveo, 2017a; USACE, 2017). The internal flow can enter at a steady or variable rate. Time-dependent flow is known as unsteady. Steady-state flow refers to conditions in which the flow at a point in the system does not change over time. This project is designed around using unsteady flow, but only steady-state hydraulic conditions were available (see Table 2). In order to use the steady-state hydraulic conditions, but meet the unsteady-flow requirements,

specific flow hydrographs must be created. Table 4 provides an example of flow hydrographs, which satisfy both unsteady and steady state requirements. Using the unsteady-flow hydrographs, the hydraulic conditions can be input into the model along “In-flow” boundaries or boundary condition lines, that is, lines drawn along the upstream boundary of the model domain.

Table 4: Flow hydrograph example for the Quartz Creek Q500 (8460 cfs) modeling scenario.

Hydrograph Data	
Simulation Time (hours)	Flow (cfs)
00:00	8460
06:00	8460
12:00	8460
18:00	8460
24:00	8460
30:00	8460
36:00	8460

2.2.6.5.2 External Boundary Conditions

There are several possible external boundary conditions (Aquaveo, 2017a; USACE, 2017):

- Stage Hydrograph – e.g., gauge data on the stream
- Flow Hydrograph – e.g., gauge data converted to flow
- Stage & Flow – e.g., combined observed state and forecasted flow
- Rating Curve – e.g., rating at a gauged location, or steady-flow rating
- Normal Depth – e.g., average slope of stream to estimate energy slope

SRH-2D External Boundary Conditions:

The SRH-2D model refers to the external boundary condition as “Exit H” for subcritical out flows, which is a stage-type exit boundary where water surface elevation may be given as a constant number, or as a stage-discharge or rating curve (Aquaveo, 2017a, 2017c). The “Constant” method is for steady-state simulation, while “Time Series” requires imported time-versus-elevation values. Since this project’s simulations are unsteady and no time series data are available, the “Rating Curve” option was used by both modelers.

Without available discharge-versus-elevation rating curve values, a rating curve must be estimated. The “Populate” dialog within SMS can be used to generate rating curves automatically based on the underlying terrain (x , y , z data). Separately, the modelers used the Populate dialog to develop their own rating curves. The Populate dialog requires a ground elevation dataset, a Manning’s n value that is individually chosen, and a slope that is given (0.01 for Lakina River and 0.003 for Quartz Creek). Using these variables, the dialog

automatically generated a rating curve, which was then used to model the downstream flow conditions.

HEC-RAS 2D External Boundary Conditions:

The HEC-RAS 2D model refers to the external boundary conditions as “Out Flow” (Brunner, 2015; USACE, 2017). Because no downstream Stage or Flow data measurements were available for this project, and because this measurement is probably the most commonly used downstream boundary condition in both steady and unsteady HEC-RAS 2D simulations, we selected the Normal Depth condition to use as the external boundary. This selection allows the modeler to enter an assumed energy slope; then HEC-RAS 2D automatically back-calculates the depth using Manning’s equation. Several methods can be used to calculate an energy slope, but regardless of the method used, errors are associated with what is chosen. Ultimately, the modeler has to guess at an energy slope. We used the averaged slope of the stream as the estimated energy slope (0.01 for Lakina River and 0.003 for Quartz Creek).

2.2.7 Modeling Results

As mentioned, numerical models are mathematical representations of physical processes and must be based on real underlying conditions. Using background data (DEMs, hydraulic data, aerial photos, and material properties) described in the preceding sections, we developed the SRH-2D and HEC-RAS 2D models for two morphological settings: Lakina River and Quartz Creek. Eight different scenarios were developed, as both modelers generated model results for each location (Table 5).

Table 5: Eight developed scenarios (two modelers each ran two models for two locations).

Model	Stream	Modeler
SRH-2D	Lakina River	Homan
		Wells
	Quartz Creek	Homan
		Wells
HEC-RAS 2D	Lakina River	Homan
		Wells
	Quartz Creek	Homan
		Wells

We ran model simulations for each of the eight developed scenarios for five hydraulic conditions (Table 2). Maximum water inundation results from the eight scenarios are provided in Figure 13–Figure 16. Visually, all of the Lakina River scenarios produced results with minor differences, with both models generating increasing water inundation extent for rising

hydraulic conditions (Q2–Q500). In general, little to no flooding reached the domain boundary, which implies that the model domains were of sufficient size. Domain boundaries act as vertical walls, so if flooding had reached the boundary limits, subsequent model results would be inaccurate.

All of the Quartz Creek scenarios generated visually similar increases in water inundation extent (Figure 17–Figure 20). However, in all Quartz Creek modeling scenarios (all five hydraulic conditions [Q2–Q500, see Table 2]), extensive flooding reached the domain boundaries. As a result, actual water levels are not accurate, as the “wall” effect of the domain boundary artificially increases water levels. Even though the model results are artificial, the comparison of model results was completed. Evaluating the accuracy of the models was never a possibility due to lack of basic field data (i.e., discharge, water surface elevation, and sediment characteristics); we only compared the differences in model results.

Excessive flooding of the modeled domains is the result of one of two possibilities: either the survey extent was insufficient for the Quartz Creek morphological setting, or the discharge values estimated using the USGS StreamStats application were unrealistically high.

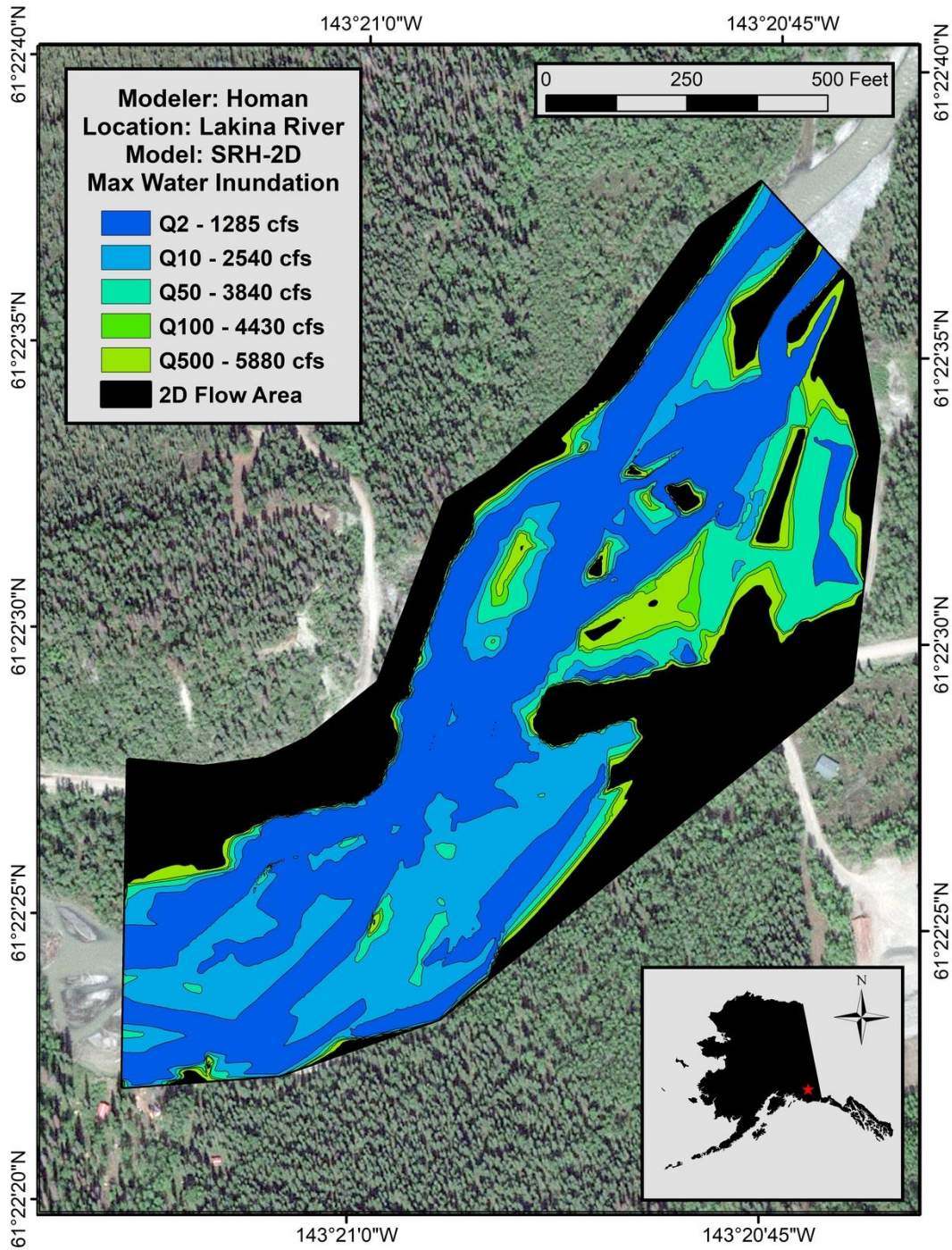


Figure 13: SRH-2D modeled maximum water inundation for Lakina River, produced by Homan for all five hydraulic conditions.

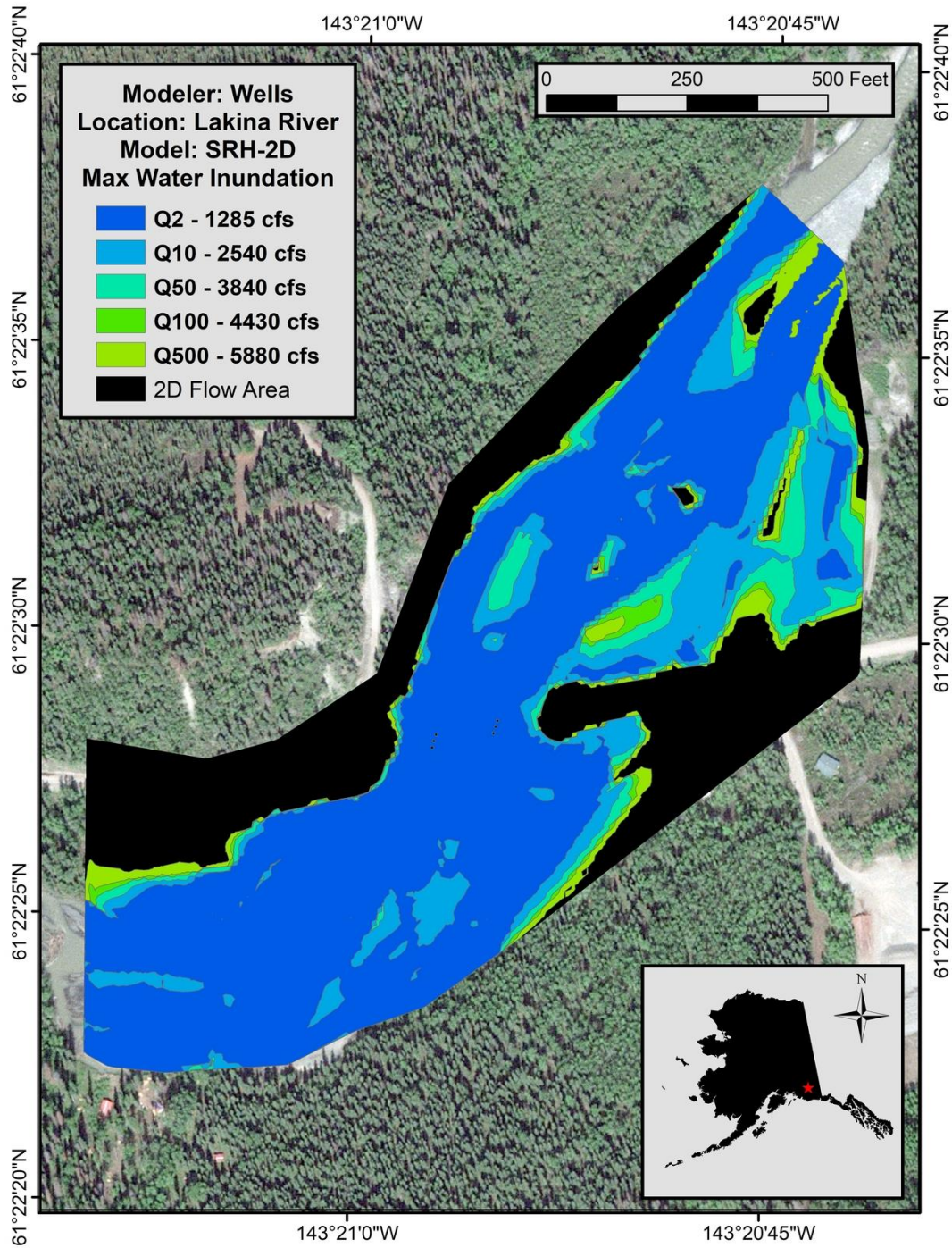


Figure 14: SRH-2D modeled maximum water inundation for Lakina River, produced by Wells for all five hydraulic conditions.

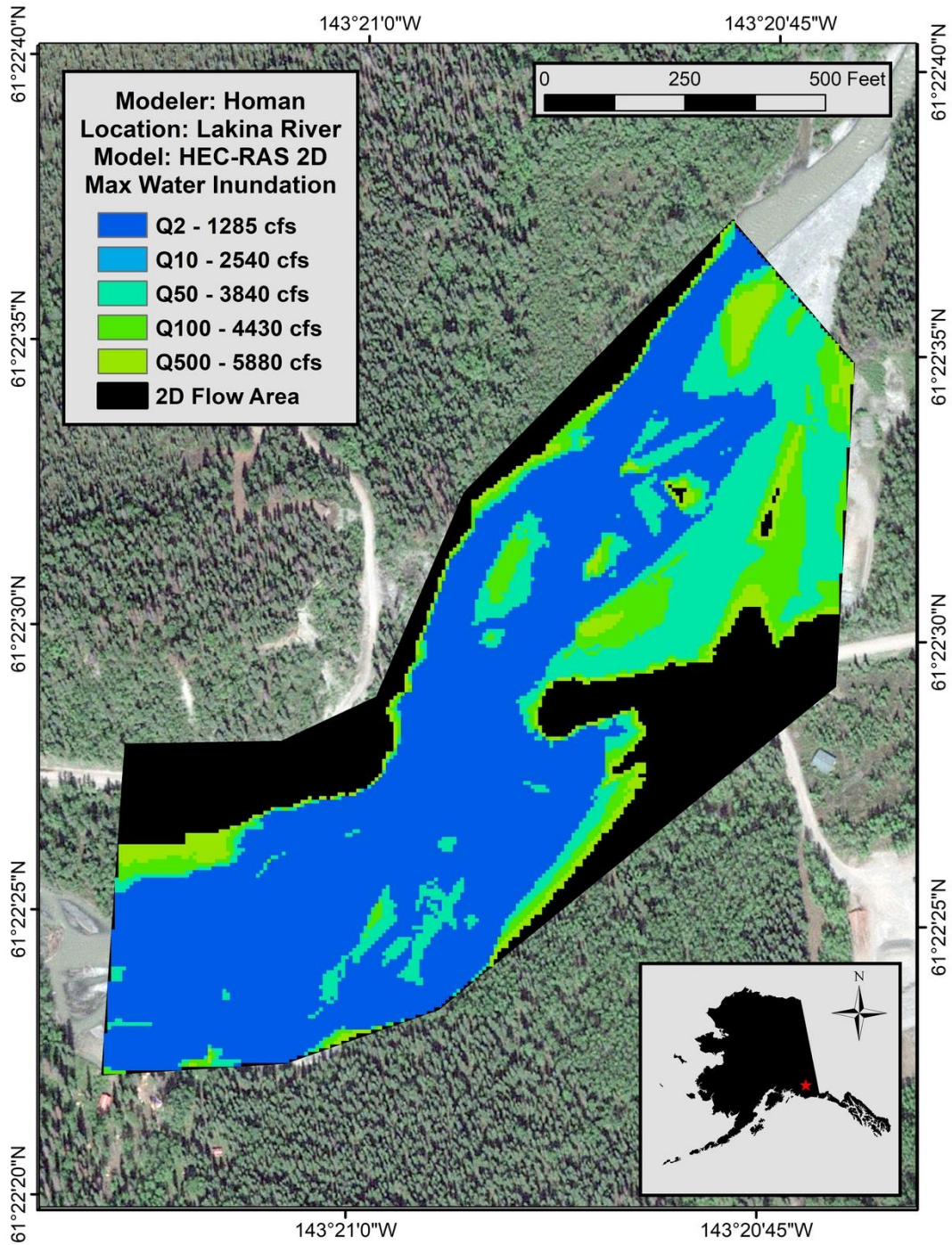


Figure 15: HEC-RAS 2D modeled maximum water inundation for Lakina River, produced by Homan for all five hydraulic conditions.

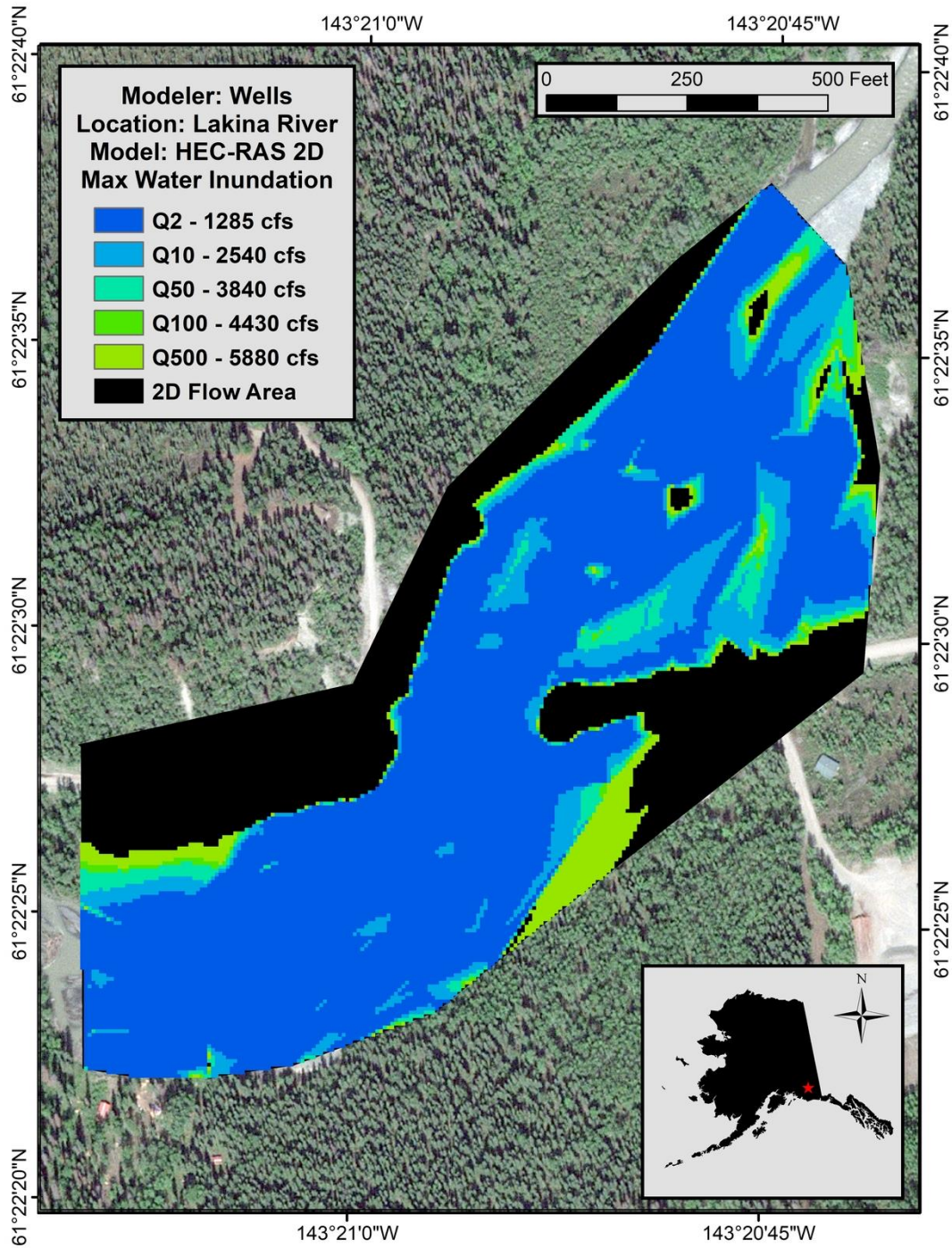


Figure 16: HEC-RAS 2D modeled maximum water inundation for Lakina River, produced by Wells for all five hydraulic conditions.

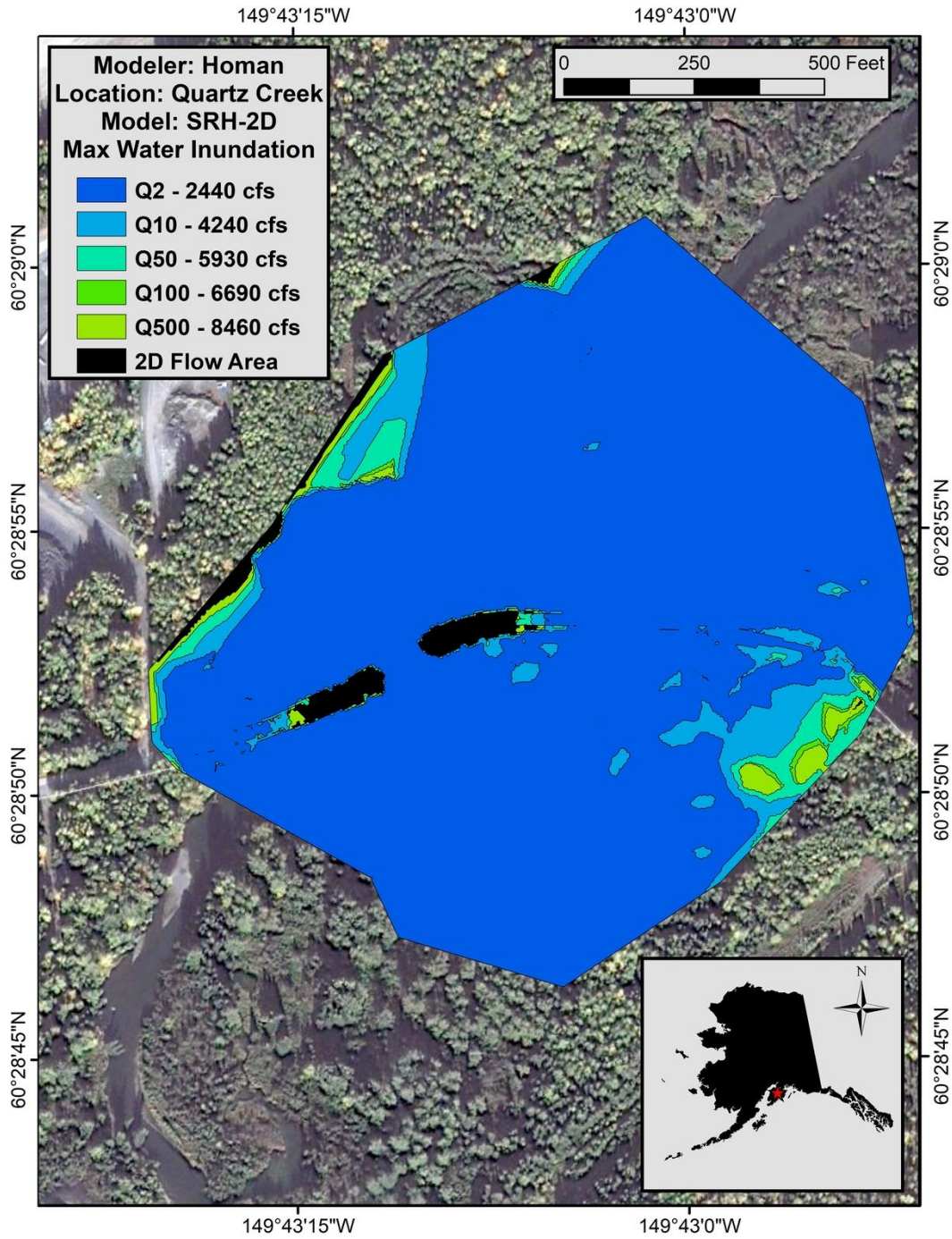


Figure 17: SRH-2D modeled maximum water inundation for Quartz Creek, produced by Homan for all five hydraulic conditions.

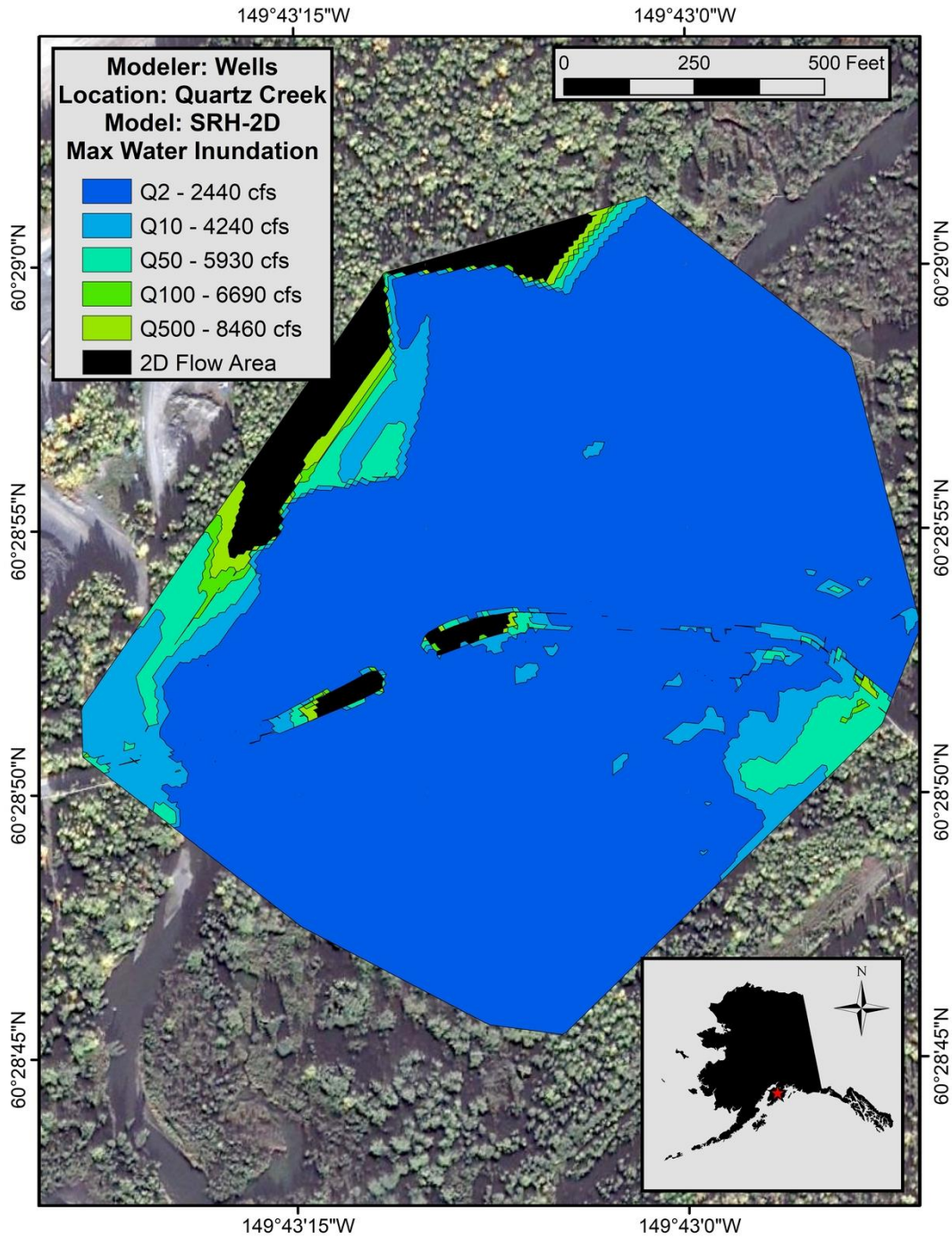


Figure 18: SRH-2D modeled maximum water inundation for Quartz Creek, produced by Wells for all five hydraulic conditions.

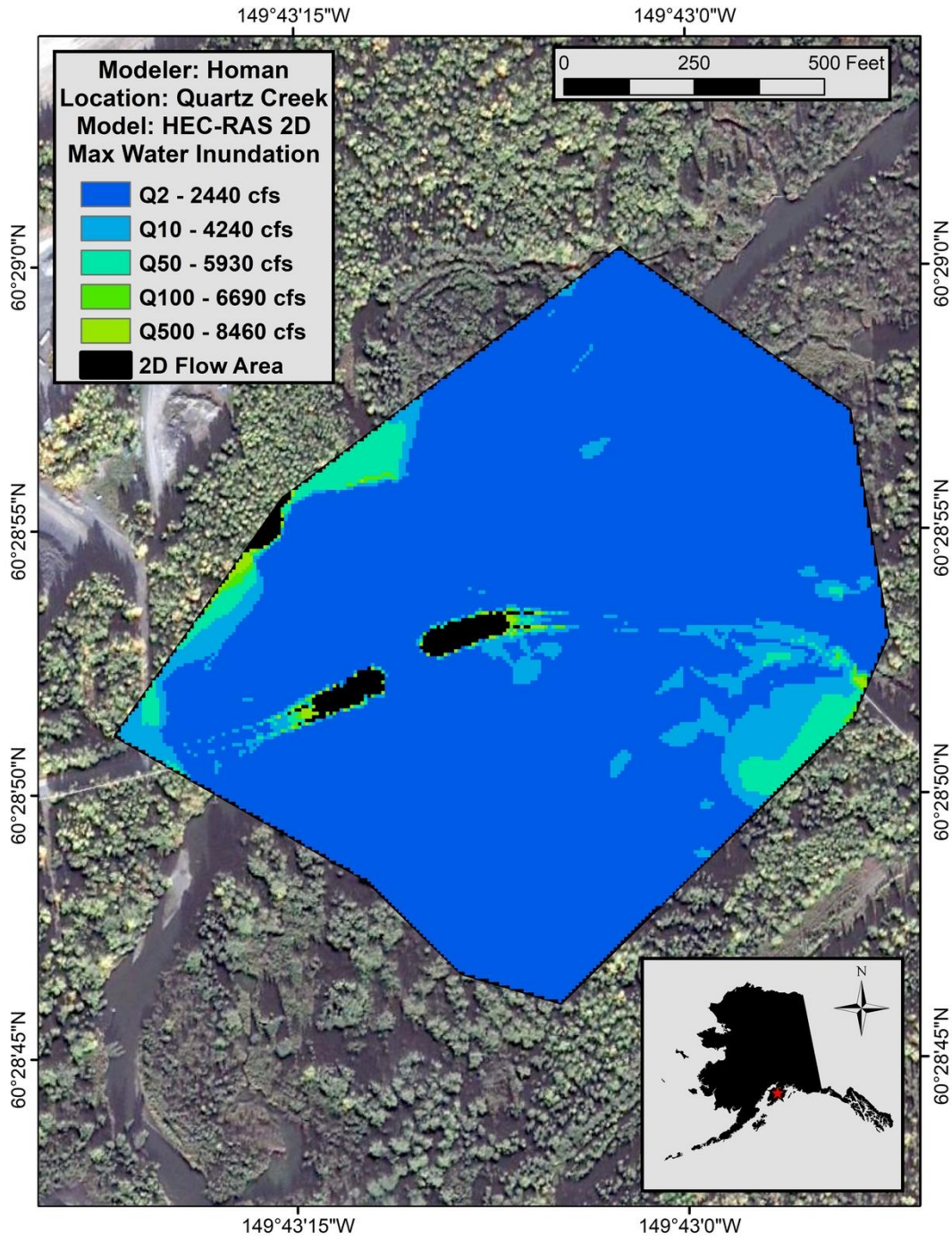


Figure 19: HEC-RAS 2D modeled maximum water inundation for Quartz Creek, produced by Homan for all five hydraulic conditions.

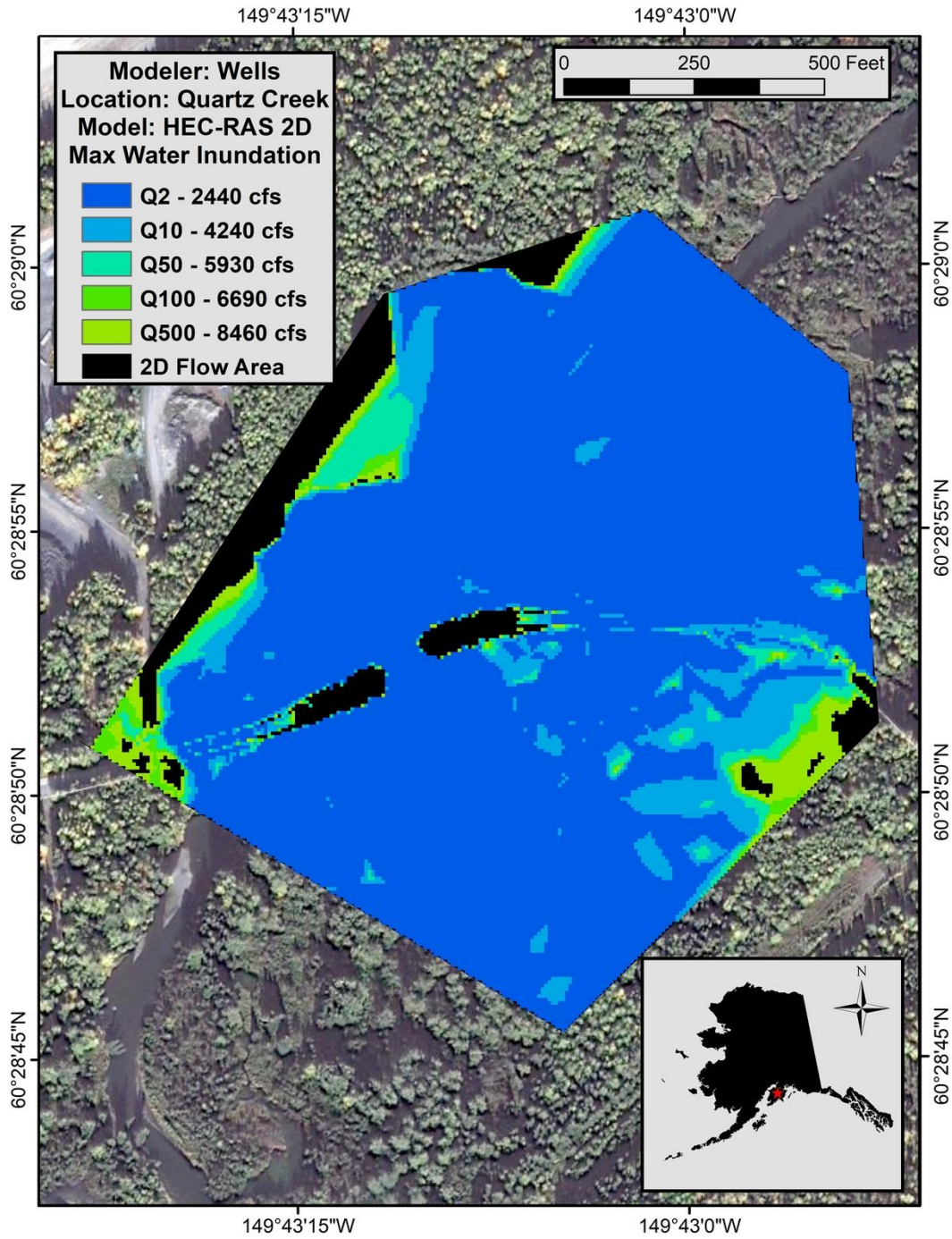


Figure 20: HEC-RAS 2D modeled maximum water inundation for Quartz Creek, produced by Wells for all five hydraulic conditions.

2.2.7.1 Modeler Comparison: Homan versus Wells

Without model calibration, it is impossible to know which model is more accurate. Since the models were not calibrated, only the differences in the model results can be compared. In this section, we provide the individual model result differences; we compared the SRH-2D and HEC-RAS 2D model results produced by Homan and Wells. The modeler comparisons are based on the simulation of the 500-year flood event (Q500). We compared model results for Water Depth, Shear Stress, and Velocity, resulting in 12 different modeler comparisons (Table 6). Only the areas within the overlapping domain boundaries can be evaluated.

Table 6: Twelve modeler scenario comparisons for the 500-year flood (Q500).

Modeler Comparison (All Q500)				
Model	Stream	Differences		
SRH-2D (Homan - Wells)	Lakina River	Water Depth	Shear Stress	Velocity
	Quartz Creek	Water Depth	Shear Stress	Velocity
HEC-RAS 2D (Homan - Wells)	Lakina River	Water Depth	Shear Stress	Velocity
	Quartz Creek	Water Depth	Shear Stress	Velocity

2.2.7.1.1 Modeler Comparison for SRH-2D

We compared the SRH-2D modeling results for Homan and Wells using the Dataset Toolbox within SMS. The Compare tool command within the Data Toolbox allows a modeler to compare two datasets computationally by subtracting the Alternate dataset from the Base dataset. In all comparisons, Wells results were set as the Alternate dataset, and Homan results were set as the Base dataset. With this mathematical arrangement, positive values indicate that Homan results were larger, negative values indicate that Wells results were larger, and near zero values indicate equality between the models. For consistency, the scale range and color scheme were fixed for all comparisons. Numerically, the scale was set from 5 to -5, in which 5 represents a difference of Homan values being greater than Wells values, and -5 represents Wells values being greater than Homan values. For the color scheme, red indicates that Homan values are greater, blue indicates that Wells values are greater, and white indicates little to no difference between modeler results.

Not all the comparison results are bound by the 5 to -5 scale, as a few locations have larger depths and/or velocity differences. The locations with larger modeling differences were generally small in area and located mostly in the main channel, where material roughness values differed between modelers. The values outside the scale of 5 to -5 were left blank (no color). To capture all the modeling differences, the scale could have been extended, but this would have reduced the resolution of all other outputs. The scale of 5 to -5 was chosen, as it provided the highest resolution and captured the majority of the results.

Modeler Comparison for SRH-2D – Lakina River:

The SRH-2D Lakina River modeler comparisons for the Q500 (5880 cfs) flood event are provided in Figure 21–Figure 23. The Water Depth (ft) comparison presented in Figure 21 is primarily faint in color, demonstrating little difference in modeler results. All water depths are roughly within a foot of each other (+/- 1ft).

The Velocity (ft/sec) comparison presented in Figure 22 illustrates more significant color contrast due to greater differences in the modeler results. In general, Homan had greater velocities within the river channel, while Wells had slightly higher velocities in the flood plain. Both modelers used the same Manning’s n of 0.035 for the channel, but the rest of the material roughness values are different (Figure 6 and Figure 7). The greatest velocity contrasts are consistently within areas with differing material properties. Note: The “no color” areas in the channels are a result of velocity differences being outside the scale range (Homan modeled velocities greater than 5 ft/sec compared with Wells velocities). The shape and placement of material property polygons and associated Manning’s n values clearly have an effect on the model outputs. In locations with differing material zones, e.g., channel versus brush or trees, velocity differences are mostly greater than +/- 3.3 ft/sec. In contrast, almost all locations with similarly chosen material properties have significantly less divergence, less than +/- 1.7 ft/sec.

The Shear Stress (lb/ft²) comparison presented in Figure 23 shows that the modelers had similar results, with differences generally less than +/- 1.7 lb/ft². The locations where modeler differences are larger, again, occurred mainly at offsets of material property polygons. The shape of material property polygons is apparent, as the results highlight these boundaries.

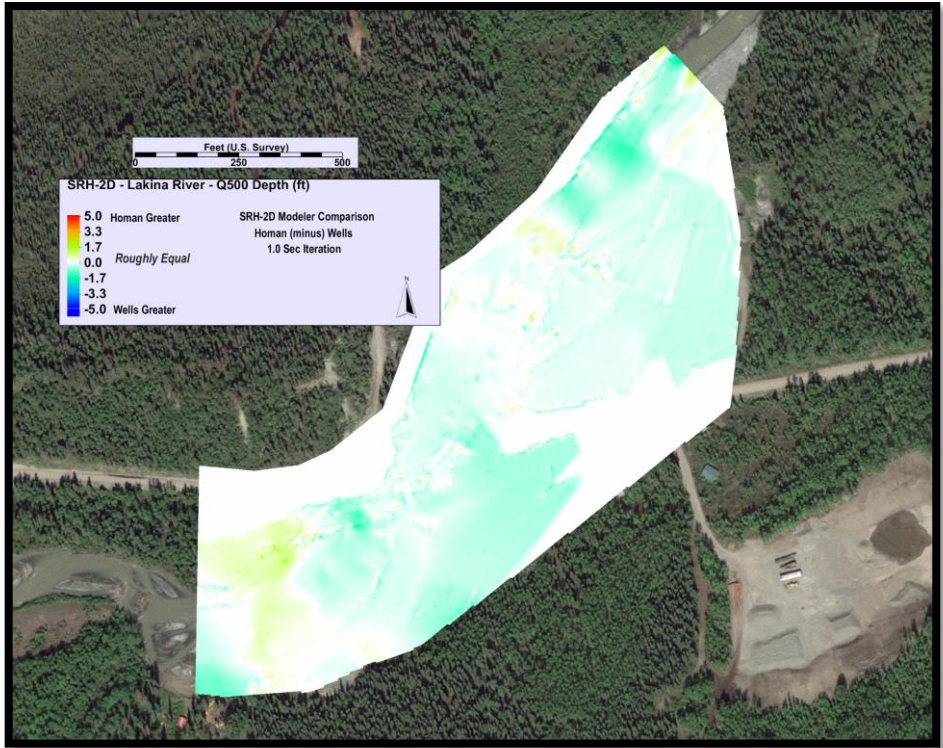


Figure 21: SRH-2D Lakina River modeler comparison (Homan minus Wells) for Q500 Water Depth (ft).

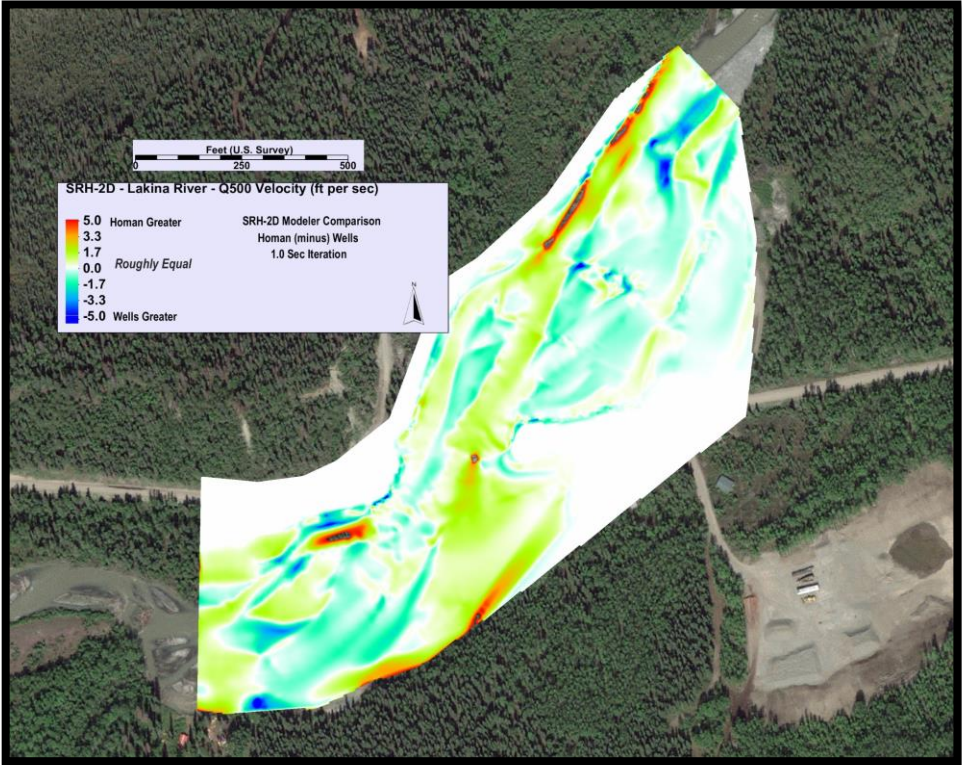


Figure 22: SRH-2D Lakina River modeler comparison (Homan minus Wells) for Q500 Velocity (ft/s).

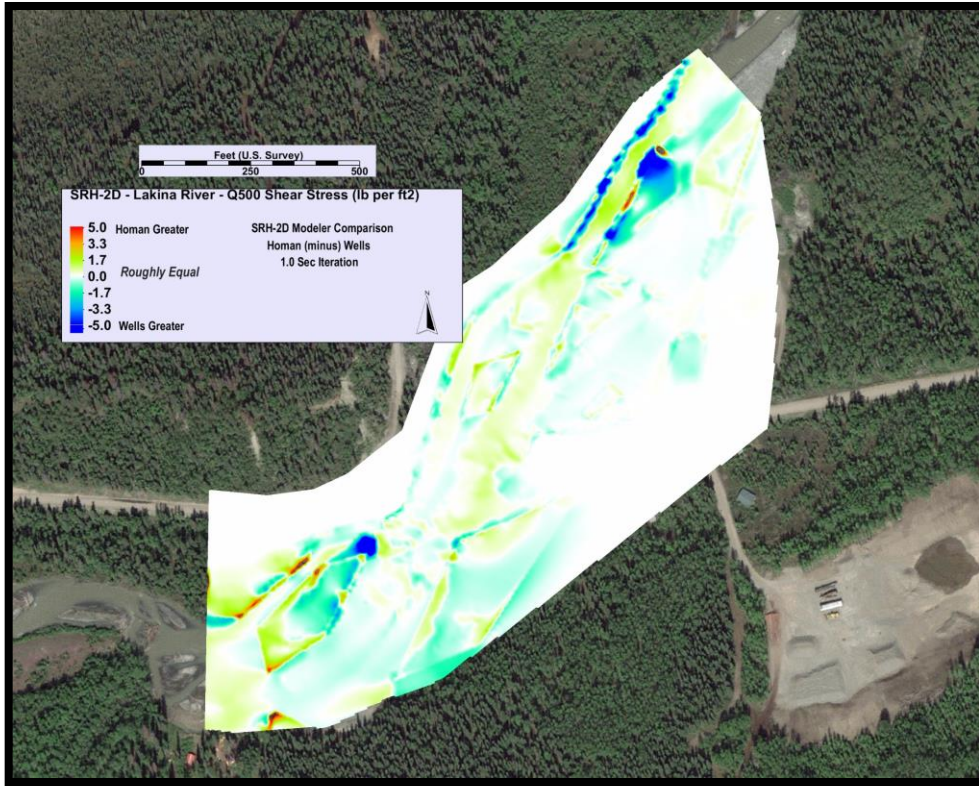


Figure 23: SRH-2D Lakina River modeler comparison (Homan minus Wells) for Q500 Shear Stress (lb/ft²).

Modeler Comparison for SRH-2D – Quartz Creek:

Recall from the discussion on maximum water inundation maps (Section 2.2.7) that extensive flooding reached the domain boundaries for all Quartz Creek modeling scenarios (Figure 17–Figure 20). Thus, the actual model results (depth, velocity, and shear stress) are not accurate, as the “wall” effect of the domain boundary artificially increased water levels. However, we were able to compare the model results.

With the inundation of the Quartz Creek domain boundaries, the size of the domain became an important factor. The same volume of water is modeled through the domains regardless of size, and if the domains are inundated, a reduction in domain size further accentuates the model results.

The SRH-2D Quartz Creek modeler comparisons for the Q500 (8460 cfs) flood event are shown in Figure 24–Figure 26. There is a substantial difference in SRH-2D domain sizes between modelers, with the Homan domain being 18% smaller than the Wells domain (Table 3). The Water Depth (ft) comparison presented in Figure 24 is primarily faint in color, illustrating relatively little difference between modelers. Even though the differences are slight, Wells modeled greater water depths throughout most of the domain. Visually, what stands out even more is the uniformity in depth differences throughout the domain, and how the topography of the area is not well reflected. Because the entire modeled domain is

inundated, the depth differences act as water surface elevations, meaning the difference of two water surface elevations results in a relatively uniform depth difference across the domain; this explains the lack of topographical characteristics represented by the model results.

Additionally, a downslope increase in modeled water depth differences is apparent. After comparing both the Homan and Wells model parameters, we found a difference in downstream boundary conditions. Both modelers used the “Exit-H” boundary condition method, described in the section headed “SRH-2D External Boundary Conditions,” but separately selected Manning’s n variables entered in the Populate dialog, which has proven to significantly change the resultant downstream boundary condition rating curves (Figure 27). We determined that Wells used a Manning’s n of 0.045 to populate the rating curve, while Homan used a Manning’s n of 0.035. The greater material roughness entered by Wells caused the exit water surface elevation for a given discharge to be higher. For Q500 (8460 cfs), the exit water surface elevation for Wells was 449.4 ft; for Homan, it was 447.4 ft. The 2 ft higher exit water surface elevations for Wells (darker blue area) is evident in the model results (Figure 24). The higher exit boundary condition acted as a weir, causing water to back up. The farther upstream from the boundary condition, the smaller the difference in modeled water depths (light blue fading to white).

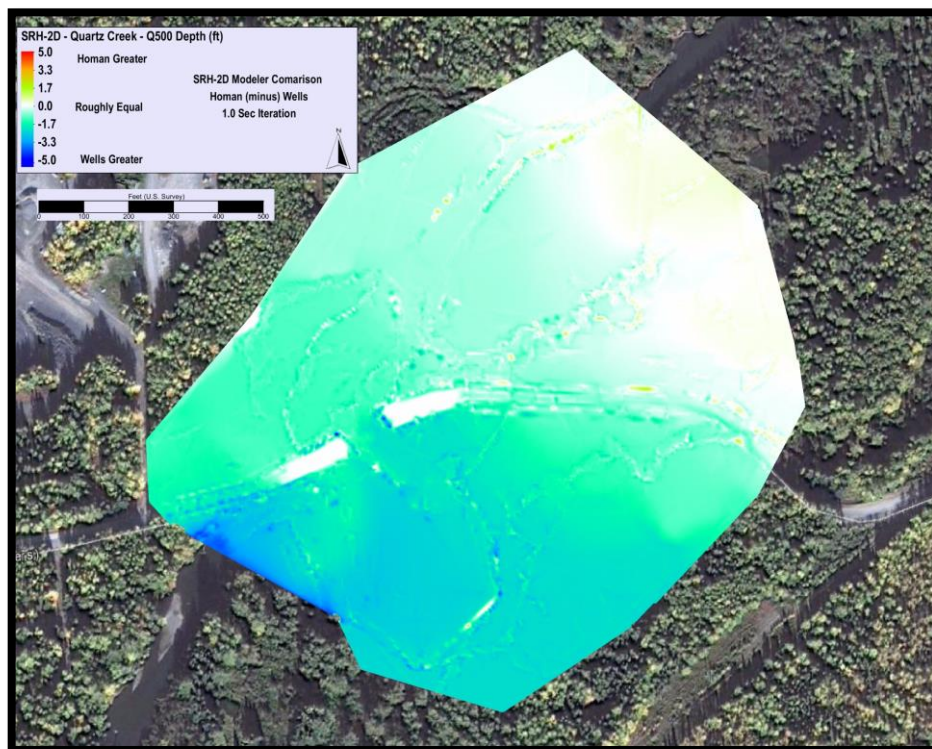


Figure 24: SRH-2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Water Depth (ft).

The Velocity (ft/sec) comparison is presented in Figure 25. As a whole, Homan modeled greater velocities (reds and yellows), which is consistent with the law of conservation of mass,

as Wells modeled greater water depths. Different channel Manning's n values, 0.045 for Wells and 0.035 for Homan, further compounded the differences. The combination of smaller channel surface roughness values and shallower waters for Homan resulted in significantly greater velocities. In two small locations near the bridge, the velocity differences were outside the scale of +/- 5 ft/sec and therefore have no color.

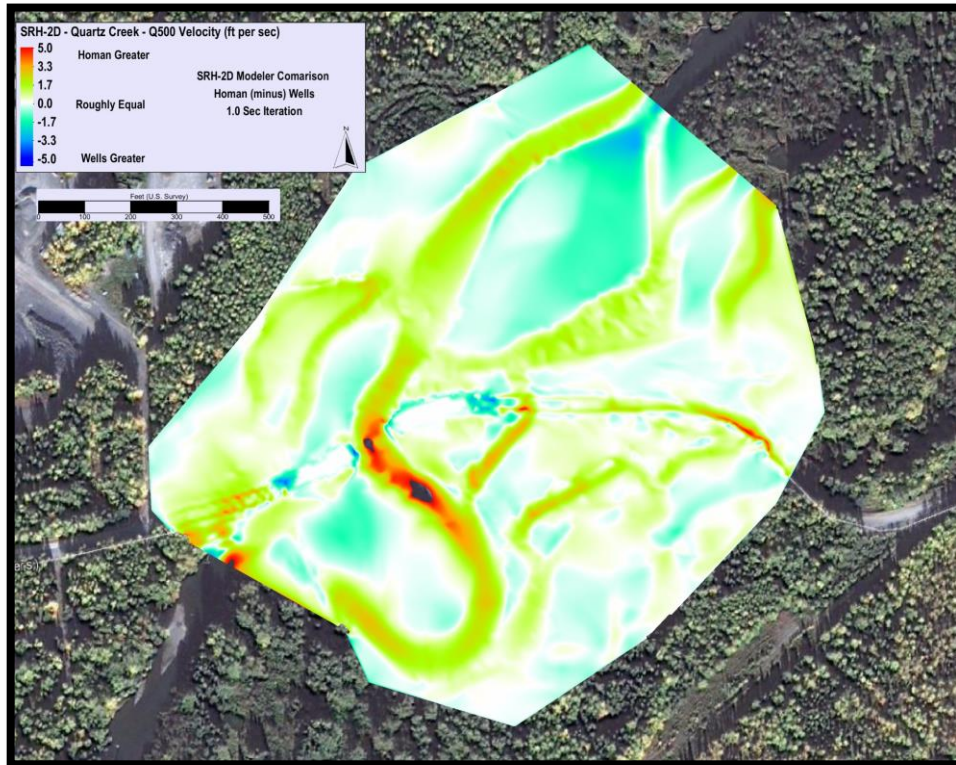


Figure 25: SRH-2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Velocity (ft/s).

The Shear Stress (lb/ft^2) comparison presented in Figure 26 shows that the modelers produced similar stresses, with differences generally less than +/- 1 lb/ft^2 . Exceptions to this are near the exit boundary and near the bridge, where Homan had much higher velocities. At these locations, Homan had greater shear stresses. The shape of material properties polygons is again apparent, as the results highlight the boundaries.

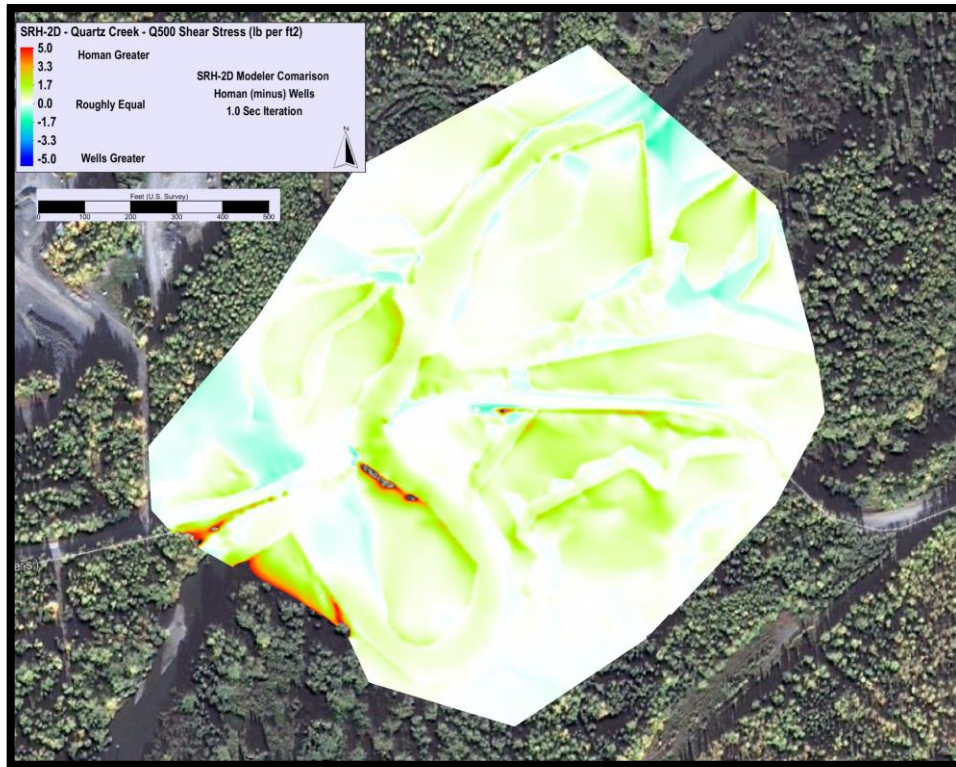


Figure 26: SRH-2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Shear Stress (lb/ft²).

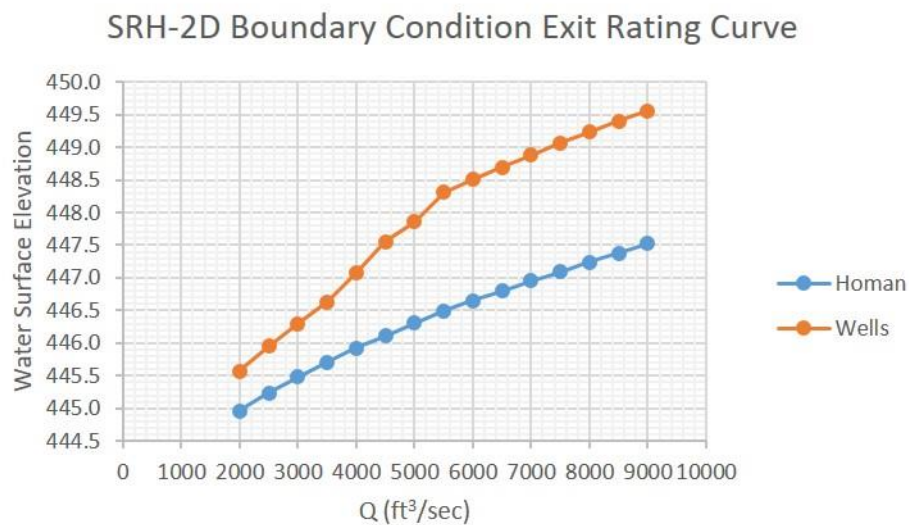


Figure 27: SRH-2D Quartz Creek downstream boundary condition rating curves for Homan and Wells.

2.2.7.1.2 Modeler Comparison for HEC-RAS 2D

The HEC-RAS 2D model is not capable of directly comparing model results. Instead, the HEC-RAS 2D results must be exported as a raster and evaluated in a separate program. By

design, HEC-RAS 2D works well with ArcGIS, but for consistency in this project, the HEC-RAS 2D model result comparisons were performed in SMS. In order to complete the HEC-RAS 2D comparisons in SMS, the HEC-RAS 2D raster exports were imported into SMS and converted into scatter data. The conversion to scatter data is necessary because SMS utilizes a TIN DEM rather than a Raster DEM. The conversion into scatter data allows SMS to use its internal capabilities of developing a TIN based on the imported scatter data. With the development of the TIN, the subsequent HEC-RAS 2D comparison processes in SMS followed the same protocol as the SRH-2D comparisons outlined in the section headed “Modeler Comparison for SRH-2D.”

Unlike the SRH-2D comparisons, which compared the entire domain regardless of whether an area was inundated with water, the HEC-RAS 2D comparisons only evaluated within the water inundation boundary. This difference is because the exported HEC-RAS 2D raster only represents where water was modeled to inundate, not the entire domain. For consistency in model comparisons, the same 5 to -5 scale and color scheme were used. There is, however, an exception to these scales for the HEC-RAS 2D comparisons; it is related to differences in size of the inundation boundaries. In areas where the Homan modeled inundation extent exceeds the Wells inundation boundary, the difference between the two is “something” minus “nothing.” As a result, SMS outputs a very high value for Homan. Several attempts were made to account for this by using the Dataset tools option, which allows a user to specify the value of an inactive layer “Value if Alternate is inactive.” No matter what value was input for the inactive Alternate value (i.e., 100 to -100), the output values were large; they therefore are red in the figures, based on the chosen color scheme.

Modeler Comparison for HEC-RAS 2D – Lakina River:

The HEC-RAS 2D Lakina River modeler comparisons for the Q500 (5880 cfs) flood event are provided in Figure 28–Figure 30. The Water Depth (ft) comparison presented in Figure 28 illustrates differences generally less than +/- 1.7 ft. The red patches along the boundaries are due to different inundation extents between Homan and Wells, not extreme water depth differences. Overall, Wells modeled deeper water depths compared with Homan. The greater depths for Wells are the result of using larger material roughness values to represent the surrounding forest. Both modelers used the same Manning’s n of 0.035 to represent the channel, but Wells used a forest roughness of 0.015, while Homan used 0.01 (Figure 6 and Figure 7). The larger roughness values used by Wells reduced the modeled velocities (Figure 29). In order to maintain a constant discharge based on the law of conservation of mass, the water depths would need to increase.

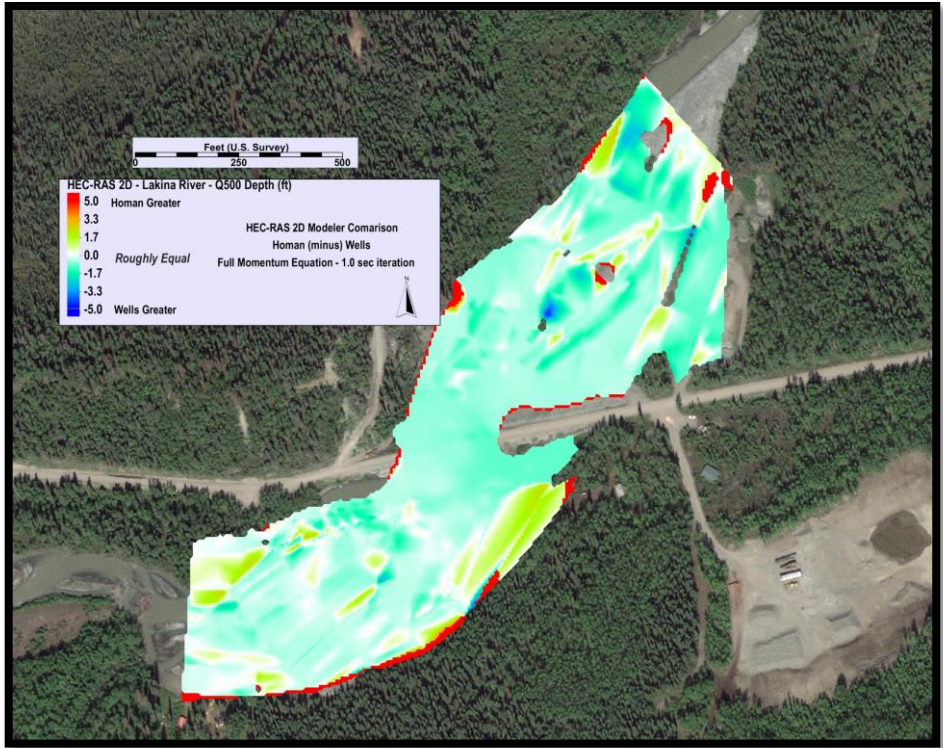


Figure 28: HEC-RAS 2D Lakina River modeler comparison (Homan minus Wells) for Q500 Water Depth (ft).

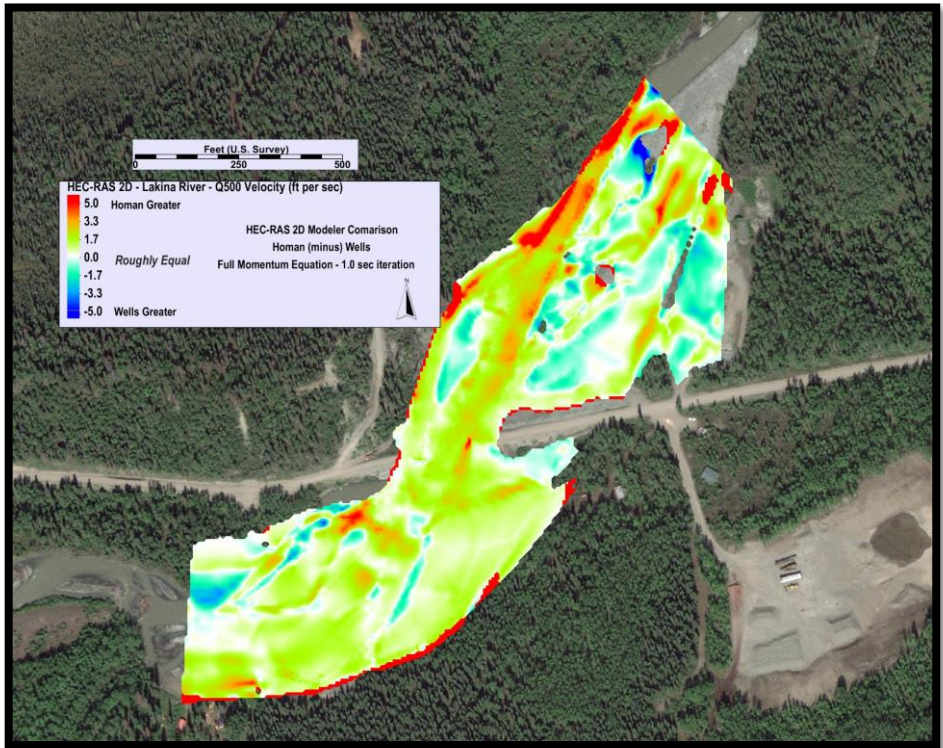


Figure 29: HEC-RAS 2D Lakina River modeler comparison (Homan minus Wells) for Q500 Velocity (ft/sec).

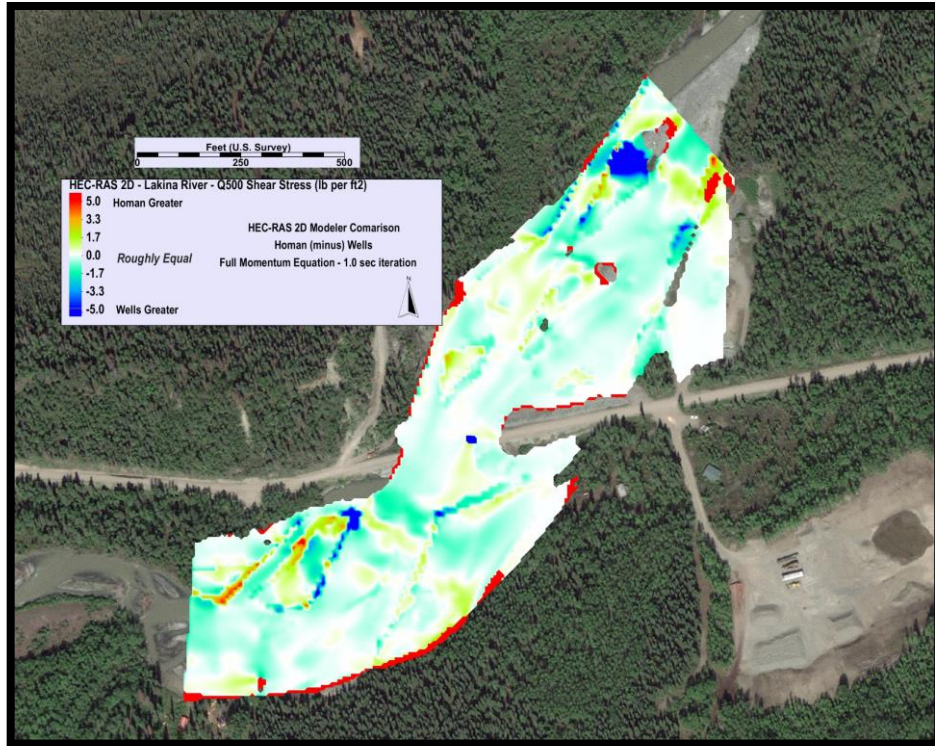


Figure 30: HEC-RAS 2D Lakina River modeler comparison (Homan minus Wells) for Q500 Shear Stress (lb/ft²).

The Velocity (ft/sec) comparison in Figure 29 indicates that Wells modeled lower velocities compared with Homan. Again, red patches along the boundaries are due to different inundation extents for Homan and Wells, but red within the channels is actually velocity differences approaching 5 ft/sec. As stated, velocity differences stem from the variances in material roughness values chosen by the modelers. The higher roughness values used by Wells resulted in slower, yet deeper waters.

The Shear Stress (lb/ft²) comparison in Figure 30 shows similar results between modelers, with differences generally less than +/- 1.7 lb/ft². The larger divergences that occur are primarily at offsets of material property polygons.

Modeler Comparison for HEC-RAS 2D – Quartz Creek:

The HEC-RAS 2D Quartz Creek modeler comparisons for the Q500 (8460 cfs) flood event are provided in Figure 31–Figure 33. The difference in HEC-RAS 2D domain sizes between modelers is almost the same as the difference in SRH-2D domain sizes, with the Homan domain being 17% smaller than the Wells domain (Table 3). Additionally, the HEC-RAS 2D water depth (ft) differences, which also lack topographical characteristics, are similar to the SRH-2D Quartz Creek modeler comparison (Figure 31). As before, the absence of topographical characteristics is related to the domain being completely inundated. Note that

because roughly the entire domain is inundated, nearly the entire domain was used for the comparison, and no red patches appear along the borders.

Regardless of the lack of topographical characteristics, Homan modeled greater water depths, which increased downslope. This result is the opposite of the modeling outcome for the SRH-2D Quartz Creek comparison, in which Wells modeled greater downslope water depths resulting in larger differences. The contrasting SRH-2D results occurred because Wells had a 2 ft higher exit surface water elevation due to differing downstream boundary condition rating curves (Figure 27). The HEC-RAS 2D model outputs, however, do not utilize downstream boundary condition rating curves, so the downslope increasing depth differences must stem from an alternative reason. We found that the greater water depths modeled by Homan are related to differences in domain size (Figure 11 and Table 3). Without the “weir” backup effect on water, the significant difference in domain size is more apparent in the model results. An additional component that affected the model outputs was the material roughness value selected by each modeler. Homan chose a smaller roughness value for the river channel, Manning’s n of 0.035 compared with 0.045 for Wells, but for most of the remaining domain, Wells chose smaller roughness values (Figure 8 and Figure 9). Collectively, the smaller domain defined by Homan and the selection of higher roughness values resulted in Homan modeling greater water depths.

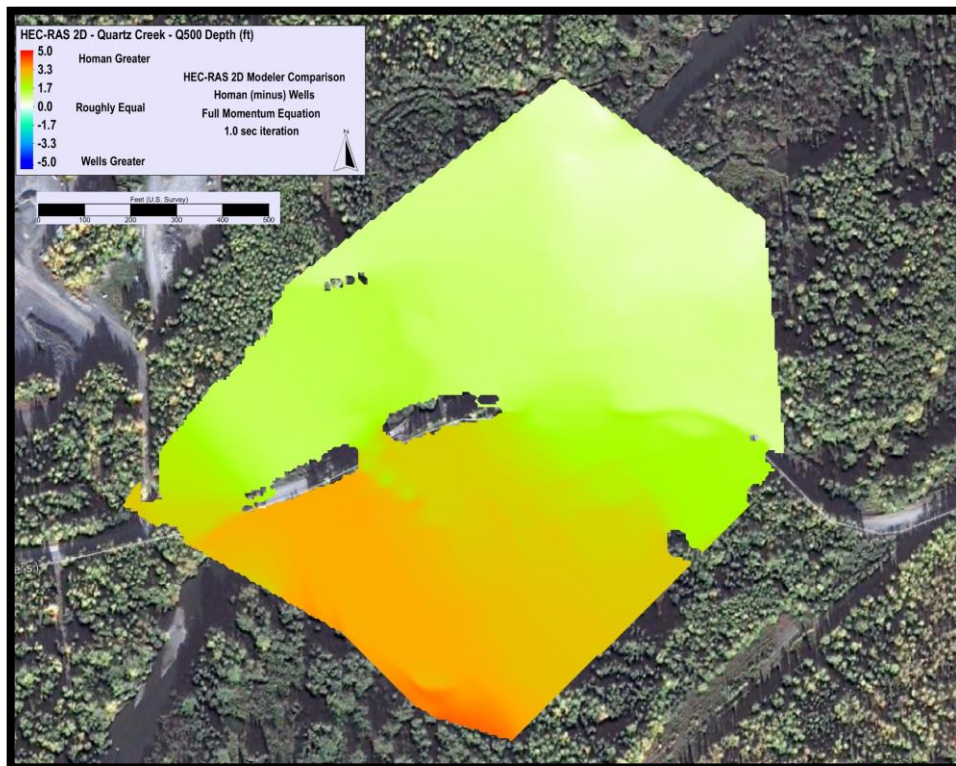


Figure 31: HEC-RAS 2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Water Depth (ft).

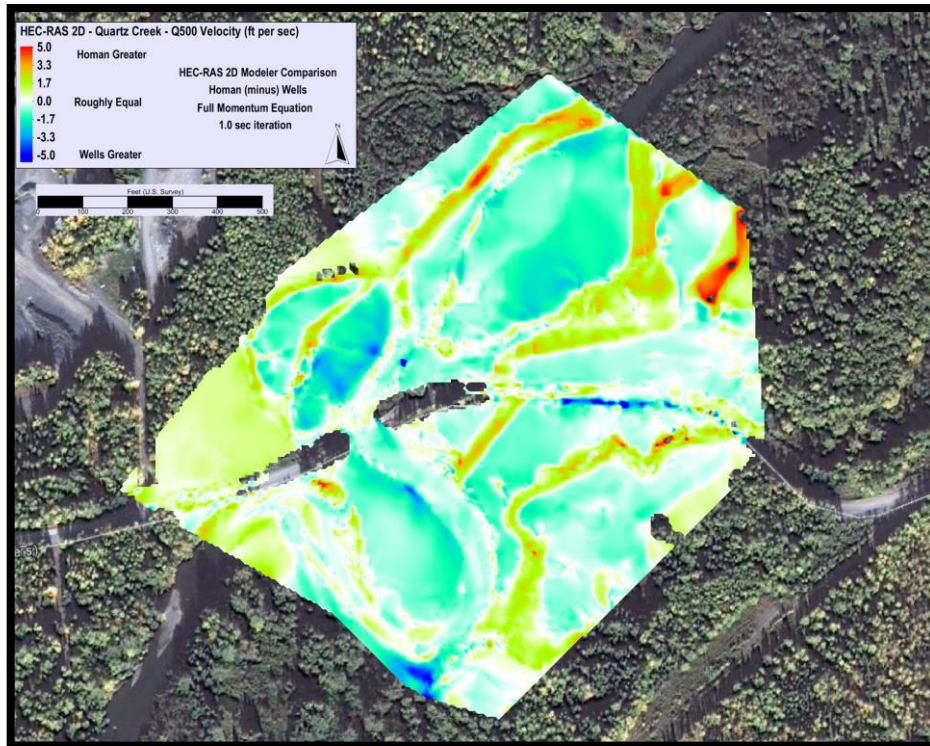


Figure 32: HEC-RAS 2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Velocity (ft/sec).

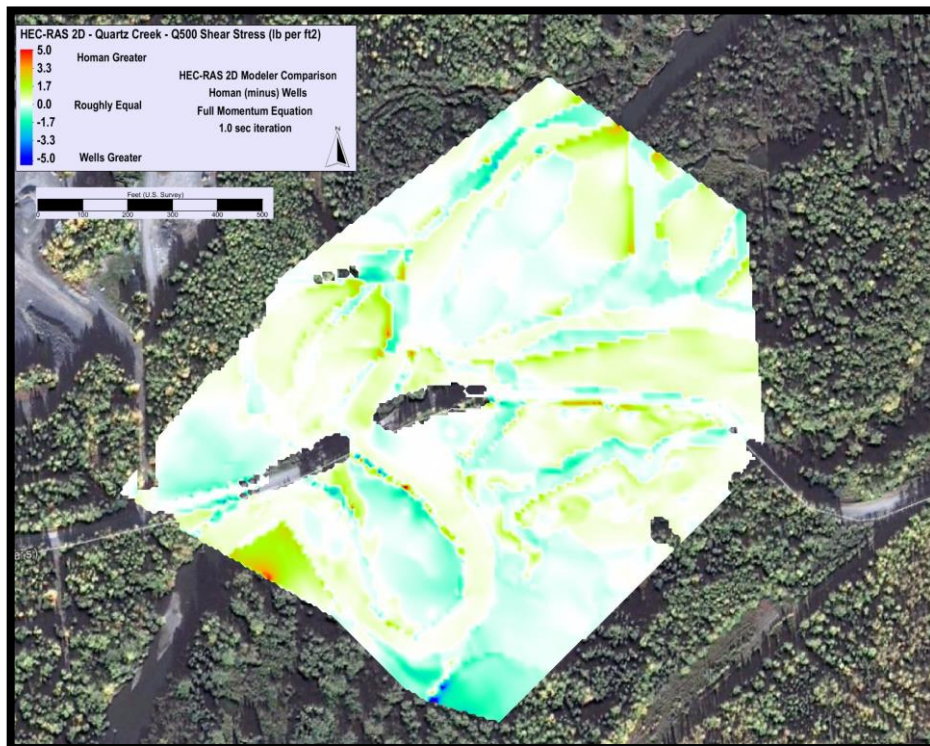


Figure 33: HEC-RAS 2D Quartz Creek modeler comparison (Homan minus Wells) for Q500 Shear Stress (lb/ft²).

The differences in material roughness values selected by Wells and Homan are also evident in the velocity differences (Figure 32). Homan used smaller roughness values in the channel, which resulted in greater channel velocities, while Wells used smaller roughness values in the remaining domain, which resulted in higher velocities in those areas.

The Shear Stress (lb/ft²) comparison presented in Figure 33 shows similar results between modelers, with differences generally less than +/- 1.7 lb/ft². The locations where larger differences occur are primarily at offsets of material property polygons.

2.2.7.2 Model Comparison: SRH-2D versus HEC-RAS 2D

Again, without model calibration, only the differences in the model results can be compared. In this section, we provide the model differences between SRH-2D and HEC-RAS 2D based on the models developed by Homan and Wells. During the comparison, parameters such as material roughness polygons and specific Manning’s *n* values were kept constant for each modeler, so the resultant differences are strictly related to model processing. All model comparisons were conducted for the 500-year flood event (Q500). We compared differences in model results for Water Depth, Shear Stress, and Velocity, resulting in 12 different model comparisons (Table 7). The domain boundary sizes varied between the models; however, they varied even more between the modelers.

Table 7: Twelve model scenario comparisons for the 500-year flood event (Q500).

Model Comparison (All Q500)				
Model	Stream	Differences		
SRH – RAS (All Homan)	Lakina River	Water Depth	Shear Stress	Velocity
	Quartz Creek	Water Depth	Shear Stress	Velocity
SRH – RAS (All Wells)	Lakina River	Water Depth	Shear Stress	Velocity
	Quartz Creek	Water Depth	Shear Stress	Velocity

Using the Dataset Toolbox within SMS, we compared the SRH-2D and HEC-RAS 2D model results produced by the modelers. We used the same Compare tool and approach used during the Modeler Comparison. Once again, the Compare tool command within the Data Toolbox allows a modeler to compare two datasets computationally by subtracting the Alternate dataset from the Base dataset. In all comparisons, HEC-RAS 2D results were set as the Alternate dataset and SRH-2D results were set as the Base dataset. With this mathematical arrangement, positive values indicate that SRH-2D results were larger, negative values indicate that HEC-RAS 2D results were larger, and near zero values indicate equality between models. For consistency, the scale range and color scheme were fixed for all comparisons. We used the same scale arrangement as we used in the Modeler Comparison results section. Numerically, the scale is from 5 to -5, in which 5 represents the difference of SRH-2D values being five units greater than HEC-RAS 2D values, and in which -5 represents the difference

of HEC-RAS 2D values being five units greater than SRH-2D values. In the color scheme, red represents greater SRH-2D values, blue represents greater HEC-RAS 2D values, and white represents little to no difference between model results.

2.2.7.2.1 Homan Model Comparison – Lakina River

The Homan Lakina River model (SRH-2D minus HEC-RAS 2D) comparisons for the Q500 (5880 cfs) flood event are provided in Figure 34–Figure 36. The Water Depth (ft) comparison presented in Figure 34 is primarily faint in color, demonstrating little difference between model results. All water depths are roughly within a foot of each other (+/- 1 ft).

The Velocity (ft/sec) comparison presented in Figure 35 illustrates more significant color contrast because of greater differences in model results. Both models produced areas with greater velocities. In general, HEC-RAS 2D produced higher velocities over the flood plain areas, while SRH-2D produced higher velocities predominantly in the main channels. For the most part, the water depths were modeled the same, so the velocity differences must be related to how the models respond to material properties.

The Shear Stress (lb/ft²) comparison presented in Figure 36 shows that the models had similar results, with differences generally less than +/- 1.7 lb/ft². The locations where model differences are largest occur primarily at offsets of material property polygons.

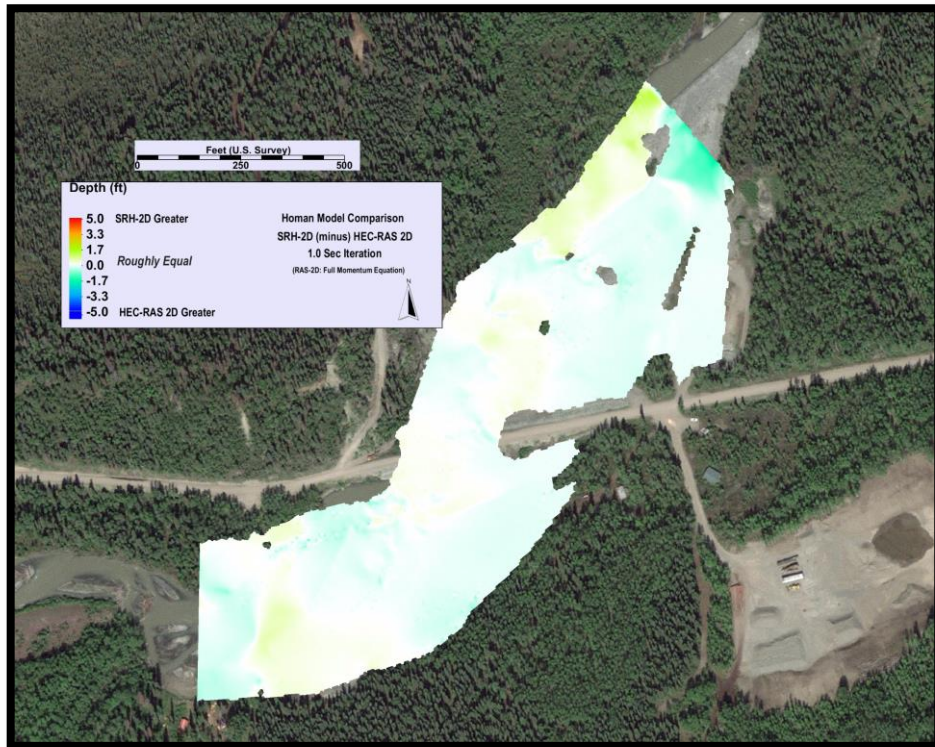


Figure 34: Homan Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Water Depth (ft).

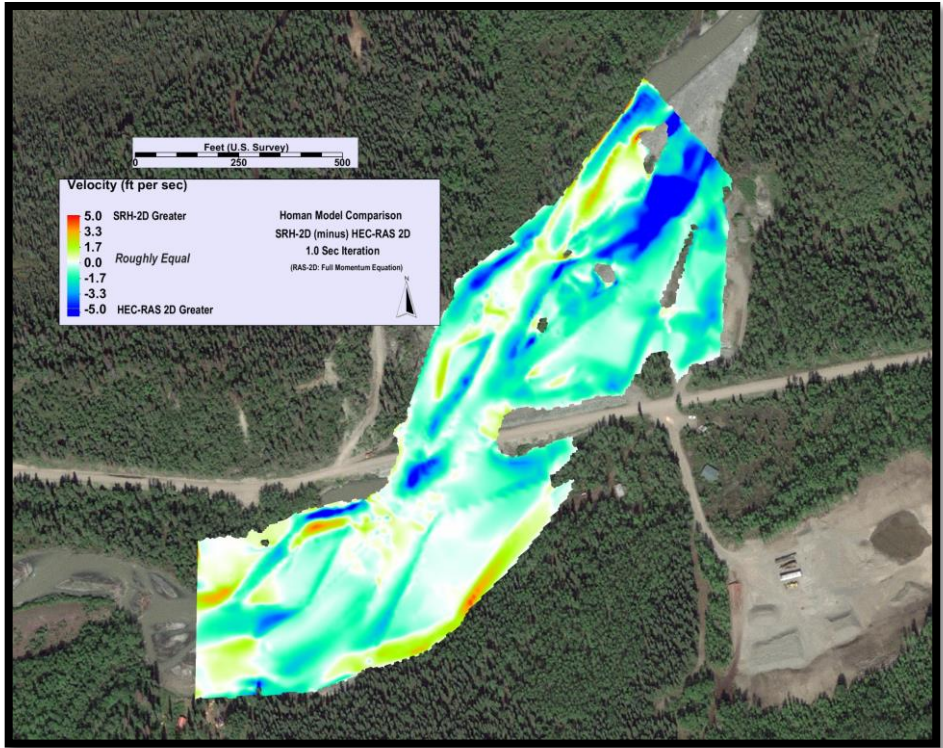


Figure 35: Homan Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Velocity (ft/sec).

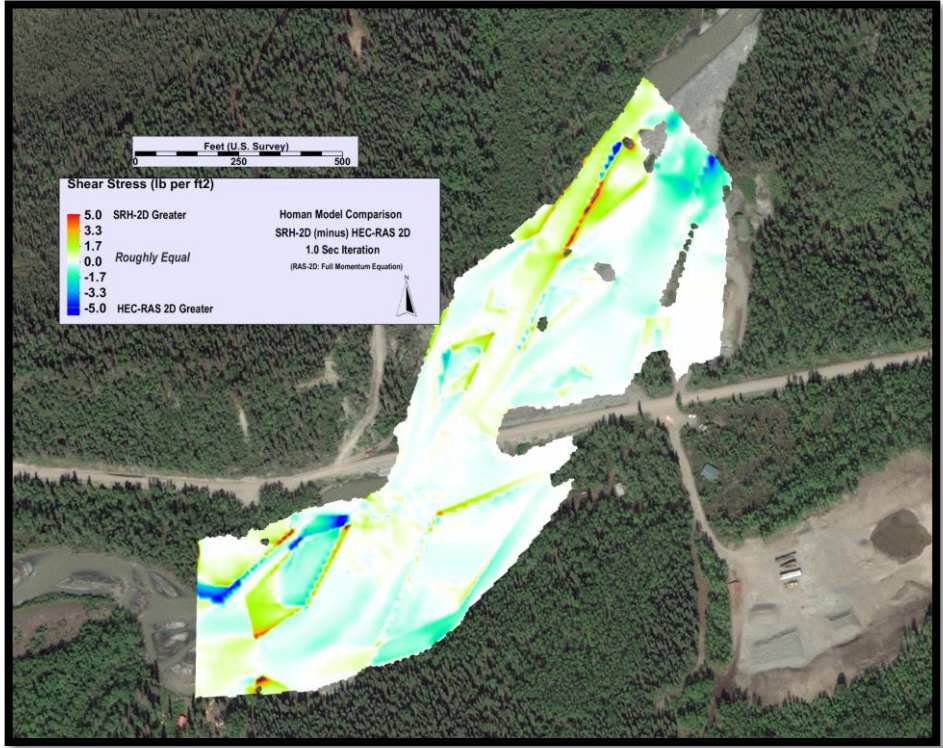


Figure 36: Homan Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Shear Stress (lb/ft²).

2.2.7.2.2 Homan Model Comparison – Quartz Creek

The Homan Quartz Creek model (SRH-2D minus HEC-RAS 2D) comparisons for the Q500 (8460 cfs) flood event are provided in Figure 37–Figure 39. There is a moderate difference in domain sizes between models, with the HEC-RAS 2D domain being 9% smaller than the SRH-2D domain (Figure 11 and Table 3). The Water Depth (ft) comparison presented in Figure 37 illustrates that HEC-RAS 2D produced slightly greater water depths throughout most of the domain. The Velocity (ft/sec) comparison presented in Figure 38 also demonstrates that HEC-RAS 2D yielded higher outputs. The reduced HEC-RAS 2D domain size likely explains both the higher depths and velocities, but what is not clear is how the models react to material properties. The model response to different material properties should not be ignored, thus we evaluated this further with a sensitivity analysis of the models to material properties, presented in Section 2.2.7.3.

The Shear Stress (lb/ft²) comparison presented in Figure 39 shows that the models had similar results, with differences generally less than +/- 1 lb/ft². The locations where model differences are largest occur primarily at offsets of material property polygons, as well as in the main channel because HEC-RAS 2D produces higher velocities.

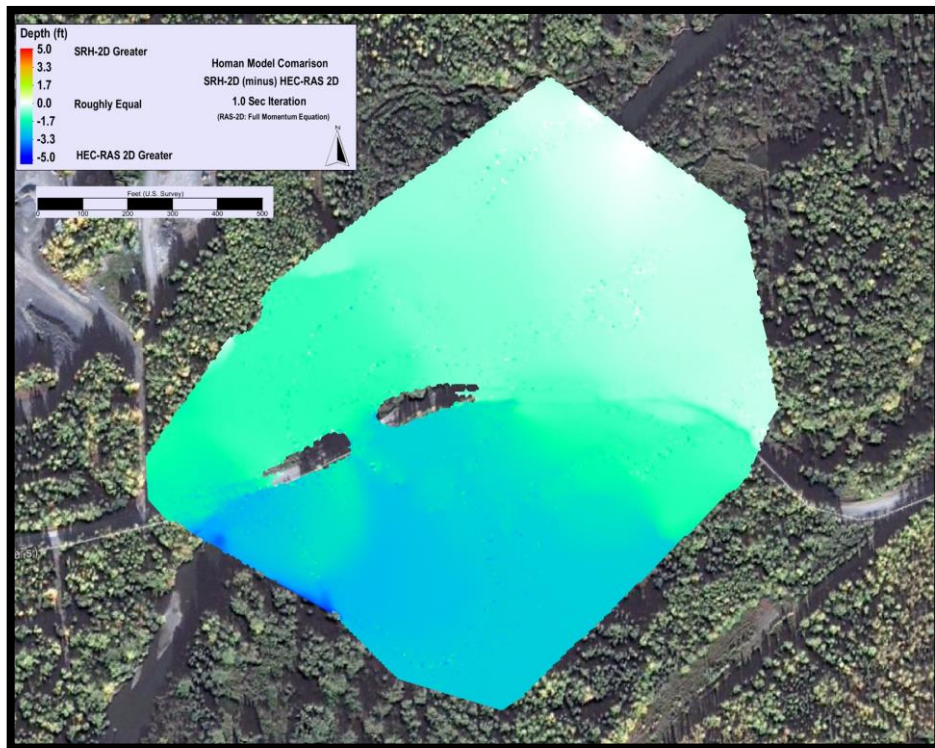


Figure 37: Homan Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Water Depth (ft).

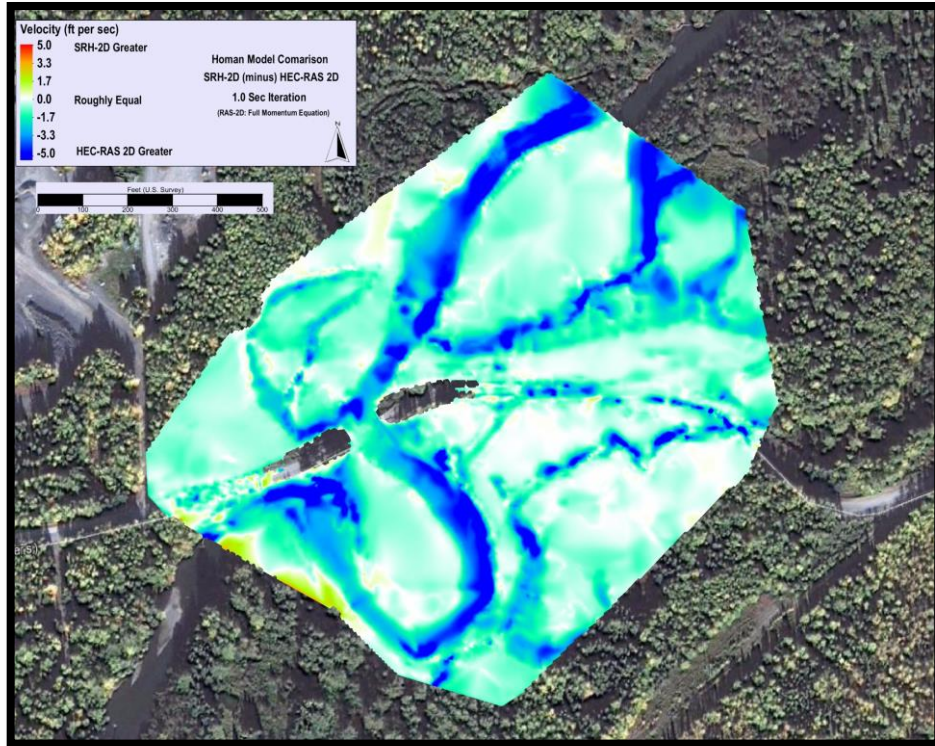


Figure 38: Homan Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Velocity (ft/sec).

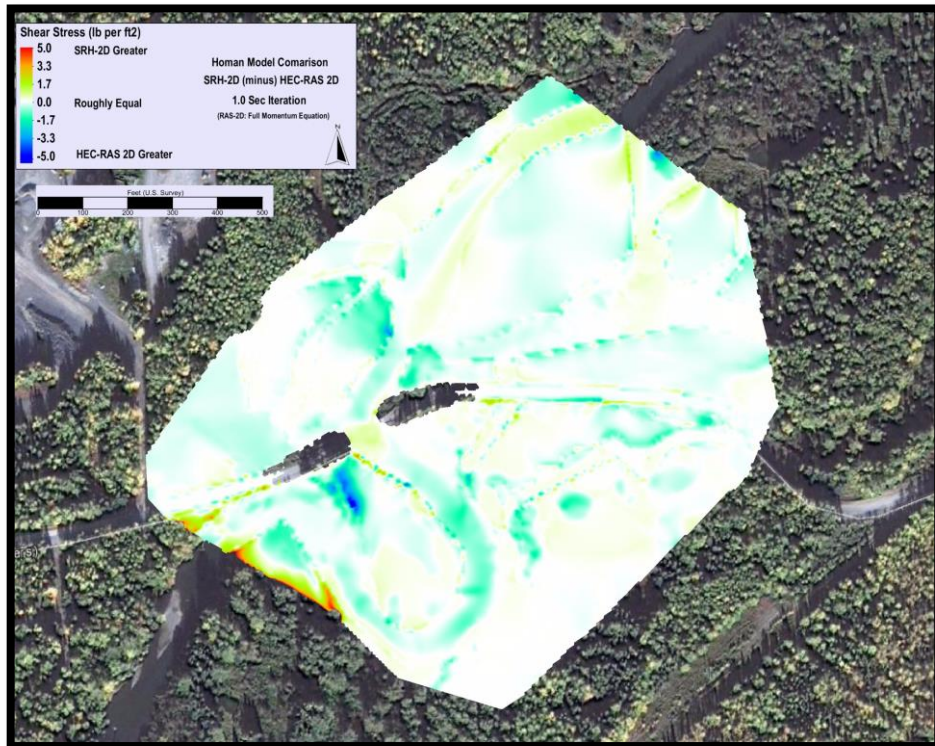


Figure 39: Homan Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Shear Stress (lb/ft²).

2.2.7.2.3 Wells Model Comparison – Lakina River

The Wells Lakina River model (SRH-2D minus HEC-RAS 2D) comparisons for the Q500 (5880 cfs) flood event are provided in Figure 40–Figure 42. The Water Depth (ft) comparison presented in Figure 40 demonstrates that HEC-RAS 2D produced greater depths for a majority of the domain. The Velocity (ft/sec) comparison presented in Figure 41, however, illustrates that SRH-2D produced greater overall velocities, with the largest differences located in the main channel. The contrasting model results hold true due to the law of conservation of mass, with HEC-RAS 2D producing relatively higher depths and lower velocities, which is the opposite for SRH-2D.

The Shear Stress (lb/ft²) comparison presented in Figure 42 shows the largest shear stress differences in any of the comparisons thus far. The greater shear stress differences are the result of contrasting depths and velocities.

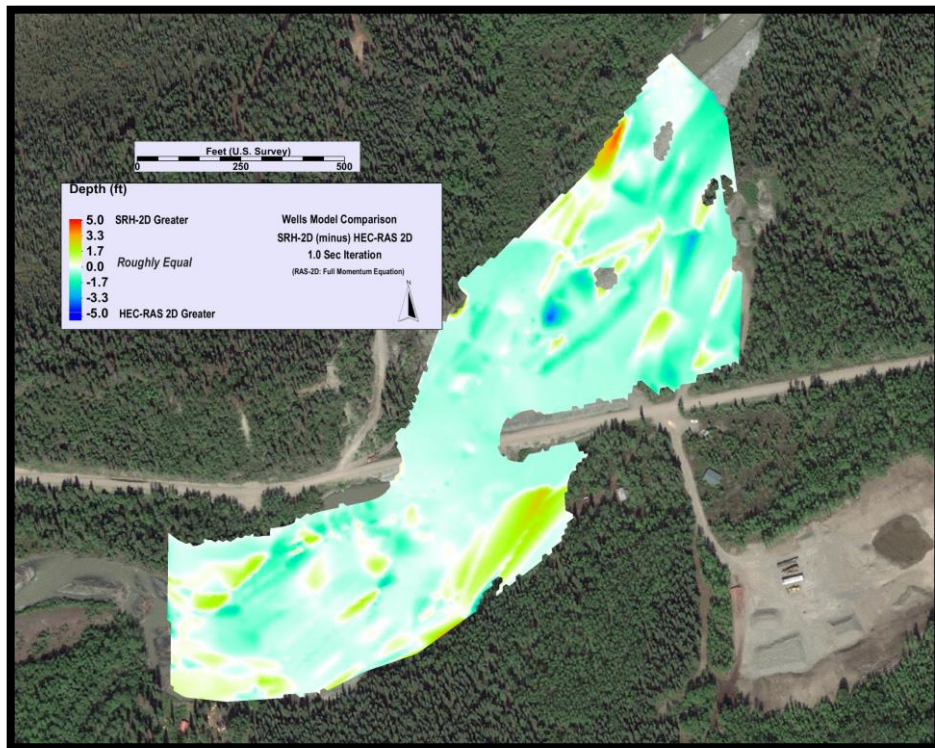


Figure 40: Wells Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Water Depth (ft).

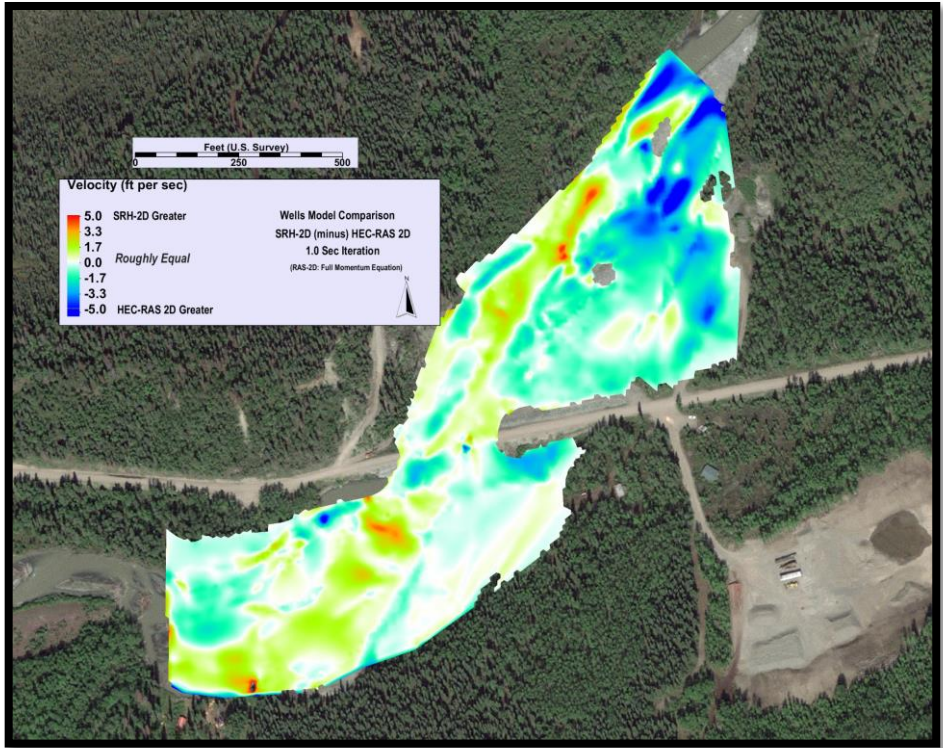


Figure 41: Wells Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Velocity (ft/sec).

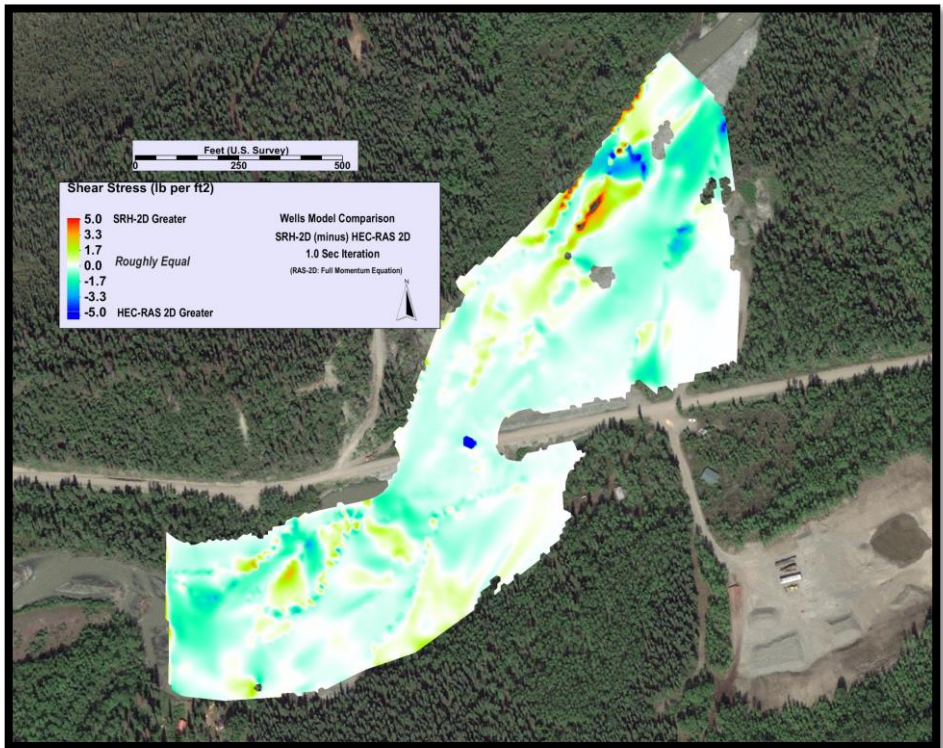


Figure 42: Wells Lakina River model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Shear Stress (lb/ft²).

2.2.7.2.4 Wells Model Comparison – Quartz Creek

The Wells Quartz Creek model (SRH-2D minus HEC-RAS 2D) comparisons for the Q500 (8460 cfs) flood event are provided in Figure 43–Figure 45. There is a reasonable difference in domain sizes between models, with the HEC-RAS 2D domain being 10% smaller than the SRH-2D domain (Figure 11 and Table 3). The Water Depth (ft) comparison presented in Figure 43 illustrates that SRH-2D produced greater water depths throughout most of the domain. The reason for greater water depth is the “weir” backup effect on water depth from the downstream boundary, even though the SRH-2D domain size is larger.

The Velocity (ft/sec) comparison presented in Figure 44 demonstrates that SRH-2D also produced higher model outputs for large portions of the domain. At the “In Flow” boundary, the velocity differences are greater than 5 ft/s, surpassing the scale range. Consequently, these areas outside the scale range are left blank (no color) in the figure. Most of the high contrasts in velocity along the channel are where the water depth differences are relatively high (Figure 43).

The Shear Stress (lb/ft²) comparison presented in Figure 45 shows very little contrast between models, with differences generally less than +/- 1 lb/ft². Where model differences are largest, HEC-RAS 2D has the greater values; the difference in shear stress values is found in the downstream channel where HEC-RAS 2D had higher velocities.

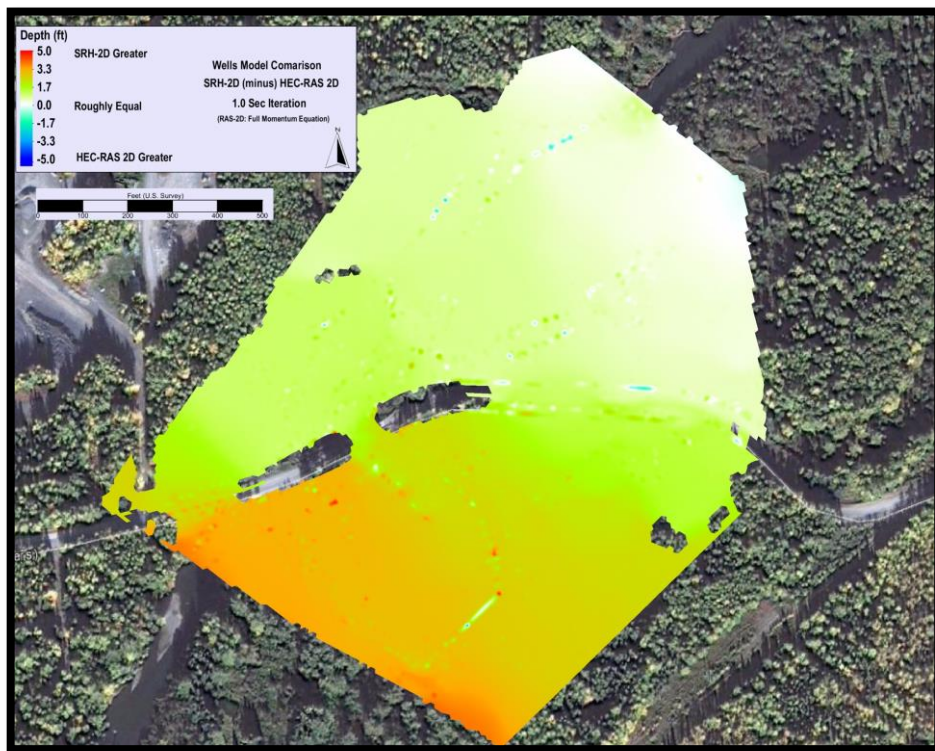


Figure 43: Wells Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Water Depth (ft).

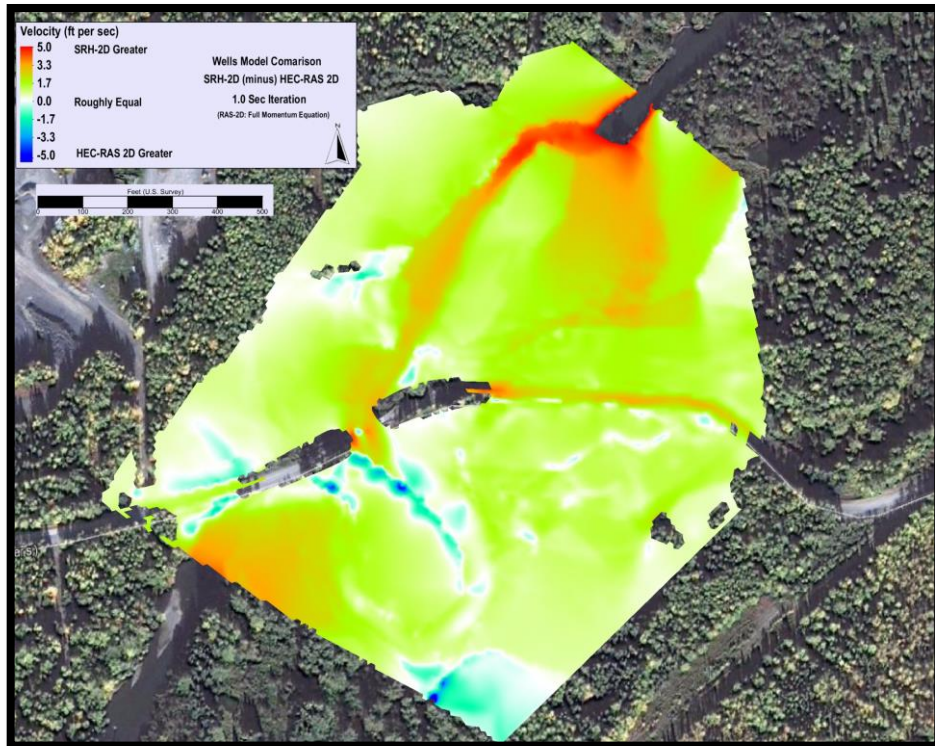


Figure 44: Wells Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Velocity (ft/sec).

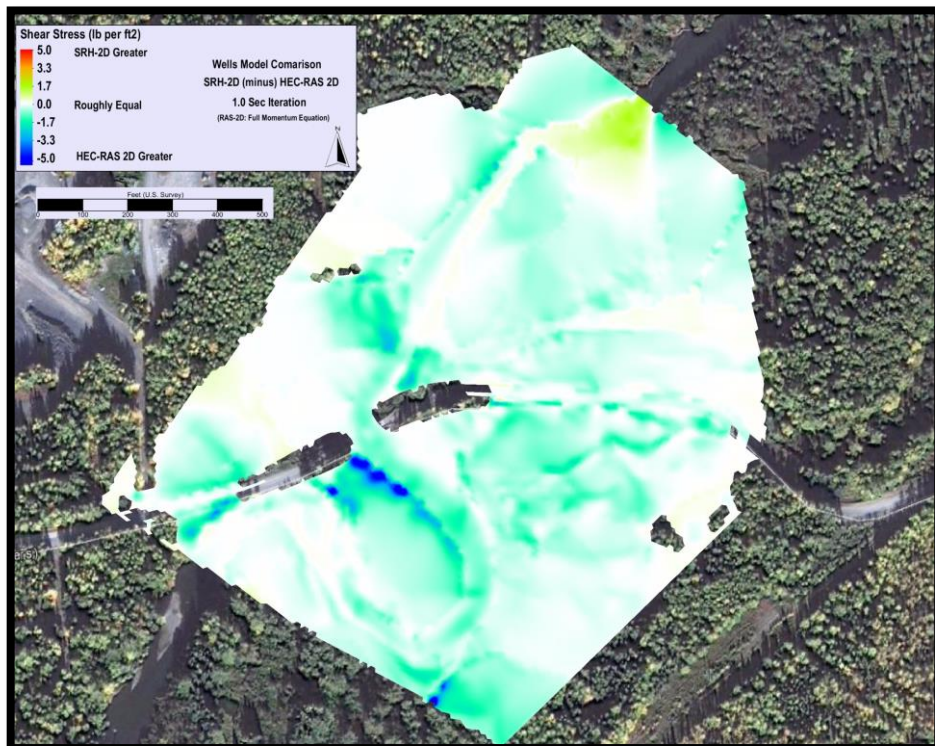


Figure 45: Wells Quartz Creek model comparison (SRH-2D minus HEC-RAS 2D) for Q500 Shear Stress (lb/ft²).

2.2.7.3 Model Parameter Sensitivity Analyses

To maintain consistency between modelers and models, an iteration time step of 1 second was fixed and the full dynamic wave equation was used for all modeling scenarios. The iteration time step, however, could have varied with modeler discretion. The modeling equation itself could have differed also, as HEC-RAS 2D has the option of choosing the diffusion wave equation, which is actually set as the default option. The following are sensitivity analyses for different iteration time steps and modeling equations (full dynamic vs. diffusion wave). We conducted an additional sensitivity analysis for material properties, as it was apparent that material properties played a large role in the model outputs. We conducted all three sensitivity analyses using only Homan model results.

2.2.7.3.1 Iteration Time Step and Modeling Equation Analyses

When we were deciding how to present the Iteration Time Step sensitivity analysis, it became clear that joining the analysis results with the Modeling Equation analysis provided greater insight into both investigations. All modeled scenarios were conducted using the Q500 flood event. Both analyses for Lakina River Q500 mean model Depths (ft) and Velocities (ft/sec) are presented in Figure 46 and Figure 47, respectively. Variations in the iteration time step from 2 to 0.1 seconds had little to no effect when modeled with the full dynamic wave equation for either SRH-2D or HEC-RAS 2D. The same iteration time-step changes, however, had significant ramifications when using the HEC-RAS 2D diffusion wave equation. The exact model outputs and associated percent changes for the analyses are provided in Table 8.

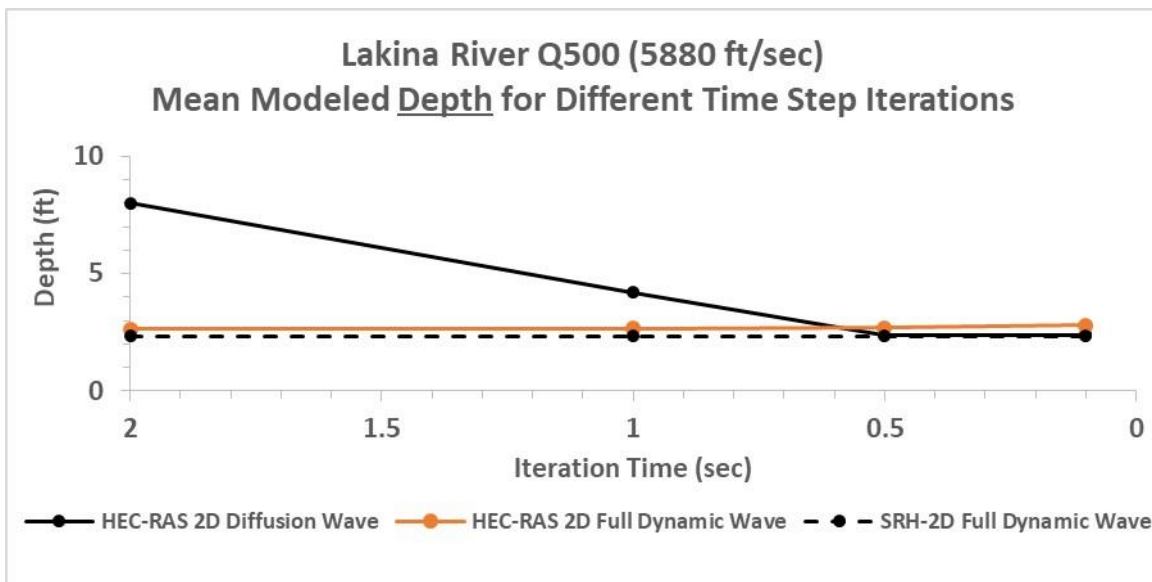


Figure 46: Lakina River Q500 mean modeled Water Depths (ft) for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

At a larger iteration time step (2 sec), the HEC-RAS 2D diffusion wave equation results for both water depth and velocity were approximately triple the results produced by SRH-2D and HEC-RAS 2D when using the full dynamic wave equation. As the iteration time step was reduced from 2 to 0.1 seconds, the resultant differences diminished and eventually converged at a 0.5-second iteration for water depth and a 0.1-second iteration for velocity. An interesting finding related to the dynamic wave equation outputs for SRH-2D and HEC-RAS 2D is that HEC-RAS 2D consistently produced higher velocities.

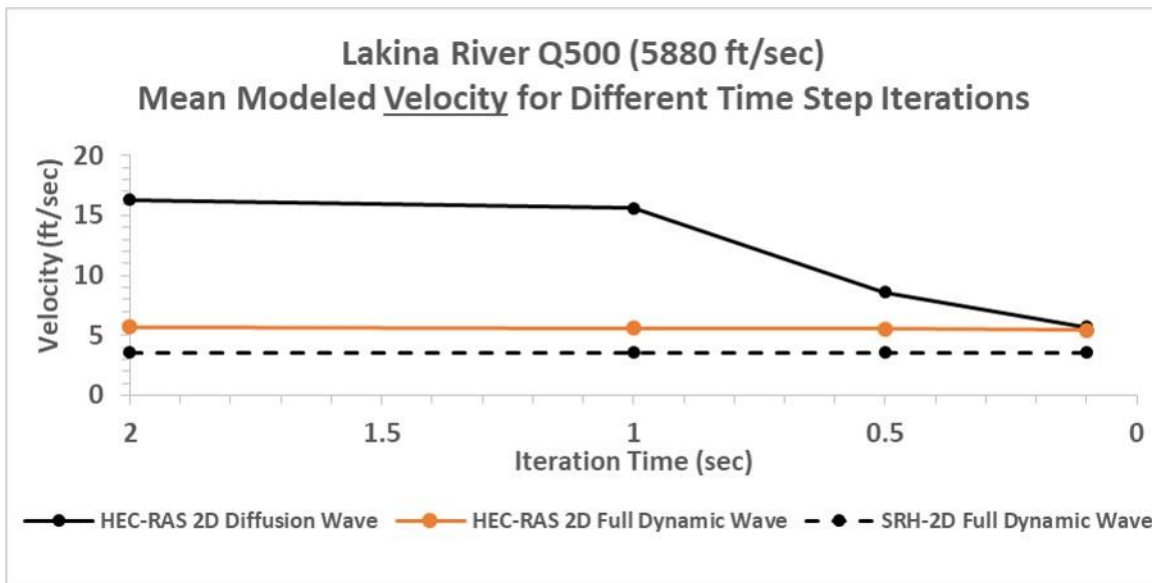


Figure 47: Lakina River Q500 mean modeled Velocity (ft/sec) for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

Table 8: Lakina River Q500 mean modeled Velocity (ft/sec) and Water Depth (ft) analyses results for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

Lakina River - Q500 Mean Velocity (ft/sec)	Time Step Iteration				
Model	2 Sec	1 Sec	0.5 Sec	0.1 Sec	Change
HEC-RAS 2D Diffusion Wave	16.3	15.6	8.6	5.7	65%
HEC-RAS 2D Full Dynamic Wave	5.7	5.6	5.6	5.4	4%
SRH-2D Full Dynamic Wave	3.5	3.5	3.6	3.6	0%
Lakina River - Q500 Mean Depth (ft)					
Model	2 Sec	1 Sec	0.5 Sec	0.1 Sec	Change
HEC-RAS 2D Diffusion Wave	8	4.2	2.4	2.4	70%
HEC-RAS 2D Full Dynamic Wave	2.6	2.7	2.7	2.8	-6%
SRH-2D Full Dynamic Wave	2.3	2.3	2.3	2.3	0%

The Quartz Creek Q500 mean model results for Water Depth (ft) and Velocity (ft/sec) for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D and the diffusion wave equation for HEC-RAS 2D are presented in Figure 48 and Figure 49. The exact model outputs and percent changes from 2 to 0.1 seconds are provided in Table 9.

Because the Quartz Creek domain is predominantly inundated, the smallest change in water depth affects a large area. When this change is combined with the continuity equation, a change in velocity occurs. This concept is apparent in Figure 48, Figure 49, and Table 9. Altogether, iteration time-step adjustments had less effect on modeled water depth, with all depths being moderately comparable. As the iteration time step was reduced from 2 to 0.1 seconds, relatively small water depth changes occurred, with a 9% decrease when using the SRH-2D full dynamic wave equation (which resulted in a 44% increase in velocity) and a 15% decrease when using the HEC-RAS 2D diffusion wave equation (which resulted in a 66% increase in velocity). The results support the idea that small depth changes within the Quartz Creek domain produce large velocity adjustments.

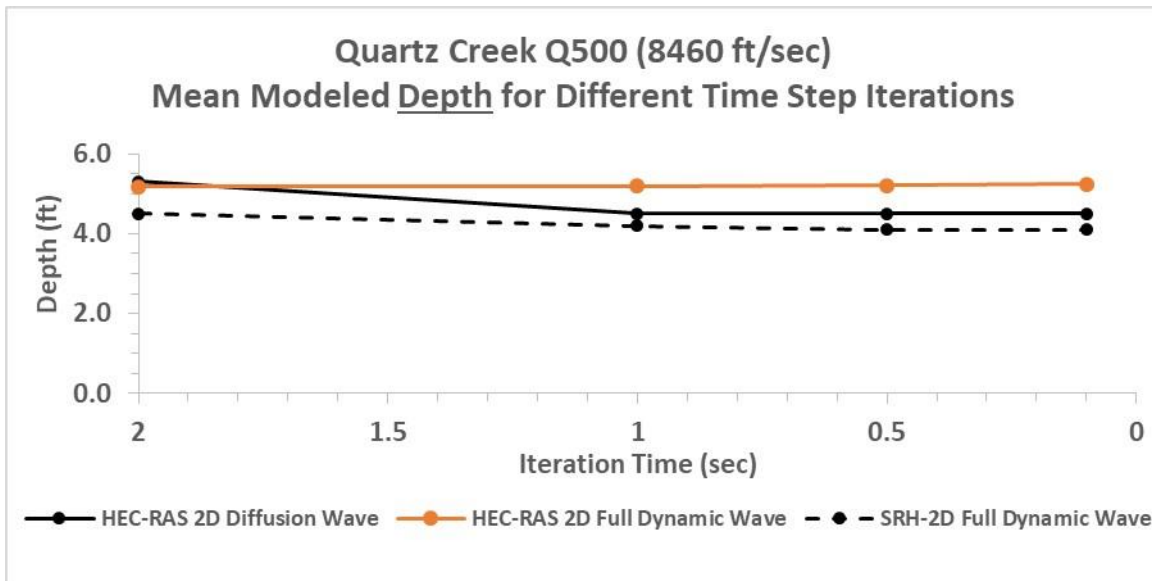


Figure 48: Quartz Creek Q500 mean modeled Water Depth (ft) for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

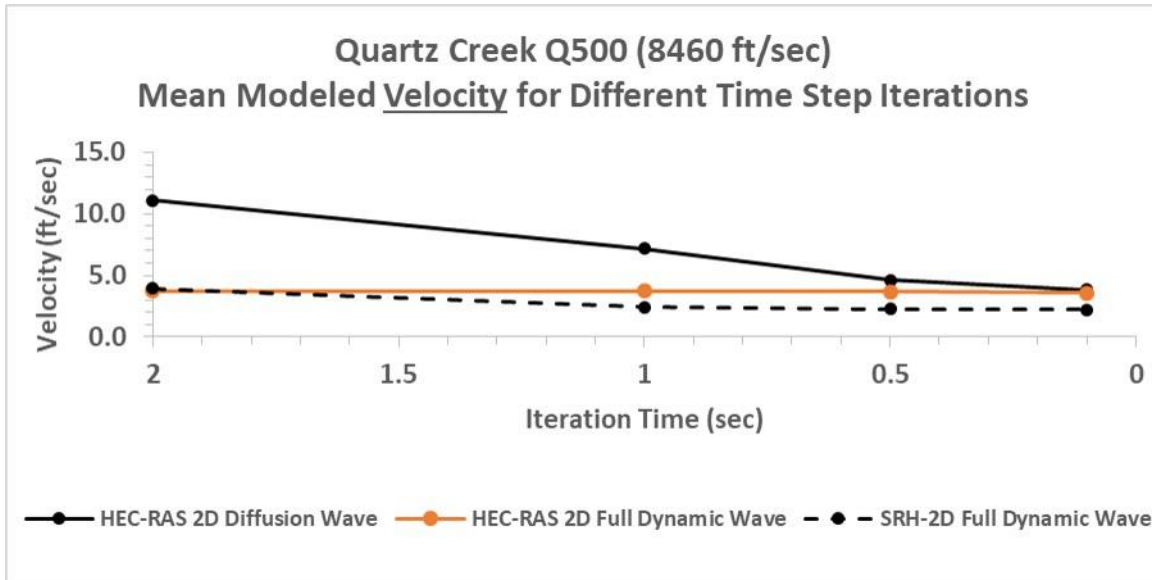


Figure 49: Quartz Creek Q500 mean modeled Velocity (ft/sec) for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

Table 9: Quartz Creek Q500 mean modeled Velocity (ft/sec) and Water Depth (ft) results for different iteration time steps using the full dynamic wave equation for SRH-2D and HEC-RAS 2D, and the diffusion wave equation for HEC-RAS 2D.

Quartz Creek - Q500 Mean Velocity (ft/sec)		Time Step Iteration				
Model		2 Sec	1 Sec	0.5 Sec	0.1 Sec	Change
HEC-RAS 2D Diffusion Wave		11.1	7.2	4.6	3.8	66%
HEC-RAS 2D Full Dynamic Wave		3.7	3.7	3.7	3.6	4%
SRH-2D Full Dynamic Wave		3.9	2.4	2.2	2.2	44%
Quartz Creek - Q500 Mean Depth (ft)		Time Step Iteration				
Model		2 Sec	1 Sec	0.5 Sec	0.1 Sec	Change
HEC-RAS 2D Diffusion Wave		5.3	4.5	4.5	4.5	15%
HEC-RAS 2D Full Dynamic Wave		5.2	5.2	5.2	5.2	-1%
SRH-2D Full Dynamic Wave		4.5	4.2	4.1	4.1	9%

In general, the full dynamic wave equation results for HEC-RAS 2D were the least sensitive to changes in iteration time steps. The diffusion wave equation results for HEC-RAS 2D, however, produced large variations for different iteration times. Specifically, at a 2-second iteration time, the diffusion wave equation produced high velocities, but as the iteration time decreased to 0.1 seconds, the velocities calculated using the two equations (diffusion wave equation and dynamic wave equation) converged. Again, similar to the Lakina River results, the HEC-RAS 2D model yielded slightly higher velocities overall.

2.2.7.3.2 Material Roughness Sensitivity

Throughout the model and modeler comparisons, it was apparent that material properties played a large role in the model outputs. We conducted a sensitivity analysis to evaluate the effects that different Manning's n values had on the model outputs (water depth and velocity). Originally, Homan selected a Manning's n of 0.035 to represent the main channel in both the Lakina River and Quartz Creek models, while Wells selected 0.035 for Lakina River and 0.045 for Quartz Creek (Figure 6–Figure 9). For this analysis, only the Homan model results were used.

Homan SRH-2D and HEC-RAS 2D models were run using four different channel material properties: Manning's n of 0.03, 0.035, 0.04, and 0.045. To acquire the information needed from these modeled scenarios, HEC-RAS 2D results were exported as rasters and brought into ArcMap. In the Layer Properties, the Source Information provided the mean value of the imported results (water depth and/or velocity). The SRH-2D results were acquired in SMS using Dataset Information, which provided the mean layer values. The mean modeled velocities and water depths from the Homan SRH-2D and HEC-RAS 2D model results using the four different material properties are illustrated in Figure 50 and Figure 51, respectively.

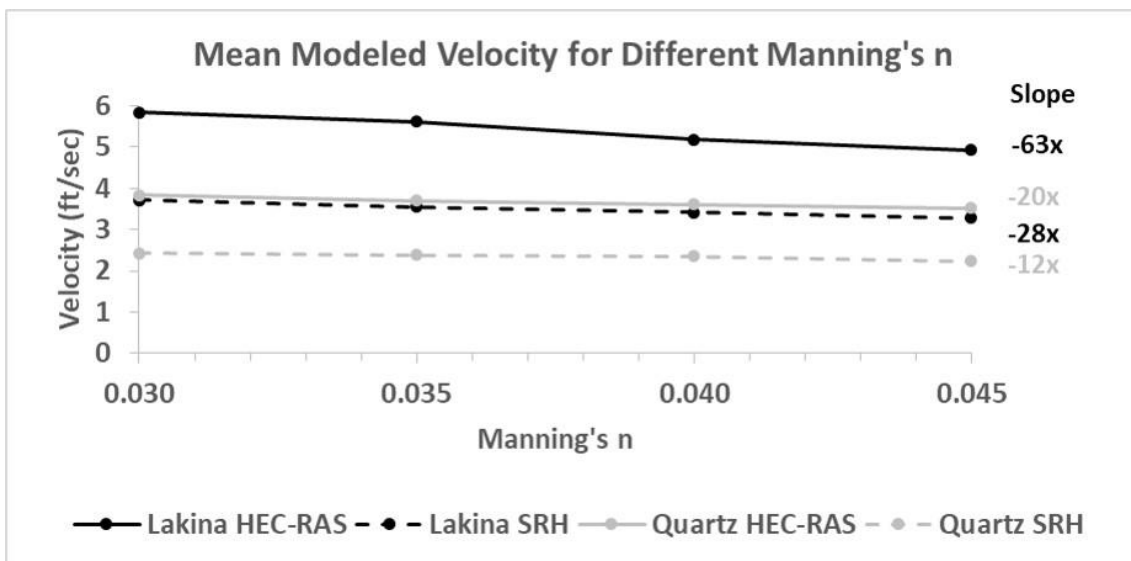


Figure 50: Mean modeled Velocity for Homan SRH-2D and HEC-RAS 2D models using different channel Manning's n values.

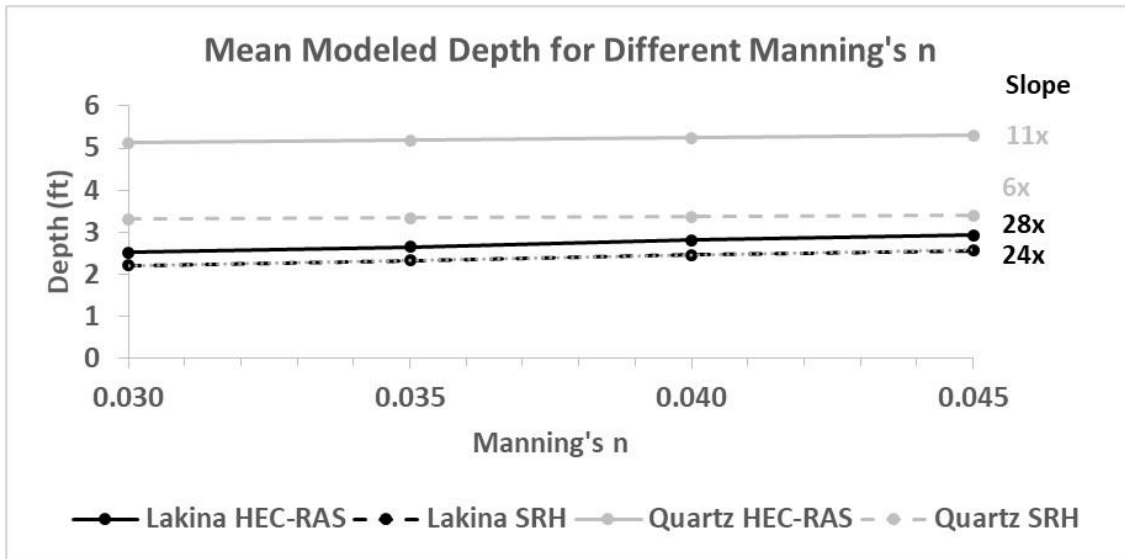


Figure 51: Mean modeled Water Depth for Homan SRH-2D and HEC-RAS 2D models using different channel Manning's n values.

For both geographic locations (Lakina River and Quartz Creek), each model (SRH-2D and HEC-RAS 2D) produced a decrease in mean water velocity (negative slopes) and a corresponding increase in mean water depth (positive slopes) as channel roughness values increased. The sensitivity of the models to the roughness properties is indicated by the change in slope, with larger slopes symbolizing greater sensitivity. Altogether, HEC-RAS 2D velocity and water depth changes (slopes) are greater compared with the SRH-2D results, indicating greater HEC-RAS 2D sensitivity to material properties.

Additionally, it is evident from Figure 50 and Figure 51 that Lakina River (black lines) had higher velocities and shallower depths compared with Quartz Creek (gray lines). These differences make sense and are related to the relative energy within the geographic settings. The low-gradient terrain of Quartz Creek means that the system has less hydraulic energy; in turn, water velocities are comparatively lower and corresponding water depths are greater.

CHAPTER 3. MODELING CONCLUSIONS AND RECOMMENDATIONS

3.1 Modeler Comparison

The modeler comparison (Homan minus Wells) results consisted of 12 comparisons, including Water Depth, Velocity, and Shear Stress differences for two geographic settings (Lakina River and Quartz Creek) and two models (SRH-2D and HEC-RAS 2D). Some of the model parameters (i.e., hydraulic conditions, iteration time step, modeling equation) were fixed between the modelers, while other factors (i.e., material properties, domain shape and size, boundary conditions) were left to modeler discretion. We found that domain size played a significant role in the modeling outputs. This is primarily the result of the Quartz Creek domain being completely inundated; a change of domain size directly affected the model results. If the survey elevation data extended beyond the water inundation limits, which is needed for accurate modeling results, differences in domain sizes would be irrelevant.

The individual parameter for establishing the downstream boundary condition rating curves for SRH-2D resulted in significant modeling contrasts. Variations in the water level exit heights caused large differences in modeling results, making this a key variable.

Material property selection played a significant role in modeler differences. The selection of higher Manning's n roughness values resulted in slower velocities and greater depths. The distinct shape and placement of material property polygons affected the differences between modelers. Offsets in polygon boundaries resulted in considerable contrasts in material properties (i.e., channel with Manning's n of 0.035 versus timber and brush with a Manning's n of 0.15) that caused large shear stress variations.

As a whole, the two modelers developed models that produced equivalent results. Large differences that occurred between the modelers frequently were the result of constructed domain size, and selection of material properties roughness values and polygon placement.

3.2 Model Comparison

The model comparison (SRH-2D minus HEC-RAS 2D) consisted of 12 comparisons, including Water Depth, Velocity, and Shear Stress differences for two geographic settings (Lakina River and Quartz Creek) and two modelers (Homan and Wells). Overall, the models produced similar results. The largest model-controlled differences were due to HEC-RAS 2D being more sensitive to material properties. Additional differences between the model results were because of the downstream boundary condition and domain sizes selected by the modelers.

Based on the sensitivity analyses, the default simulation equation for HEC-RAS 2D—the diffusion wave equation—model results varied greatly for different iteration time steps. At the smallest possible HEC-RAS 2D iteration time step, 0.1 seconds, the HEC-RAS 2D diffusion wave equation results were comparable to the full dynamic wave equation outputs. At greater iteration times, however, the diffusion wave equation produced unrealistic results, as the

equation does not account for acceleration (rapid rise or fall). In order to capture the rapid changes in acceleration, the iteration time step when using the diffusion wave equation needed to be very small. Furthermore, the diffusion wave equation is only appropriate for straight channels with no flow contractions (i.e., bridges and piers), and as mentioned before, it does not account for local acceleration.

Without model calibration, it is impossible to know which model is more accurate, so only the differences in results were evaluated. As a whole, HEC-RAS 2D produced slightly higher velocities, which is evident in the iteration time step and modeling equation analyses, but less apparent in the model comparisons.

3.3 Recommendations

Based on the model and modeler comparisons, we recommend that background elevation survey data cover a larger area, especially for lower-gradient geographic areas. Lower gradients and thus areas with lower hydraulic energy were shown to have reduced velocities and deeper water depths. Consequently, in flooding scenarios, the modeling domain needs to be larger to capture the full flooding extent.

We also recommend that the background base maps be of the highest resolution possible. Material properties and polygon placements, which were built using these base maps, were shown to affect the modeling results considerably. Attention should be given to the creation of material property polygons, and higher resolution base maps assist this process. Furthermore, the selection of material properties could benefit from a few simple aggregate size samples from the river channel. The combination of higher resolution base maps (to determine the material property boundaries and surrounding roughness values) and site-specific channel material sizes contribute significantly to a model's ability to simulate the hydraulic conditions of a given geographic area. However, hydraulic data are still needed to calibrate the model, at least during normal flow conditions.

The ability to calibrate the model maximizes the model's potential and helps troubleshoot any problems that arise. Model calibration helps ensure that the developed hydraulic model represents measured variables in the river and that the modeled results are within the desired calibration tolerances. Without model calibration, there is no certainty that the model can reproduce the system being modeled. Therefore, a model without calibration cannot be accepted.

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APPENDIX A
SUGGESTED SUMMARY CHECKLIST OF INFORMATION THAT SHOULD BE
PROVIDED TO ADOT&PF

The following Hydraulic Modeling Summary Checklist is suggested for reviewing 2D model results generated by other organizations or in-house modeling. The checklist is a modified version of the Federal Highway Administration 2D modeling review form (courtesy of S. Hogan).

Hydraulic Modeling Summary Checklist

Date:

Reviewed by Name:
 Title:
 Address:
 Phone Number:
 E-mail:

Modeling by Name:
 Title:
 Address:
 Phone Number:
 E-mail:

Topic	Information/Values Used	Comments
Project Location		
Waterbody:		
Location Description:		
Nearest Town/City:		
Project Information		
Main Purpose/Objective:		
Name of Project File:		
Display Projection:		
Background Elevation Data (Mapping Data and Supporting Information)		
Horizontal Datum:		
Vertical Datum:		
Source of Overbank Mapping:		
Date of Survey:		
Source of Channel Bathymetric Mapping:		
Date of Survey:		
Number of Points in Scatter Set:		
Are Bridges or Other Structures Present in the Model Domain?		

Hydraulic Conditions (Discharge Data)		
Source of Discharges:		
Number or Hydraulic Conditions:		
Base Map (Aerial Imagery or Topographical Map)		
Type of Base Map:		
Source of Base Map:		
Date Acquired:		
Hydraulic Model Used		
Hydraulic Model Name:		
Dimensions (1D, 2D, 3D, or Combination):		
Version:		
Date Released:		
Graphical User Interface:		
Model Parameters		
Numerical Equation:		
Simulated States (Steady or Unsteady):		
Representation of Terrain (TIN or Raster DEM):		
Flow Regimes (Subcritical, Transcritical, Supercritical):		
Model Domain (Study Area)		
Domain Size (Area):		
Length of Modeled Reach:		
Approximate Channel Slope:		
Distance Upstream of Project:		
Distance Downstream of Project:		
Approximate Floodplain Width:		

Mesh		
Mesh Shape (Triangles, Squared, Rectangles):		
Number of Meshes:		
Mesh Descriptions:		
Number of Elements:		
Approximate Element Size:		
Other Mesh Features (i.e., Piers):		
Mesh Quality		
Maximum Interior Angles:		
Minimum Interior Angles:		
Element Area Change:		
How Well Does the Mesh Represent the Terrain Mapping?		
Material Coverages (Manning's <i>n</i> Roughness Coefficients)		
Material Types:		
Roughness Values:		
Boundary Conditions		
Inflow Boundary Conditions (Method Used):		
Downstream Boundary Conditions (Method Used):		
Other Boundary Conditions:		
Monitoring Lines		
Monitoring Points:		
Number of Monitoring Points:		
Monitoring Point Locations:		

Simulations		
Number of Simulations:		
Simulation Summary:		
Iteration Time Step:		
Total Simulation Time:		
Initial Model Condition (Dry or Wet):		
Turbulence Model Used / Turbulence Coefficient:		
Output Frequency:		
Model Results		
Continuity Check		
Results for (i.e. Water Surface Elevation, Depth, Velocity, Froude Number, Bed Shear Stress, Sediment Transport):		
Culvert Verification:		
Model Calibration		
Was the Model Calibrated to Any Known Data (i.e., Measured Low Flows, High Water Marks, Aerial Flood Photos, Anecdotal Information)?		
Summary of Key Recommendations		

APPENDIX B

GUIDELINES FOR 2D MODEL REVIEW AND ACCEPTANCE

The following guidelines were developed as part of the project, Developing Guidelines for Two-Dimensional Model Review and Acceptance. Consequently, use of these guidelines requires that the reviewer is familiar with the project's final report.

The guidelines process is organized by main topics. Specific questions and the corresponding technical criterion are provided. An analysis of the answers is given in the Possible Answers section.

Questions

1. Topo-bathymetric data

a) Are available?

Criterion: Both topographic and bathymetric datasets are needed to develop the model's mesh.

b) Is the extent of the data adequate?

Criterion: If water levels during the simulations reach the lateral limits, the extent is not adequate. The model creates an artificial wall at these boundaries. Consequently, water levels would be affected.

c) Is the density of the data adequate?

Criterion: Topographic data should capture all important points in the terrain (changes in slope and elevation, location of areas of interest, etc.). The distance between consecutive river cross sections should not be greater than the wavelength of existing bedforms.

2. Hydraulic data

a) Are discharge, water elevation, and cross-sectional velocity profiles available?

Criterion: These data are required to calibrate the numerical model. We suggest that modeled and measured water levels must be equal and a 5% average error between the magnitude of velocity vectors (where the data for comparison are available) to consider the model calibrated. NOTE: Smaller errors were reported in the literature (see Toniolo et al., 2010).

b) Are the bed sediment characteristics (representative grain-size distribution) known?

Criterion: Sediment size is important in the selection of the roughness coefficient.

c) Are existing data (see [a] above) at bankfull or above bankfull conditions?

Criterion: Model calibration using high flow conditions would improve confidence in the model.

- d) Are multiple datasets available?
Criterion: If more than one dataset is available, the model could be calibrated and validated.
- e) Are longitudinal riverbed profiles available?
Criterion: Bedforms can alter the roughness coefficient used in the model.

3. Boundary conditions

- a) Do the boundary conditions cover the entire zones where the water can enter and exit the domain?
Criterion: A limited boundary condition will produce artificial velocities and water levels.
- b) Are the simulations at steady state?
Criterion: A single measurement of hydraulic data requires a steady-state simulation.
- c) Are the correct boundary conditions used in the simulations?
Criterion: Selecting wrong boundary conditions will produce wrong results.

4. Mesh

- a) Is the mesh size adequate?
Criterion: If two model simulations with similar variables and parameters, using different mesh sizes, produce similar results, the bigger mesh size used is adequate.
- b) Are all features (piers, approach roadways, guide banks, etc.) of interest included?
Criterion: All these features should be included in a modeling design effort.
- c) Are breaklines used in the domain?
Criterion: Breaklines are used when the topo-bathymetric data do not capture features (gravel bars, old channels, etc.) that are visible in images of the study reach.
- d) Are monitor lines used during the simulations?
Criterion: Monitor lines provide information about the model condition (reach steady state or not). If placed correctly, monitor lines can verify mass continuity in the system.

5. Roughness coefficient

- a) Are the coefficients used in the river and floodplain domains within the range of published values?
Criterion: The roughness coefficient plays a key role in the simulations, because the velocity is dependent on this value. Extensive literature is available (see for instance, Chang, 1988; Henderson, 1966; Julien, 2002; Sturm, 2001).
- b) Are the coefficients modified during the simulations?
Criterion: The roughness coefficient, especially along the floodplain, would change if a long-term flood event is simulated.

6. Time step

- a) Is the step used in the simulations adequate?

Criterion: Model simulations should be performed with the minimum time step possible. If not, a sensitivity analysis for time step should be conducted (i.e., if two model simulations with similar variables, parameters, and geometric configurations, using different time steps, produce similar results, the bigger time step used is adequate).

7. Main model equations

- a) Does the model have more than one set of fundamental continuity and momentum equations?

Criterion: Some numerical models have a full and a simplified set of equations. Model simulation results might change if different versions of the equations are used.

- b) What is the order of the numerical schemes used to solve the partial differential equations?

Criterion: Numerical errors are reduced when a higher order scheme is used in the simulations.

- c) Are the default values for the coefficients needed to solve the equations used in the simulation?

Criterion: All models require a series of coefficients to solve the governing equations. Each model has a default value, which in some cases can be changed.

Possible Answers

- A negative answer for 1.a) precludes any additional steps (i.e., modeling not possible). The remaining points consider a positive answer to 1.a).
- A negative answer for 1.b) indicates that the model results cannot be accepted.
- A negative answer for 2.a) and 2.b) point out that the model cannot be calibrated (i.e., the ability of the model to reproduce a known value of discharge, water level, or cross-sectional velocity profile remains unknown). Thus, the model results are unacceptable.
- A positive answer for 1.b) and 2.a) but the lack of near-bankfull condition data [2.c)] would somewhat reduce the confidence in the design model simulations. NOTE: Even though the design flow conditions will be higher than the bank-full conditions, a calibrated model proves that the model can reproduce the river flow conditions.
- A set of positive answers from 1. to 2.d) indicates that the model can be calibrated and validated (i.e., the model is calibrated first; then the same model parameters are successfully used to reproduce another flow condition). This situation really increases confidence in the design model results.

- The longitudinal profiles [2.e)] are important in sand-bed rivers (ASCE, 2008).
- Any negative answer to 3., 4.a), 4.b), 4.d) (in terms of continuity), 5., and 6. should prevent acceptance of the model.
- Two models are comparable if both of them were calibrated, or when the models were calibrated and the only difference is due to 7.b) (i.e., higher- or lower-order numerical schemes have been used in the models).
- A positive answer to 7.c) is an indication that the model might not be apt for the specific situation being modeled.

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APPENDIX C

SRH-2D and HEC-RAS 2D

Hydraulic Modeling Workshop Workbook

University of Alaska Fairbanks

**SRH-2D and HEC-RAS 2D
Hydraulic Modeling Workshop Workbook**

**by Joel W. Homan
March 2017**

2D Hydraulic Modeling of Rivers Using SRH-2D

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Modeling Exercise #1 – Background Data – Part A

Gathering Data

1. Introduction

This workshop is based on real data collected by the State of Alaska Department of Transportation and Public Facilities (ADOT&PF) for a bridge replacement over the Lakina River on McCarthy Road (Figure 1).

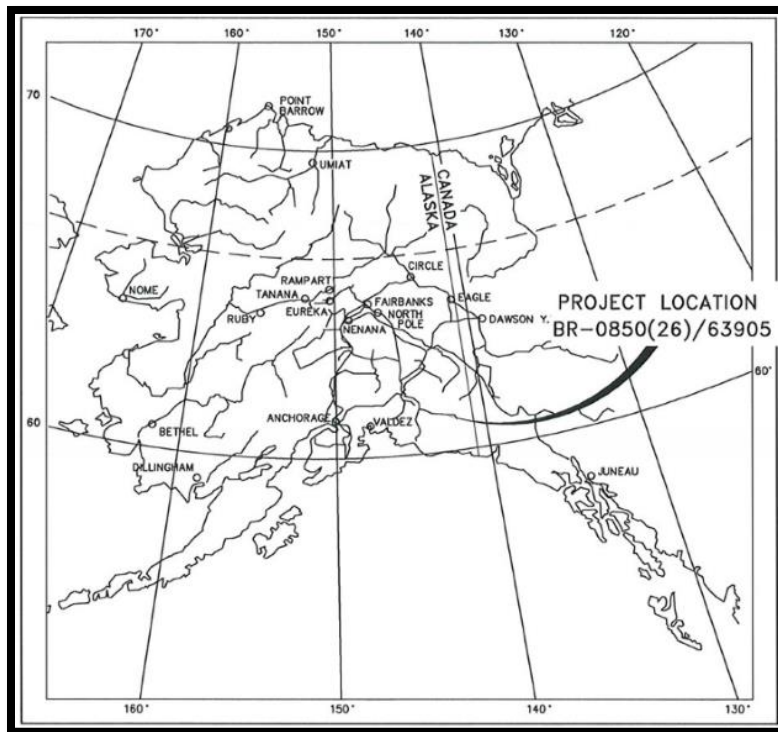


Figure 1: Project location map for the Lakina River bridge replacement.
Image from Lakina River Bridge right-of-way plans.

This exercise illustrates a typical set of steps to import background data used when beginning a hydrodynamic modeling project in SMS including surveyed xyz data and base maps.

The data files for this workshop are located in the “Workshop” folder.

Launch SMS from the desktop icon, start menu or from file browser. SMS will open with a display window.

2. Projection

In an SMS project, the coordinate system used to represent the geographic data is referred to as a projection. Each data object, whether it is an image, a survey, a CAD file, or any other geographic data is referenced to a projection.

For this project, the projection can be found using the DOT plans for the Lakina River Bridge Right of Way (ROW), which is located in the “Workshop\DOT Plans” folder. Using the Lakina River plans, find the following information:

Projection: _____

Zone: _____

Datum: _____

Planar Unit: _____

Set the Display Projection for the Lakina River using the following steps:

- Select *Display | Projection | Global Projection | Set Projection...*
- Fill in the recently acquired information.

*Note: The Vertical and Horizontal units need to be the same: Feet (U.S. Survey).

- Click OK to exit the dialog.

The projection to be used for this SMS project has now been defined.

Save the project:


- Select *File | Save New Project...* enter a name of “Lakina River” and click save.

* Note: SMS does not have an “undo” option, so it is important to save frequently.

3. Digital Elevation Data



The first source of geometry data for this project is a scatter set. A scatter set is a set of points at any x,y location. Each point has one data value. For this exercise, this data value represents an elevation. The scatter set was collected by ground based survey crews. This process is time-consuming and often results in poor resolution datasets.

To load the elevation data:

- Select *File* | *Open* or use the *Open Shortcut* tool . The open dialog will appear. Select the file *LakinaRiver.dwg* in the “Workshop\DOT Scatter Data\AutoCAD” folder.




This data file is from AutoCAD and includes many data layers. Quickly experiment with the dataset to see if you can display just the elevation scatter data. Don’t spend too much time on this, as the point of bringing in the AutoCAD file is to demonstrate that some file types are easier to work with than others.



Let’s delete the AutoCAD file and bring in an Extensible Markup Language (XML) instead. XML files are plain text files and are similar to HTML.

- To delete the file, R-click *LakinaRiver.dwg* in the Project Explorer tree and select *Delete*.
- To open the XML file, Select *Open*  then select the Lakina River in the “Workshop\DOT Scatter Data\XML” folder.
 - The layer can be renamed by R-clicking on the scatter data  “EG – 63905” in Project Explorer and selecting *Rename*. Rename to “Lakina Scatter.”

4. Display Options

We are now going to learn about different Display Options:

- To zoom in to the layer:
 - R-click scatter data  in project explorer | *Zoom to Scatter*.
- To view scatter points:
 - Click *Display* in the Menu Bar | *Display Options*. This will cause the Display Options dialog to appear. Next time we will use the *Display Options* Shortcut  tool.
 - Make sure *Scatter* is highlighted.
 - A message might appear saying “Too many contour values to show. Contours options will be change to 1000 contours.”
 - Click OK; this just auto adjusts the contour interval.
 - Select Points and un-select Contours. Then Click OK. You should now be able to see all the data points.
- To turn the contours back on and change the contour method to include contour lines:
 - Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, un-select points and select Contours.

- Then choose the *Contours Tab*. In the *Contour method* drop down, choose *Color Fill and Linear*. Then Click OK.
- Contour line should now be visible, but there might be too many of them.
- To change the contour interval and color ramp:
 - Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted and under the *Contours Tab* the Contour Interval can be changed. Try selecting *Specified Interval* from the drop-down menu, then enter 1.5 for the contour interval.
 - There are many color scheme possibilities. Explore the *Color Ramp* and subsequent color options. Click OK when finished.
- The “Rotate” tool  found in the Dynamic Tool bar is a great way to see if the terrain makes sense. Once the rotate tool is selected, click on the screen and move your mouse around to get the contour map to illustrate the topography (Figure 2).

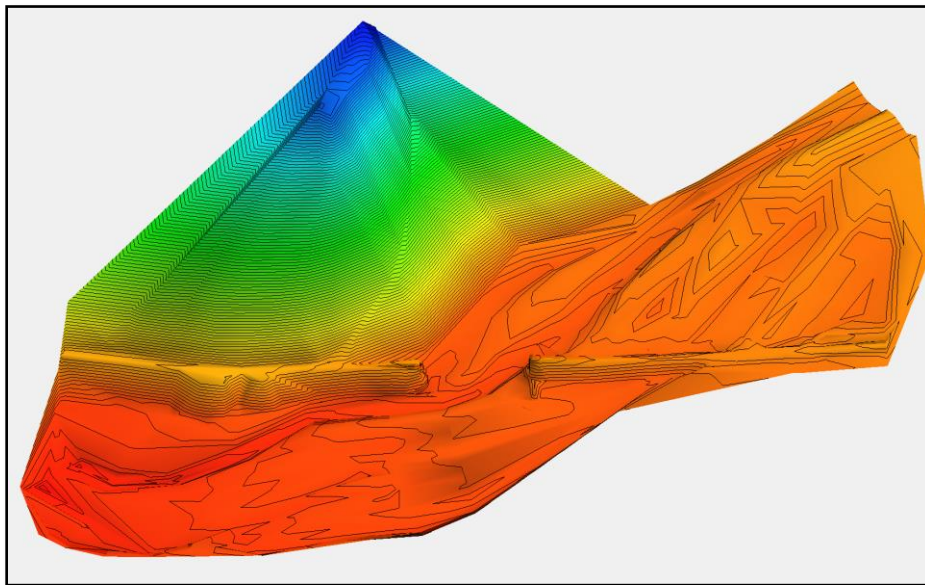





Figure 2: Image of Lakina River contours rotated to illustrate topography.

- To make the elevation change more exaggerated, the Z magnification can be changed. To do so, select the *Display Options* Shortcut  tool | *General* | and enter 3 or 4 into the Z magnification space. Check OK to exit.
- To get back to the original overhead view, select the *Plan View*  tool.
- SAVE Project .


5. Background Image

A good way to help visualize the model is to import a digital image of the site. This image may be an aerial photo or a topographic chart. In this exercise, an aerial photo will be used.

SMS supports several different image formats. Some of the more common ones include JEJG, TIF, PNG, BMP, SID, and ECW. Images may be available from online map services and government sites, or obtained locally.

5.1. Loading an Image

To load an image of the site:

- Select *Open*  then select the Lakina_13 image in the “Workshop\DOT Images\Lakina River” folder.

A *Register Image* dialog window should pop up (Figure 3) because the image file is not geo-referenced. Before an image can be displayed, the image must be "registered" or geo-referenced. Registering an image involves identifying points on the image corresponding to locations with known real-world (X,Y) coordinates. Once these points are identified, they are used to scale and translate the image to the proper location when it is drawn with the other objects in the Graphics Window.

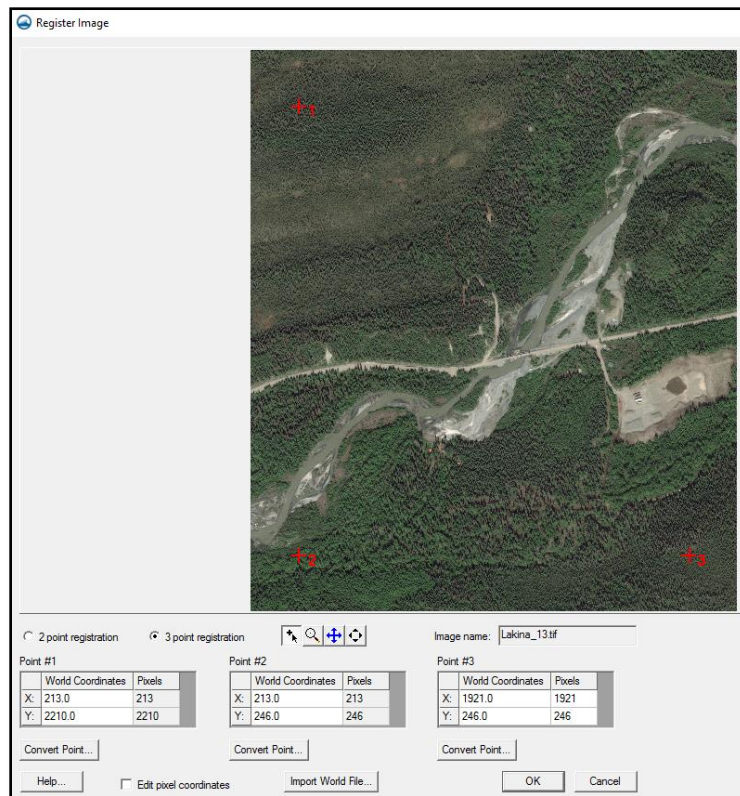


Figure 3: Register Image dialog.

5.2. Registering Images





Register Image Dialog:

An image is registered using the *Register Image* dialog. The main feature of the *Register Image* dialog is a large window in which the image is displayed. Two or three points (shown by "+" symbols) are also displayed in the window. These points are used to identify locations with known real-world coordinates. The real-world coordinates (X,Y) and image coordinates (U,V) of the registration points are listed in edit fields below the image. The points are moved to the desired locations on the image by dragging the points using the tools described below. Once the points are located, the real-world coordinates can be entered in the corresponding edit fields. The dialog contains the following options:

- Two-point or three-point registration – Two-point registration rotates and uniformly scales an image. Three-point registration allows for non-uniform scaling to account for some parallax.
- Import World File – Used to import a TIFF world file (*.tfw). A TIFF world file has the information needed to set the (X,Y) and (U,V) coordinates in order to place the image in the correct world coordinates.


Register Image Dialog Tools: The following tools can be used to help position the registration points (Table 1):

Table 1: Register Image Dialog Tools. From "Registering an Image," 2017, http://xmswiki.com/wiki/Registering_an_Image.



Tool	Tool Name	Description
	Select Point Tool	The Select Point tool is used to select and drag register points to a location on the map for which real coordinates are known so that they can be entered in the corresponding XY edit fields.
	Zoom Tool	In some cases, it is useful to magnify a portion of the image so that a registration point can be placed with more accuracy. The Zoom tool is used to zoom in a portion of the image.
	Pan Tool	After zooming in on a portion of the image, the Pan tool is used to pan the image vertically or horizontally.
	Frame Macro	The Frame macro is used to automatically center the entire image within the drawing window of the dialog after panning and zooming in on a specific location.

Before we begin the image registration process, we need some real-world coordinates (X,Y), so let's *Cancel* to leave the *Register Image* dialog and get world coordinates. *Cancel* again to fully escape.

Acquiring real-world coordinates (X,Y) from our dataset is easiest if the scatter points are turned on.

- Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, then select Points. Check OK to exit.

The next step involves selecting 3 scatter points, writing down their associated coordinates, and making approximate image location notes for where the points are located. Successfully registering the image will require many iterations of this process.

- Click on the scatter data  Lakina River to make sure it is highlighted in the Project Explorer.
- Using the *Select Scatter Points*  tool select three points of interest. Record the X and Y coordinate information below. The coordinates for the selected points appear at the top of the screen. The coordinates are also provided at the bottom of the screen, but those values change with the movement of the mouse, while the values at the top of the screen stay fixed for the selected point.

○ Point 1:

- X:

-
- Y:

-
- Description:
-

○ Point 2:

- X:

-
- Y:

-
- Description:
-

○ Point 3:

- X:

-
- Y:

-
- Description:
-

Make detailed location notes for the three points; i.e., Point 3 is located at the very southeast corner of the bridge, or point 1 is located west of the bridge at the intersection of the main road and spur road that heads north (Figure 4). It will help to have the image open using an image viewer while you complete this step. Spread the points out for better scaling of the image.

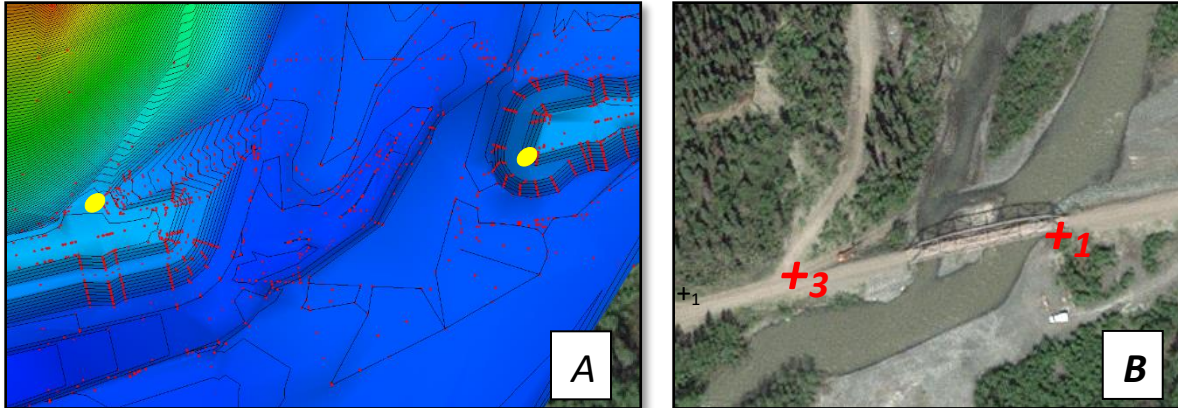





Figure 4: A) Two selected points of interested are represented by yellow dots (●). B) Corresponding to the yellow dots in image A, location notes need to be made so the image can later be registered.

Now that we have some reference points, we can reattempt to register the image.

- If the “Lakina_13.tif” image is under the GIS Data in the Project Explorer, then R-click the image and select *Register Image...*
- If the image is not present, it needs to be reopened:
 - Select *Open*  then select the Lakina_13 image in the “Workshop\DOT Images\Lakina River” folder.
- In the *Register Image* dialog, use the *Select pointer*  tool to move the three points (shown by “+” symbol) to the location of your three selected scatter points. Use the Zoom tool to zoom in for a better location placement. The *Pixel* coordinates (X and Y) should change as you move the points around.
- Once the three points (+ symbol) are in position, fill in the real-world coordinates (X,Y) into the *World Coordinate* locations.
- When finished click OK.

Voila! The image should be somewhere near your scatter points. I assume it’s not perfect the first time. Registering images can be a very time-consuming and tedious process.

By making the contours transparent, the alignment can be better seen:

- Select the *Display Options Shortcut*  tool and navigate to the *Contours* tabs. Make the Transparency 50% and click OK.
- Zoom to Scatter.

Instead of wasting time making the alignment perfect, we will move on to import a prepared World File.

5.3. World File

By itself, an image does not correspond explicitly to any point on a map or location in a project. The process of aligning the image with a projection is known as geo-referencing.

A common and simple way of geo-referencing uses an extra file known as a “world file.” This file may have an extension of “.wld” indicating it is a world file.

In the *Register Image* dialog, an *Import World File* button allows you to bring in a world file associated with a previously registered image. The file contains registration data that can be used to register the image.

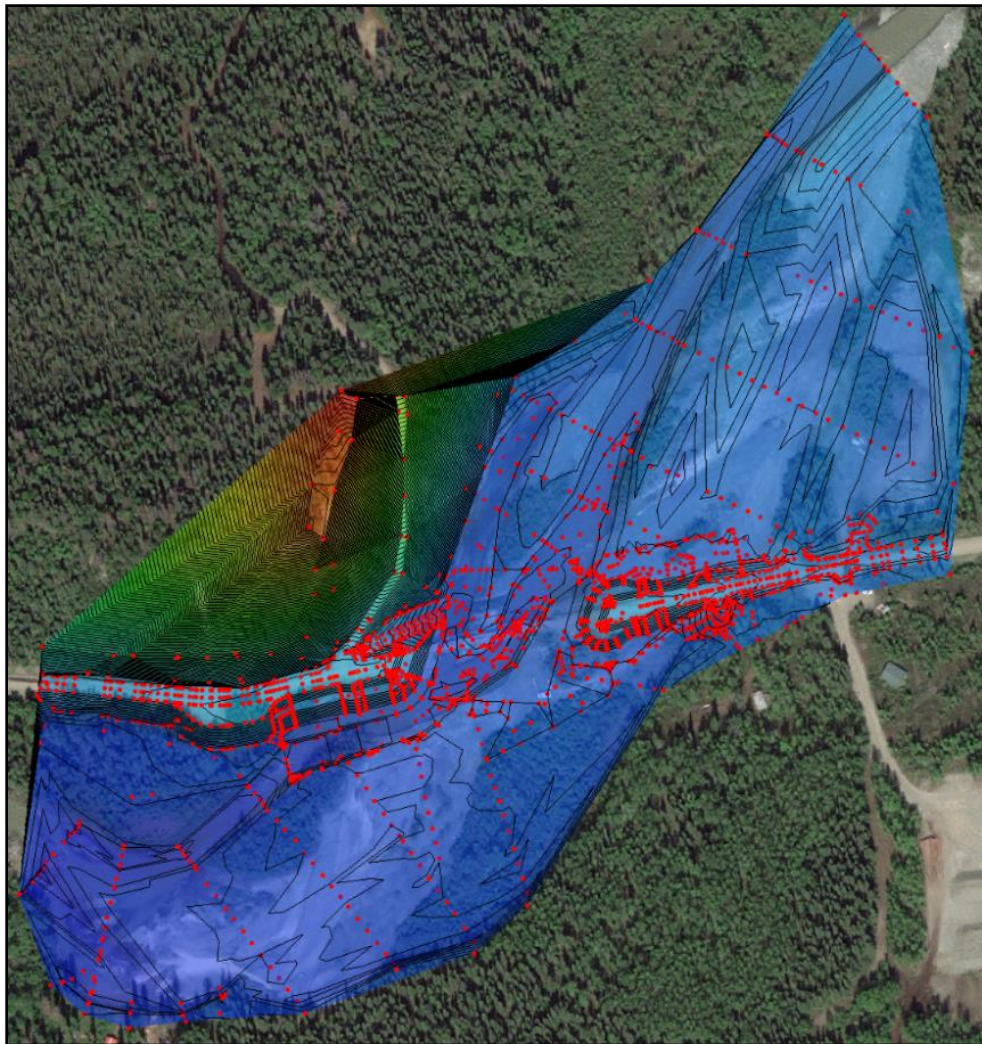



Figure 5: Successfully geo-referenced image.

- R-click on the “Lakina_13.tif” image under the GIS Data in the *Project Explorer* and select Register Image...



- Select *Import World File...* down at the bottom.
- Navigate to Workshop\DOT Images\Lakina River\Lakina_13 World and select Lakina 13.wld and click *Open*.
- Finally, click OK and the image should be aligned with our dataset (Figure 5).
- Zoom to Scatter.
- SAVE Project .

6. Hydraulic Structures – Bridge Piers

The Lakina River Bridge has spill-through abutments that are represented in the topo data, but six piers still need to be represented. The piers are 3-ft-diameter piles. The coordinate information is provided in an Excel spreadsheet located in the “Bridge Data” folder.

- Open the “Substructures” file in Excel to view the data. There are three tabs: Both, Quartz, and Lakina. Briefly familiarize yourself with the spreadsheet.
- Save the Lakina tab as a .txt file.
 - While the Lakina tab is open, select *File | Save As*:
 - Change the *Save As* type to “Text (Tab delimited)” using the drop-down menu.
 - Click save.

To import the Bridge data into SMS, follow the subsequent steps:

- Select *Open*  and navigate to your .txt file and Open it.
- Select Use Import Wizard | OK.
- The data are *Tab* delimited, so make sure that Tab is selected .
- Also make sure that *Start import at row* is “1” and *Heading row* is selected , then click Next >.
- Make sure that the *Type* is correct... X for X and Y for Y, then click finish.
- Using the *Zoom*  tool or the *Zoom to Scatter* command for the Substructures layer, zoom in to see if the piles look to be in the correct locations (Figure 6).



- You can turn off the contours by selecting the *Display Options* Shortcut  tool; make sure *Scatter* is highlighted and un-select Contours. Check OK to exit.
- SAVE Project .



Figure 6: Lakina River Bridge piers represented by red dots.

The river channel and gravels are constantly in flux, and the background image outdates the survey data. For a more current view, the new bridge can be seen in images located in this folder: Workshop\DOT Images\Lakina River\New Bridge at Lakina River.

7. Conclusion

This exercise illustrated how to initialize a project, set up projections, import CAD data and elevation data, import geo-reference images, and import world and text files.


Modeling Exercise #2 – Background Data – Part B

Evaluating and Editing Data

1. Introduction

This exercise illustrates a typical set of steps to modify triangulation, manually and with breaklines.

Launch SMS from the desktop icon, start menu, or file browser. To ensure consistency, read in a set of completed files from the end of Exercise #1.

- Open SMS and select Open .
- Navigate to “SMS Modeling Exercises\Exercise 1 – Background Data A” directory
- Select the file named “Lakina River.sms.” Then select *Open*.

If it asks, “Do you want to delete existing data?” click Yes.

2. Cleaning Up the Triangulations

SMS triangulates the scatter points, creating a triangulated irregular network (TIN) (Figure 7). This triangulation creates a surface, or finite element mesh, using all the points. For many cross-section datasets, this results in large areas inside of river meander bends included in the TIN which have no data points and therefore do not represent the elevation. To clean this up, the triangles in these areas must be deleted. Cleaning up the triangulation can be done manually, but it can also be done by selecting a maximum edge length.

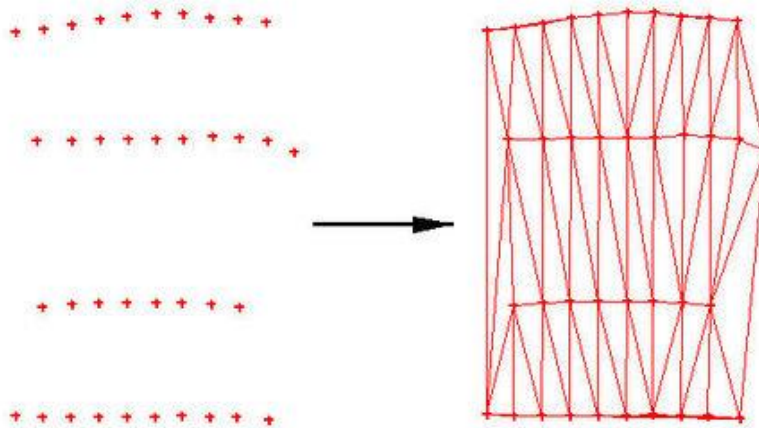




Figure 7: Triangulated Irregular Network (TIN).

To see if we need to clean up the Lakina River TIN, we first need to turn on the triangles.

- Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, then select *All Off* at the bottom and select *Triangles*. Check OK to exit.
- Click on the scatter data  Lakina River to make sure it is highlighted in the Project Explorer, and un-select the Substructures scatter data.
- Zoom to Scatter.
- The background image can be left on or turned off by un-selecting Lakina_13.tif.

Our area of interest for the Lakina River channel is relatively straight, so there are no excessive areas in the floodplain without data. There are large triangles in the hills; they are not relevant, as floodwater will not be modeled that high.

There is a major problem with the TIN, but it is hard to see in this view.

Using contours (Color Fill and Linear), reversing the color ramp, the rotate tool, and a Z-magnification of 4, Figure 8 was made to illustrate the problem. As a result of the triangulation process, the downstream boundary has an artificial lip at the end, which acts as a wall. This bogus boundary will cause the prevention of modeled flow.

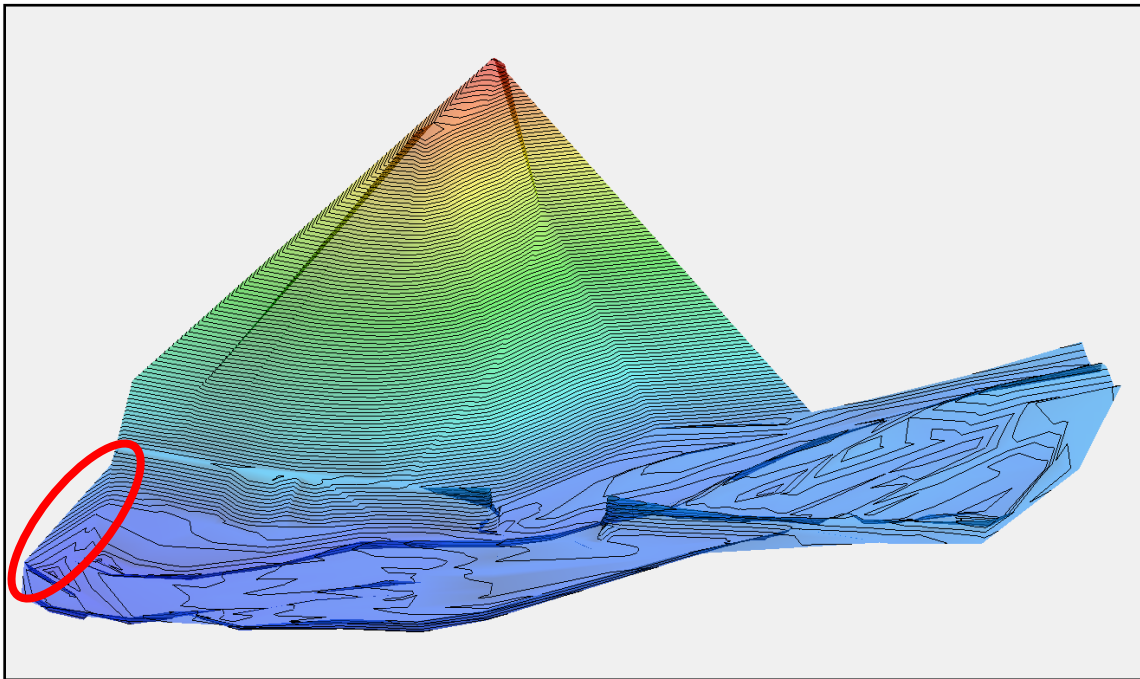





Figure 8: Lakina River contours map illustrating artificial lip, which is defined within the red circle.

To fix this problem, we need to manually clean up the downstream triangulations. A zoomed-in view of the triangles can be seen in Figure 9. We need to remove the triangles, which form a wall in the middle of the channel.

- SAVE Project . Remember SMS does not have an “undo” option, so be careful during this process. If you incorrectly delete some triangle, we can always shut the project down without saving it and reopen.
- Choose the *Select Triangle*  tool from the toolbar.
- Holding the *Ctrl* key, multi-select several of the triangles at the downstream boundary by clicking the mouse on one triangle and dragging the cursor through the other triangles, as shown in Figure 9.
- Press the *Delete* key to delete the highlighted triangles. Click yes to confirm the deletion.
- Make sure to zoom in and delete all the unnecessary triangles.
- The artificial lip should now be removed and the model will be able to appropriately channel the flow.
- SAVE Project .

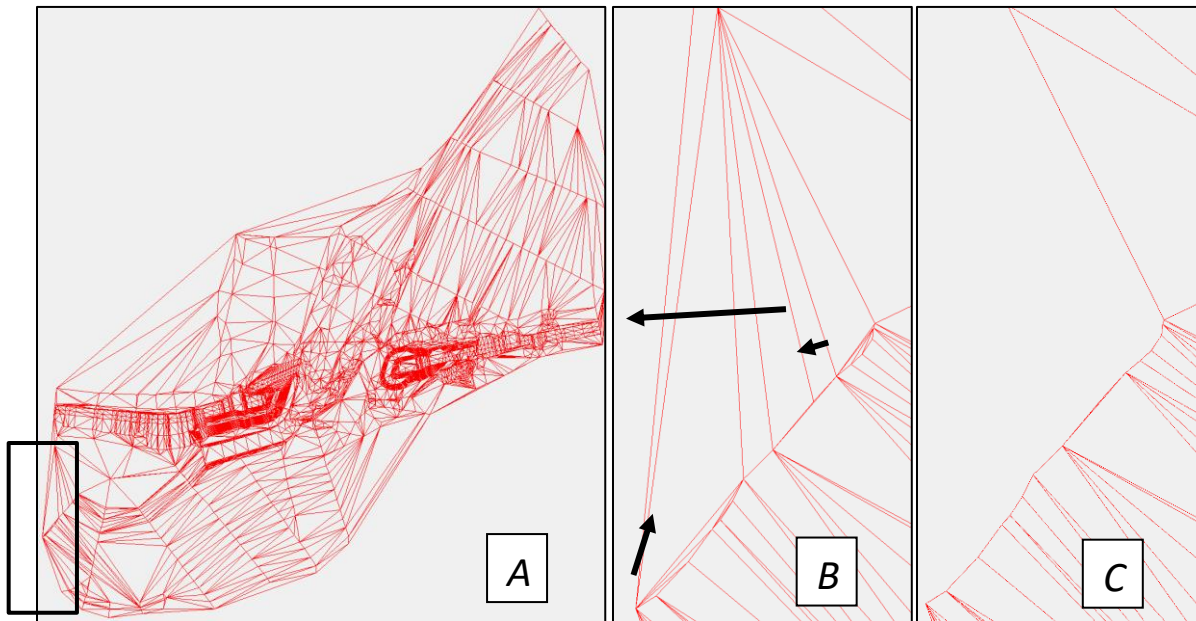


Figure 9: A) The entire Lakina River TIN with an inset box showing where Figure 9B and C are located. B) The arrows show which triangles to remove in order to eliminate the artificial lip. C) The zoomed-in portion of the TIN after the triangles have been removed.

3. Breaklines

The triangles of the TIN created by SMS honor the Delaunay criteria, which result in the creation of triangles as close to equilateral as possible. Since our dataset is composed of cross sections that are

straight lines, the triangles connect a point on one section to the closest point on an adjacent section. To give a truer representation of the geometry, it is usually best to connect points of constant elevation.

A breakline is a feature line or polyline representing a stream channel, ridge, or some other feature to preserve in a TIN. In other words, a breakline is a series of edges to which the triangles should conform. SMS includes a function to force breaklines into a TIN.

To see if the TIN needs to be adjusted using breaklines, the contour map will be evaluated.



- Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, then select *All Off* at the bottom and turn on *Contours*.
- Under the *Contour* Tab, make sure the *Contour method* is *Color Fill and Linear* in the drop-down menu. Then click OK and zoom to the Lakina Scatter.
- To better visualize the elevations, the contour display range can be changed. Select the *Contour Options*  shortcut at the bottom of the screen. In the *Data Range* options, select *Specify a range*. For *Min* enter "1360" and for *Max* enter "1400." Change the transparency to "60%." The display should appear something like Figure 10.
- Zoom to Scatter.






Figure 10: Lakina River contours.

For the most part, the Lakina River contours follow the stream channels in the aerial photo, but for a learning experience, we will add some breaklines and modify the TIN.

- Turn off the *Lakina Scatter* in the *Project Explorer*.

Notice the two whitish diagonal channels upstream of the bridge in Figure 11A. Refer to Figure 10 and notice that the contour lines do not incorporate those smaller side channels. Breaklines will be added so they are:

- Turn the Lakina Scatter layer back on.
- Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, then turn on *Points*, *Triangles*, and *Breaklines*, and turn off *Contours*. Click OK to exit.
- To add breaklines, we will use the *Create Scatter Breaklines*  tool from the toolbar.
- After selecting the *Create Scatter Breaklines*  tool, we will draw in breaklines similar to Figure 11B. Start by clicking on a scatter point and work your way down the white channel, clicking on additional points in the subsequent cross sections. Ideally, the points would have similar elevations (contour color). The similar elevation concept does not always work, because we are decreasing in elevation as we work our way downstream. Regardless, continue along the channel clicking on points until you stretch the length of the channel. Double-click to end the breakline.

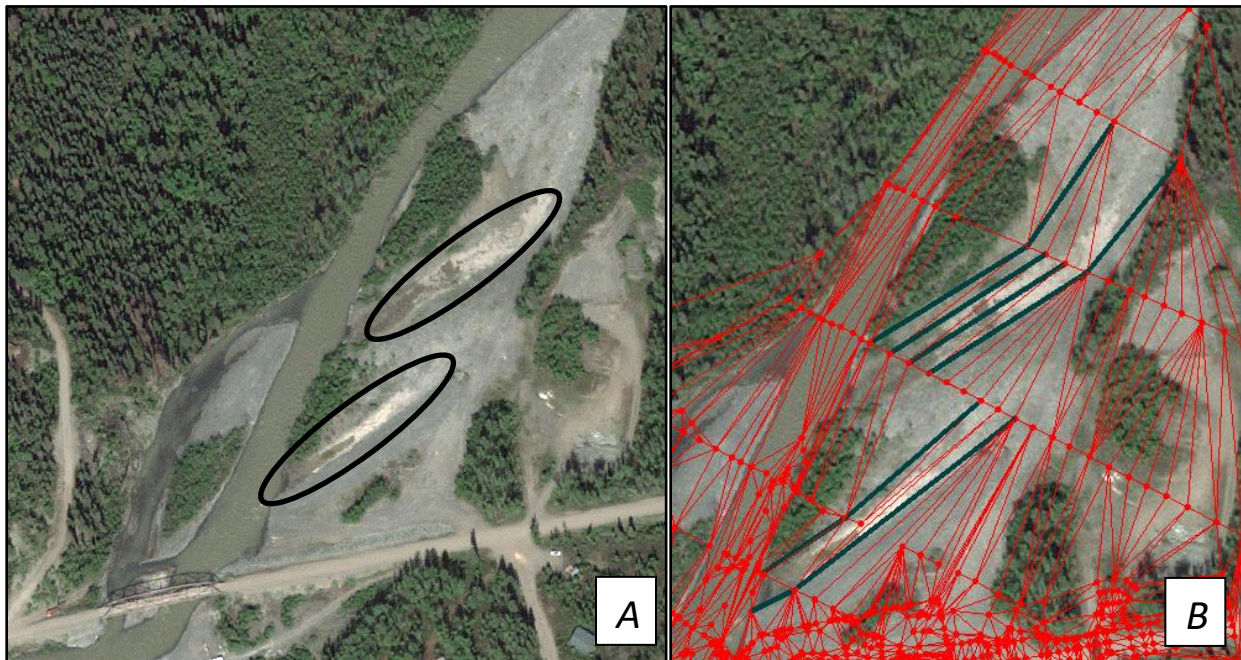



Figure 11: A) Diagonal channels highlighted with circles. B) Breaklines for the diagonal channels.

- Repeat the process creating multiple breaklines to ensure a smoother channel bottom. Your breaklines should be created similar to those in Figure 11B.

Now the breaklines need to be forced into the TIN.

- To do this select *Breaklines | Force Breakline* from the menu. The dataset will be re-triangulated and appear similar to Figure 12, which now has contours that incorporate those smaller side channels
- SAVE Project .

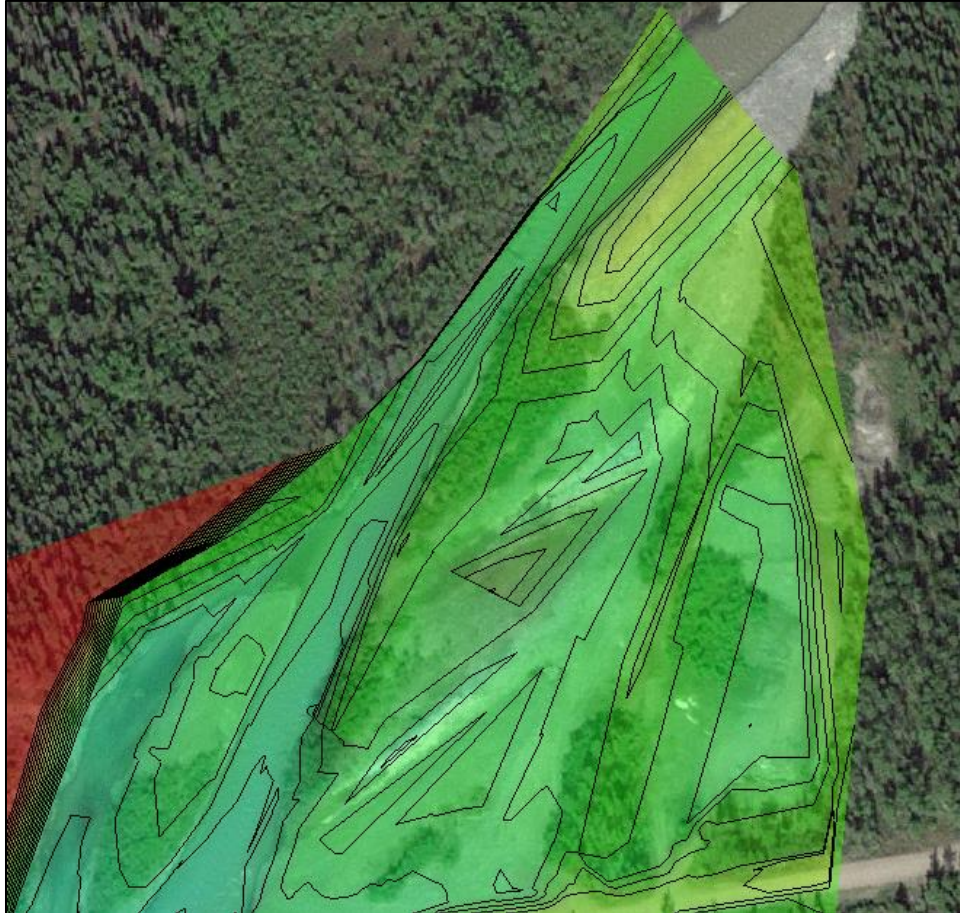


Figure 12: Contours realigned as a result of forcing breaklines within the TIN. The contours should now follow the channel more correctly.

4. Conclusion

In summary, the TIN was cleaned up by removing an artificial downstream lip by manually removing triangles. Additionally, breaklines were added to improve the elevation data representation.

Modeling Exercise #3 – Parameters


Building Feature Objects

1. Introduction

This modeling exercise describes the process of creating a model domain using the Map Module and the conceptual modeling approach. This approach is a powerful option to generate a model, using feature objects to define parameters for boundary conditions, materials, and automatic mesh generations.

2. Initializing the SMS Workspace

The previous Background Data modeling exercises showed how to import a scatter set of elevation data and work with images in SMS. The data from the Background Data exercise will be used as the starting point for this workshop. To ensure consistency, read in a set of completed files from the end of the previous exercise. To do this:

- Open SMS and select Open .
- Navigate to “SMS Modeling Exercises\Exercise 2 – Background Data B” directory.
- Select the file named “Lakina River Editing.sms.” Then select *Open*.

If it asks, “Do you want to delete existing data?” click Yes.

3. Using Feature Objects

The purpose of the exercise is to become familiar with creating feature objects in SMS, and to create the components (coverages) needed to run an SRH-2D model simulation. The background image and scatter set will be used as a guide to create the feature objects. Feature objects in SMS include points, nodes, arcs, and polygons.

Usually for SRH-2D simulations, a Mesh Generator coverage, a Boundary Condition coverage, and a Materials coverage are required. An optional Monitor Points coverage is also usually defined. To practice creating feature objects in SMS, one of each of these coverages will be created.

4. Mesh Generator Coverage





First, a *Mesh Generator* coverage will be created to define the model domain. This coverage will also be used in the next lesson to assign the automatic mesh generation.

- R-click on the “Area Property” coverage in the Project Explorer.
- Select Type | Generic | Mesh Generator.
- R-click on the “Area Property” coverage again and select Rename.
- Rename to “MeshGen.”

4.1. Creating Feature Arcs

Feature arcs are used to define boundaries for the model. Feature arcs are often digitized directly inside SMS using the background data as a guide. They may be created from other data imported into SMS such as scatter, CAD, or GIS data.

To define the boundary “model extent” using feature arcs:

- Set up the display: Select the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, click *All Off*, and select *Contours*.
- Click on the *Contours* tab, change the *Contour method* to *Color Fill and Linear*, and change the *Data range Max* to 1400. Click OK to exit.
- Click “MeshGen” coverage in the Project Explorer.
- Choose the *Create Feature Arc*  tool from the *Toolbar*.
- Draw a boundary within the contour define. **The boundary must be completely within the TIN.** Start by clicking on the map, then click along the boundary to define the model domain. Don’t worry about uniform spacing, just quickly click out the general boundary similar to Figure 13. The forested hill (red area) does not need to be completely included. Double-click on your starting point to finish the arc boundary.
- To turn on the Nodes, Arc, and Vertices, select the *Display Options* Shortcut  tool, make sure *Map* is highlighted, then select *Node* and *Arc*.
 - Select the *Line Attributes* and make the arc width “5” and the color black | Ok | OK. Your map should appear something like Figure 13.
- SAVE Project .

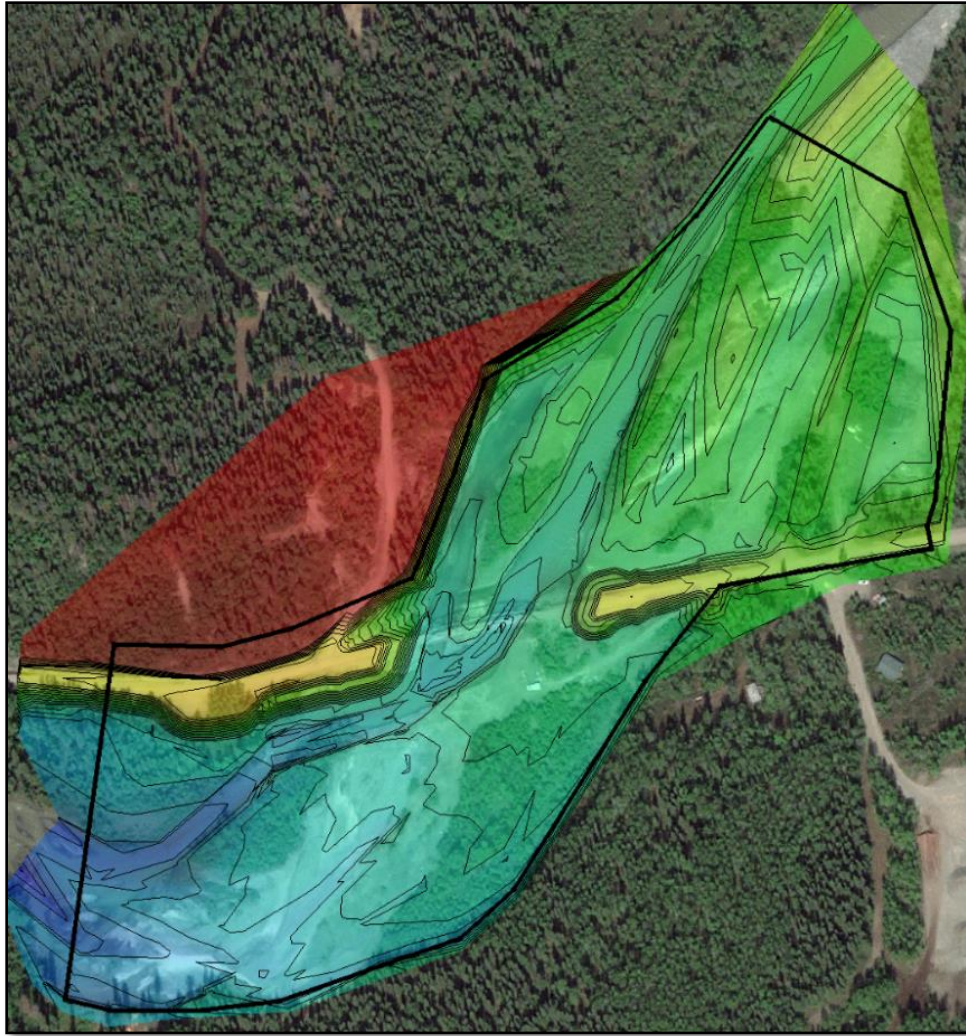



Figure 13: Model domain.

4.2. Adding Internal Features

Internal features such as riverbanks, ridges, structures, roads, material zones, and boundary conditions are defined using arcs and polygons. We will now add additional arcs to define internal features.

- Choose the *Create Feature Arc*  tool from the *Toolbox*.
- Make an arc in the shape of both the roads, as shown in Figure 14. You can end the arc by double-clicking on the boundary arc.

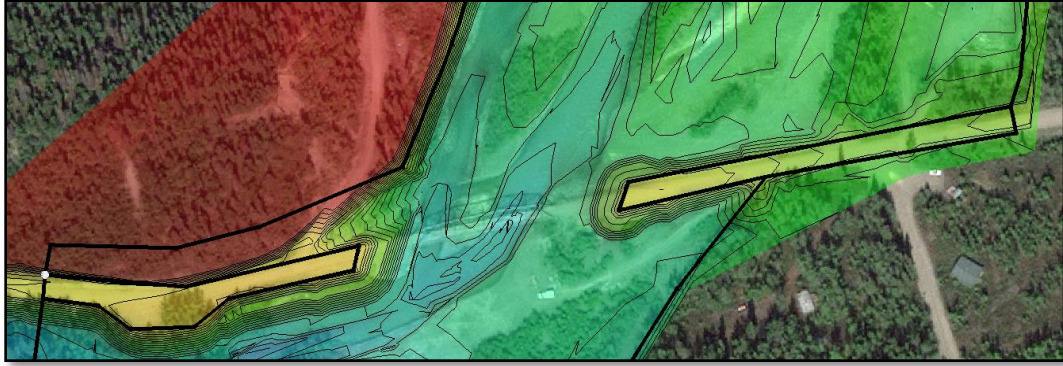




Figure 14: Completed feature arcs for the roads.

Next, we will draw arc “circles” around the bridge piers:

- Un-select the *Lakina Scatter* coverage and select the *Substructures* coverage in the *Project Explorer*.
- Turn on the *Substructures* points by selecting the *Display Options* Shortcut  tool, make sure *Scatter* is highlighted, then select *Points* and un-select *Contours*.
- Zoom in to the bridge, click on the “MeshGen” coverage, and use the *Create Feature Arc*  tool to draw little circles around each of the six piers (see Figure 15).

This is the *Cookie Cutter* approach for piers, as we are basically cutting out the mesh where the piers are located. The model will treat the boundary conditions as a “Wall” (no flow, no slip).



- SAVE Project .





Figure 15: Completed feature arcs for the piers.

4.3. Redistribute Vertices

The primary function of the vertices of an arc is to define the geometry of the arc. If the arcs are to be used for automatic mesh generation, the spacing of the vertices is important. The spacing of the vertices defines the density of the elements in the resulting mesh. Each edge defined by a pair of vertices becomes the edge of an element. The mesh gradation is controlled by defining closely spaced vertices in regions where the mesh is to be dense and widely spaced vertices in regions where the mesh is to be coarse. To redistribute the vertices:

- Zoom to coverage by R-clicking on *MeshGen* and selecting *Zoom to Coverage*.
- Select the *Select Feature Arc*  tool, then select *Edit* in the main menu and *Select All*. The arcs should now all be highlighted.
- R-click on any arc and select *Redistribute Vertices...* to open the Redistribute Vertices dialog.
- Change the *Average* spacing to “15.0” feet and click OK to redistribute the vertices.
- To make the vertices more visible, select the *Display Options* Shortcut  tool, make sure *Map* is highlighted, then using the *Symbol Attributes for Vertex*, change the size to 10. Click Ok | OK to get back to the map.

Let’s add more vertices to the pier feature arcs.

- Zoom into the piers and using the *Select Feature Arc*  tool, draw a box around the 6 piers. R-click one of the highlighted arcs and select *Redistribute Vertices...* to open the *Redistribute Vertices* dialog.
- Change the *Average* spacing to “2.0” feet. Click the OK button to redistribute the vertices.
- SAVE Project .



4.4. Building Polygons from Arcs

Next, polygons must be generated. Before creating polygons, the data should be cleaned to avoid potential errors. To clean the feature arcs:

- Zoom to coverage by R-clicking on *MeshGen* and selecting *Zoom to Coverage*.
- Select Feature Objects in the main menu and then select *Clean...* to open the Clean Options dialog.

- Turn on *Snap nodes and vertices* and set the *Tolerance* to “0.001.” This means that if two feature nodes are within 0.001 feet of each other, they should be merged into a single point.
- Turn on *Intersect arcs*.
- Make sure *Remove dangling arcs* is un-selected; otherwise, it will remove the 6 pier arcs.
- Click the OK button to clean the data.


Next, we will build polygons from the cleaned arcs.

- Be sure no arcs are selected, then choose *Feature Objects* in the main menu, and select *Build Polygons*.
- To confirm that the polygons have been created, choose the *Select Polygon*  tool from the toolbar. Click on any polygon to select. The selected polygon will be highlighted.
- SAVE Project .

This Mesh Generation coverage will form the basis of the automatic mesh generation. We will stop the process for mesh generation coverage at this point. These polygons will need to be subdivided, and mesh generation parameters need to be assigned or edited.




5. Boundary Conditions Coverage

A Boundary Conditions (BC) coverage will be created to define the inflow and outflow for the simulations. For this exercise, the inflow and outflow boundaries will be specified and monitor lines will be created.

- R-click on “Map Data” in the Project Explorer and select *New Coverage*.
- For the coverage type, select the SRH-2D | *Boundary Conditions* coverage and specify the coverage name as “BC.”
- Select OK, and a new SRH-2D boundary conditions coverage will be created.
- SAVE Project .

5.1. Define Monitor Line Arcs

Monitor lines can be created to extract flow information from the model. Two monitor lines will be created for this model to check flow continuity on either side of the bridge, as shown in Figure 16.

- Create the monitor line arcs upstream and downstream of the bridge.
- Click on the “BC” coverage in the Project Explorer to activate the coverage.
- We need to first make the existing arcs from the “MeshGen” coverage visible, so select the *Display Options*  shortcut tool, make sure *Map* is highlighted, then select *Inactive coverage* option. This will make the arcs from the inactive coverage visible. Click OK to exit.
- Choose the *Create Feature Arc*  tool. Draw in the lines similar to what is seen in Figure 16.
- SAVE Project .

The default boundary condition type is Monitor Line; therefore, the two arcs just created are already defined as monitor lines and do not need to be reassigned. In the next steps, two additional arcs will be created for the inflow and outflow boundary conditions.



Figure 16: Completed monitor lines.

5.2. Define Inflow Arcs

An arc defining the inflow boundary will now be created.




- Inflow and Outflow boundary conditions must lie along the boundary of the model domain. We will use the arcs from the inactive coverage for tracing.
- To accurately trace features in an inactive coverage, the snapping feature will need to be activated. Select *Edit*, then *Preferences...* and choose the “Map” tab. Ensure that “Snap feature objects to display inactive coverage nodes and vertices” is turned on .
- To create the inflow arc, we will be using the *Create Feature Arc*  tool. Begin the arc by clicking on the node in the upper right corner of the domain (see Figure 17). With the snapping feature turned on, SMS will snap to the inactive node. Draw the line across the upstream boundary by clicking on any nodes or vertices along the inactive northeastern boundary. Terminate the arc by double-clicking.





Figure 17: Completed BC coverage arcs.

- The newly created “Monitor-Line” needs to be converted to an inflow boundary arc. Select the *Select Feature Arc*  tool and double-click on the arc to launch the *Linear BC* attributes dialog. Select *Inlet-Q* (subcritical inflow) in the drop-down menu.
- The inflow will be defined as Constant. Enter 1285 cfs in the field for the *Constant Q*. Click OK to close the dialog.
- SAVE Project .

5.3. Define Outflow Arcs

An arc defining the outflow boundary will now be created.

- The outflow arc will be created in the same manner that the inflow arc was created. Using the *Create Feature Arc*  tool, draw an arc across the downstream boundary in the lower left corner of the domain (see Figure 17).
- Convert the arc to an outflow boundary arc. Select the *Select Feature Arc*  tool and double-click on the new arc to launch the *Linear BC* attributes dialog. Select *Exit-H* (subcritical inflow) in the drop-down menu.
- For this case, the outflow will be defined as *Rating Curve* in the drop-down menu for *Exit water surface Options*.
- Double-click the “Undefined” box to open the XY Series Editor.
- Then select *Populate*. The Populate dialog will be used to generate a best estimate of the rating curve variables (Figure 18A). Fill in the form with the following information:
 - Type: Normal depth rating curve.
 - The model needs to know what scatter set to use for the *Ground Elevation Dataset*:
 - Select “z” under the Lakina Scatter Data | click OK.
 - Units: U.S. Units
 - Composite Manning’s *n*: 0.035
 - Slope: 0.01 ft/ft
 - Populate Flows.
 - Min: 500
 - Max: 6000
 - Delta: 500
 - Click “Add” to populate flows from 500 to 6000 cfs with an interval of 500 cfs.

- Click OK and the XY Series Editor should be populated with a *Rating Curve* (see Figure 18B).

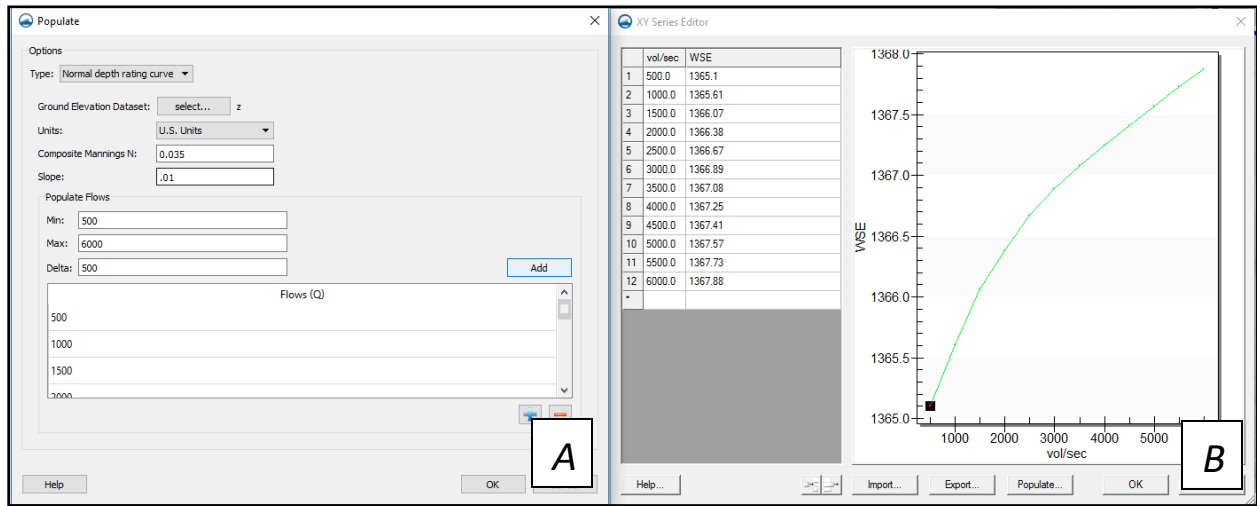



Figure 18: A) Rating curve population values. B) Rating curve.

- Click OK to close the XY Series Editor. The “undefined” box should now have a red rating curve on it.
- Click OK to finish defining the outflow boundary condition.
- SAVE Project .

6. Material Coverage

A material coverage will be created to define the unique material zones for the simulation. There are two ways to create a material coverage. It can be created manually by digitizing polygons to define the material zones, or by reading polygons from a shapefile.


6.1. Digitizing a Material Coverage

One of the material zones has already been digitized, when the roadway arcs were created within the mesh generator coverage. To utilize this work, a duplicate of the mesh generator coverage will be used as a starting point.

- R-click on the “MeshGen” coverage in the *Project Explorer* and select *Duplicate*. A new coverage will be created with the name “MashGen (2).”
- R-click the “MashGen (2)” coverage and select *Rename*. Rename the coverage to “Materials.”
- R-click on the “Materials” coverage.

- *Select Type | Models | SRH-2D | Materials.*

First, names will be assigned for the materials to be used (roughness values will not be assigned at the point).

- Select the *Edit | Materials Data* menu command. The *Material Properties* dialog will appear.
- Initially, only the “unassigned” material will be present in the table. This material can be used to assign areas where water will not flow. We will create three new materials and name them “Channel,” “Trees,” and “Roads.”
- Add a new material by clicking on the  button. A new material called “new material” will be created.
- Double-click on the *new material* name and change it to “Channel.”
- Repeat the previous two sets to add material names for “Trees” and “Roads.”
- Double-click on the *Color* boxes to change their colors and textures.
- For each of the materials, leave the *Manning’s Roughness as Constant*, but change the *Constant N* values to:
 - Channel: 0.035
 - Trees: 0.1
 - Road: 0.015
- Click *OK* to exit the *Material Properties* dialog.

Arcs defining the material zone will now be created. The arcs already created defining the roads will be used to define the road material zone. Other polygons will be digitized to enclose other material zone areas.




- Un-select the “BC” coverage in the *Project Explorer*.
- Select “Material” in the *Project Explorer*.
- Choose the *Create Feature Arc*  tool from the Toolbox.
- Quickly click out arcs to define polygons representing the forested area (Trees). All other areas will be assumed to be the “Channel” (see Figure 19). Don’t spend too much time on this. It does not need to match the figure perfectly.



Figure 19: Material coverage polygons.

- Once complete, build polygons using the *Edit | Select all | Feature Objects | Build Polygons* menu command.

Next, the material must be assigned to each polygon.

- Select the *Display Options*  tool, make sure *Map* is highlighted, then select the *Polygon: Fill* and *General: Legend* option. Click OK to exit.
- To define the polygons, choose the *Select Polygon*  tool | *Edit | Select All | R*-click the “Materials” coverage in the *Project Explorer* and choose *Material Properties* to launch the Assign Material Properties dialog.
 - Because there are mostly “Trees” polygons, we will select the “Trees” material. Make sure the *Constant N* is 0.1 and the texture represents trees (i.e., is green). Click OK to close the menu. All polygons should be the textures you choose for “Trees.”
- Now double-click on the polygon defining the “Channel.”
 - Select the “Channel” material. Make sure the *Constant N* is 0.035 and the texture represents a channel (i.e., is blue). Click OK to close the menu.


- Repeat for the two road sections. Make sure the *Constant N* is 0.015.
- With the *Select Polygon*  tool, draw a box around the 6 piers. R-click one of the piers | *Assign Material Properties*. Select “unassigned.” Click OK to exit.
- The completed materials coverage line arcs should look similar to the image in Figure 20. The color and patterns may be different based on your definition.





Figure 20: Defined material coverage polygons.

7. Monitor Points Coverage

A Monitor Point (MP) coverage will now be created. Monitor points can be defined to extract data values at specified points. Also, during the execution of the model, the water level at two monitor points will be displayed on a graph and updated at each hour of the simulation. This provides a good option for monitoring the solution during execution to determine that the solution has reached steady-state conditions or that the inflow hydrograph for an unsteady run has propagated to the outflow boundary.

7.1. Creating the Monitor Points Coverage

- R-click on the “Map Data” item in the *Project Explorer* and select *New Coverage*. This will cause the *New Coverage* dialog to appear.

- *Select Models | SRH-2D | Monitor Points* coverage type. Leave the default name "Monitor Points." Click OK. Using the *Create Feature Point*  tool, create monitor points as shown in Figure 21.
- SAVE Project .

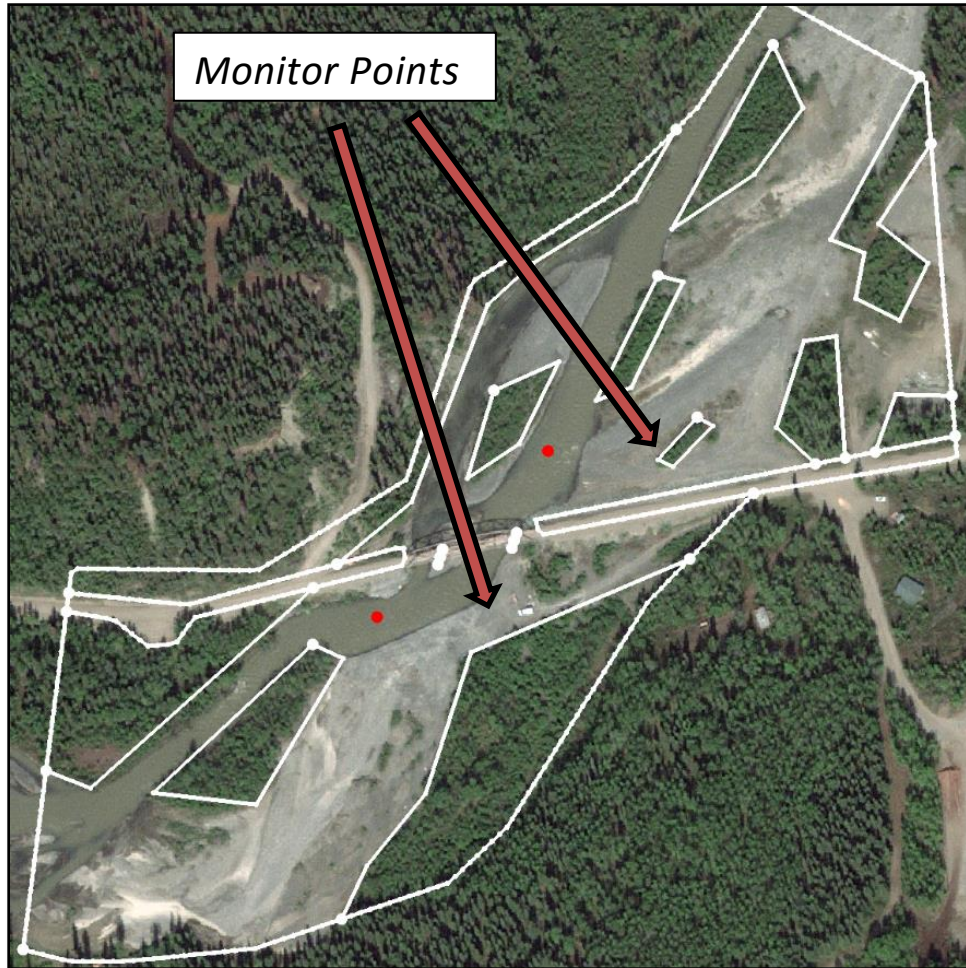


Figure 21: Monitor points.

8. Conclusion

This concludes the Parameters exercise. You should now be familiar with some of the features in SMS for creating a model domain, creating coverages, and using feature objects to assign model parameters.

Modeling Exercise #4 – Geometry


Generating a Mesh

1. Introduction

This modeling exercise will provide an example of how to generate an unstructured grid (or mesh) of the Lakina River Bridge model domain suitable for use in a hydrodynamic simulation in SMS. The workshop includes:

- Subdividing feature polygons in a Mesh Generator coverage.
- Adding automated mesh generation attributes to feature polygons.
- Specifying material and geometric data sources for polygons.
- Generating a mesh.

We will begin with the data from the previous exercise. To ensure consistency, read in a set of completed files from the end of the previous exercise. To do this:

- Open SMS and select Open .
- Navigate to “SMS Modeling Exercises\Exercise 3 – Parameters” directory.
- Select the file named “Lakina River Parameters.sms,” then select *Open*.

If it asks, “Do you want to delete existing data?” click Yes. Select *No*, if asked if you would like to generate image pyramids.

2. Subdividing the Domain

Some models can be defined using a single polygon in the Mesh generator coverage and creating triangles through the entire domain. For most, however, the model domain will be broken up into several polygons. For this model, a polygon defining the roads has already been defined. Polygons defining the piers have been defined too.

3. Model Resolution

The model resolution in each area of the mesh is controlled by the spacing of the vertices on the polygon arcs. Vertex spacing can be reduced to create a fine grid in critical areas and a coarser grid in less critical areas. Care must be taken to ensure that the transition between high- and low-resolution

areas is gradual. For this model, we already redistributed the vertices using 15-foot spacing for all the arcs, then further redistributed the pier polygon spacing to 2-foot.


4. Meshing Parameters



Meshing parameters will be defined for each polygon in the domain to define how elements will be automatically generated in the mesh. Users can experiment with variations of mesh resolution by changing parameters or vertex distribution of individual arcs and polygons. These changes can be visualized before actually creating the mesh. The mesh is automatically created using a single command.

During the automated meshing process, SMS interpolates elevation for each node from a background data source (scatter set). SMS also assigns a material type to each element created. Material types are specified using a separate SRH-2D Materials coverage.

This example will illustrate various options for mesh generation parameters assigned to feature polygons. We will explore variation in mesh type and various ways to adjust vertex spacing.

4.1. 2D Mesh Polygon Properties Dialog

- Un-select the “BC,” “Materials,” and “Monitor Points” coverages in the *Project Explorer*.
- Click on the “MeshGen” coverage in the *Project Explorer* to activate the layer, then R-click on it and select *Zoom to Coverage*.
- Choose the *Select Feature Polygon*  tool. Select *Edit* in the main menu, then choose *Select All*.
- Choose *Feature Objects* in the main menu, then click on *Attributes* to open the 2D Mesh Multiple Polygon Properties dialog.
 - Select Mesh type and in the drop-down menu choose *None*. We are starting with *None* because we have 6 pier polygons that will have no mesh and only 3 polygons (two roads and the main domain) that will have meshes.
 - Select Bathymetry type and in the drop-down menu choose Scatter Set. We are choosing to do this because the three meshes will use the scatter set.
 - Click on *Scatter Options...* then under the *Scatter Set to Interpolate From*, select the “z” under Lakina Scatter (active).
 - Click OK | OK.

- Select the *Display Options*  shortcut tool and make sure *Map* is highlighted. Select *Polygon: Fill* if it is not already. You can change the color for *None* if you want.
- SAVE Project .

4.2. Paving

Paving meshes work for all polygon shapes. The paving method fills the polygon with triangles. The size and number of elements created inside the polygon are based on the vertex spacing of the polygon arcs and the bias specified by the user. The paving method creates rows of elements, working from the polygon boundaries to the center.

- Choose the *Select Feature Polygon*  tool and double-click on the main polygon to open the 2D Mesh Polygon Properties dialog (Figure 22).

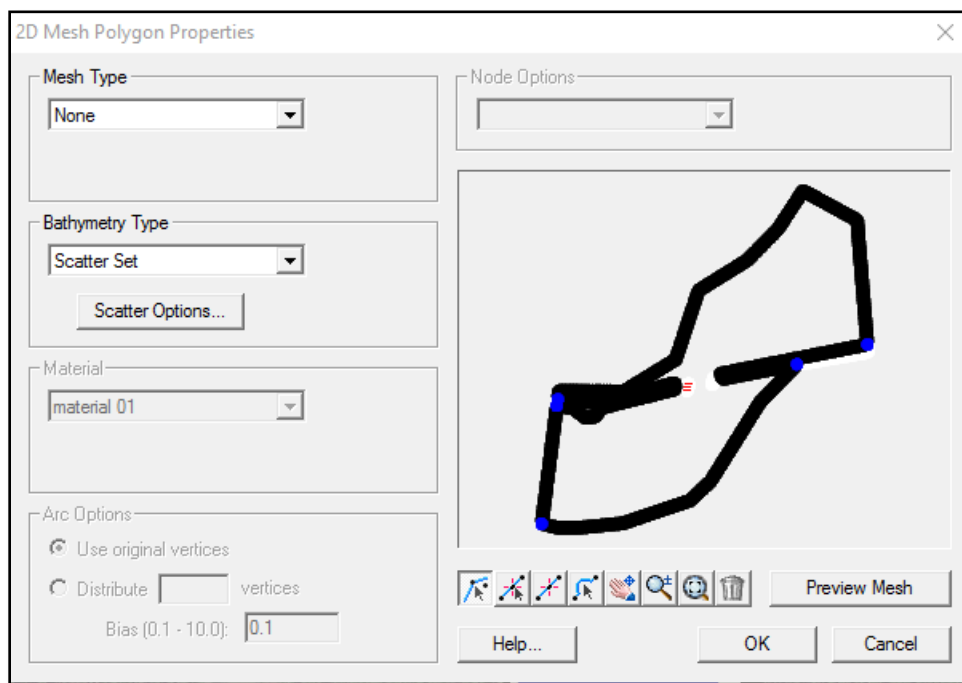



Figure 22 Mesh Polygon Properties dialog.

- We already specified the *Mesh Type* to be *None* and the *Bathymetry Type* to be *Scatter Set*.
 - Change the *Mesh Type* to *Paving* using the drop-down menu.
- Click the *Preview Mesh* button. SMS updates the preview to show the polygon shape and how that shape will be filled with elements using the current settings.
- Beneath the preview window, the dialog includes a toolbox for viewing and modifying the arcs of a polygon without exiting the dialog. Select the *Zoom* .

tool to the *Toolbox* dialog. Drag a box around the bridge area (piers) of the polygon (Figure 23).

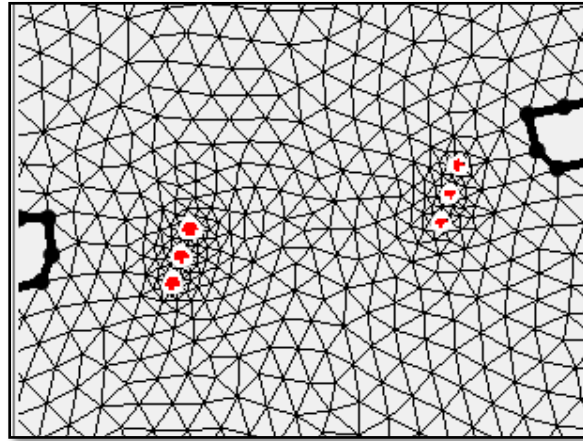




Figure 23: Paving mesh preview around the piers.

- Select the *Pan*  tool. Click on the dialog display window and drag the mouse to move around the polygon.
- Press OK to close the Mesh Polygon Properties dialog.
- SAVE Project .

4.3. Patches

The “Patch” mesh type is generally used to define areas of the mesh that can be represented by 4 “sides” made up of 1 or more arcs. As with paving, the patch mesh type uses the vertex distribution along the sides to set the element size. For patches, elements are created by “connecting” the vertices on opposite sides in a “checkerboard” pattern. If the number of vertices on opposite sides is equal, then the patch will contain only quadrilateral elements. If the number of vertices is not equal, triangles are inserted as transition elements. Figure 24 shows an example of meshes created using the patch method for both cases.

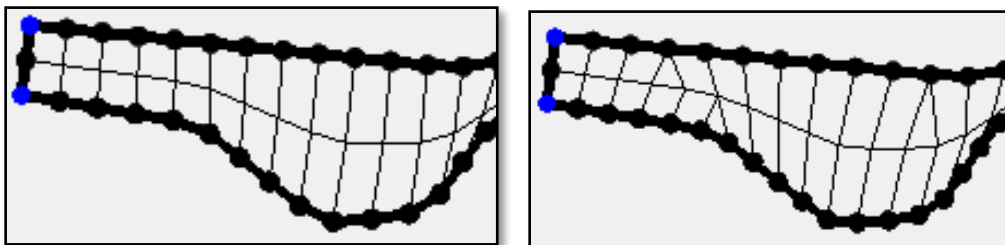



Figure 24: Patching with equal and unequal number of vertices on opposite sides.

Patches often create better mesh representation for long, thin polygons. Therefore, patches will be used to represent the road sections of the mesh.

- Choose the *Select Feature Polygon*  tool and double-click on the western road polygons to open the 2D Mesh Polygon Properties dialog.
- Change the *Mesh Type* to *Patch* using the drop-down menu.
 - An error should pop up: “Patches require three or four edges. Select a node and set the Node Options to Merge to treat multiple feature arcs as a single edge.”
 - Click OK to exit.

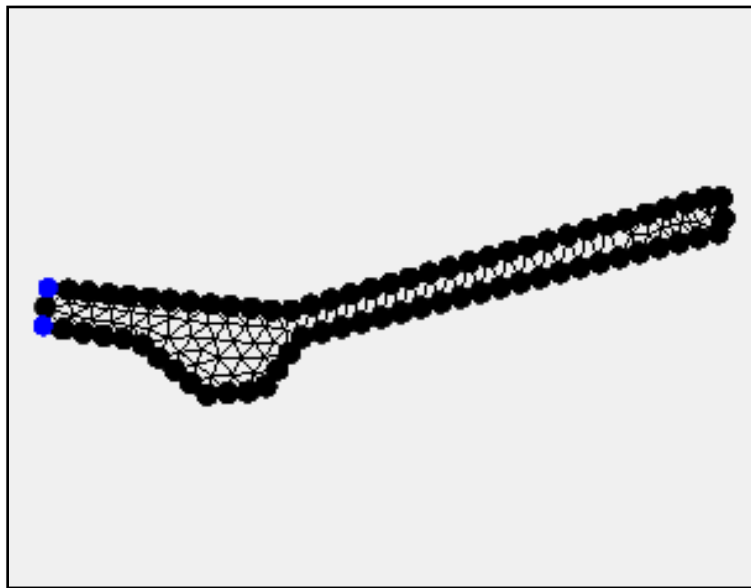





Figure 25: Road section polygon mesh preview with two nodes.

Before we can choose a *Patch* mesh type, we need to add some Nodes and change the distribution of vertices, so that the polygon has 4 sides and equal vertices on opposite sides.

Currently there are only 2 nodes, which are the blue dots in Figure 25. To add *Nodes*, we must exit the Mesh Polygon Properties dialog.

- Click OK to exit the dialog.
- Select the *Zoom*  tool and zoom into the western road polygon (see Figure 26).
- Select the *Select Feature Vertex*  tool from the *Toolbar*. Click on one of the vertices represented with a black star  in Figure 26. R-click on the highlighted vertex and choose *Convert to Node*. The vertex should now be a node and probably white in color.
- Repeat this process for the second black vertex in Figure 26.

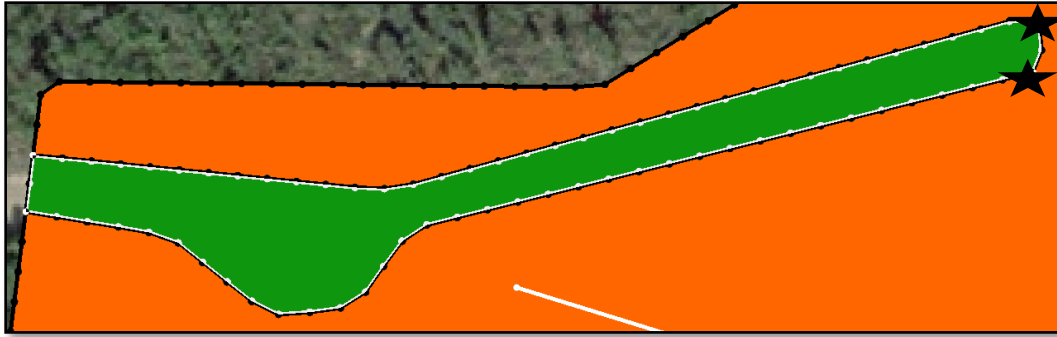




Figure 26: Western road polygon. The stars indicate the vertices that need to be converted to nodes.

Now there are 4 sides to the road polygon, so the *Mesh Type* can be changed to *Patch*.

- Choose the *Select Feature Polygon*  tool and double-click on the western road polygons to open the 2D Mesh Polygon Properties dialog. There should now be 4 blue nodes in the polygon mesh preview.
- Change the *Mesh Type* to *Patch* using the drop-down menu. Click on *Preview Mesh*.
 - Select the *Zoom*  tool and zoom in to see if there are any triangles. For the most part, the Patching looks good, but there are a few triangles (Figure 27A).

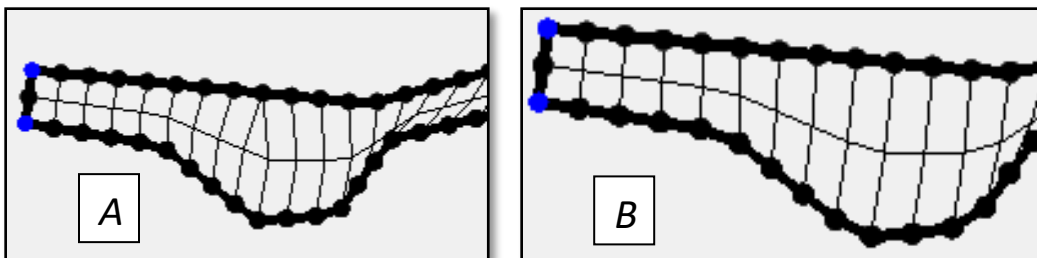






Figure 27: Mesh Patching. A) The number of vertices is not equal; triangles are inserted as transition elements. B) The number of vertices is equal, and there is a complete “checkerboard” pattern.

- To make the vertices even on opposing sides of the polygons, select the *Select Feature Arc*  tool from the *Toolbox*. Select the arc on the top of the polygon. Selecting an arc activates the *Arc Options* section in the lower left of the dialog. Select the *Distribute* option. Change the number of vertices to 34.
- Now select the bottom polygon arc using the *Select Feature Arc*  tool. Select the *Distribute* option and change the number of vertices to 34, so that the opposite sides have the same value.
- Click *Preview Mesh*. The triangles should no longer be there, and the whole polygon should be a “checkerboard” pattern (Figure 27B).

This process needs to be repeated for the eastern road polygon.

- Click OK to exit the dialog.
- Select the *Zoom*  tool and zoom into the eastern road polygon (see Figure 28).
- Select the *Select Feature Vertex*  tool from the *Toolbar*. Individually select and convert the 3 vertices represented with black stars ★ in Figure 28 to nodes.

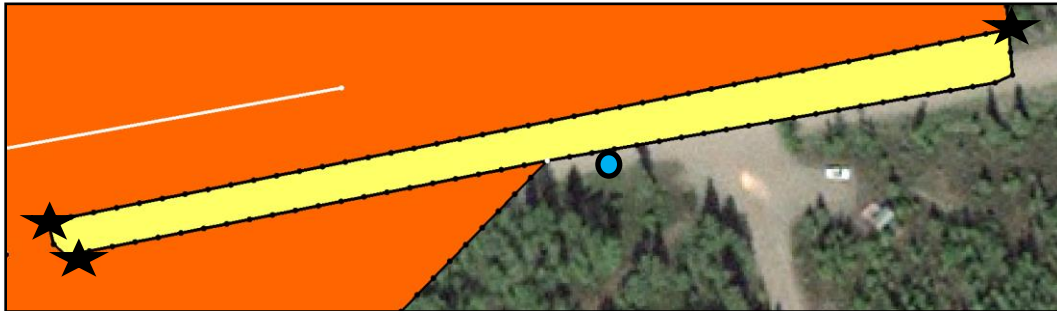






Figure 28: Eastern road polygon. The stars indicate the vertices that need to be converted to nodes.

- Choose the *Select Feature Polygon*  tool and double-click on the eastern road polygons. Note that the bottom “side” of this polygon has two arcs.
- Select *Patch* in the *Mesh Type* drop-down menu.
 - The error message appears again. “Patches require three or four edges. Select a node and set the Node Options to Merge to treat multiple feature arcs as a single edge.”
- To correct this, the middle blue node along the bottom side must be specified as a vertex for this polygon in order to merge the arcs. Click OK to exit the error message.
- Select the *Select Feature Point*  tool from the *Toolbox*. Select the middle blue node on the bottom arc.
 - The *Node Options* section of the dialog window will now be active. Select *Merge* in the drop-down menu. Select again anywhere in the open space in the dialog display window. Note that the node has changed from blue to red, indicating that the node is a *Merge* node.
 - Select *Patch* in the *Mesh Type* drop-down menu. Click the *Preview Mesh* button.
- Select the *Zoom*  tool and zoom in to see if there are any triangles. If there are triangles, make the distribute vertices values equal on opposing arcs. Notice that the Bathymetry is already set to Scatter Set, which is what we want.

- Click OK to exit the dialog.

All of the polygons have now been assigned a *Mesh Type*. Make sure the “Piers” have *No Mesh*, the “Roads” have *Patch Mesh*, and the rest of the “Domain” has *Paving Mesh*. This can be easily accomplished by making sure the polygon colors match the legend (see Figure 29). Your colors might be different.

- SAVE Project .

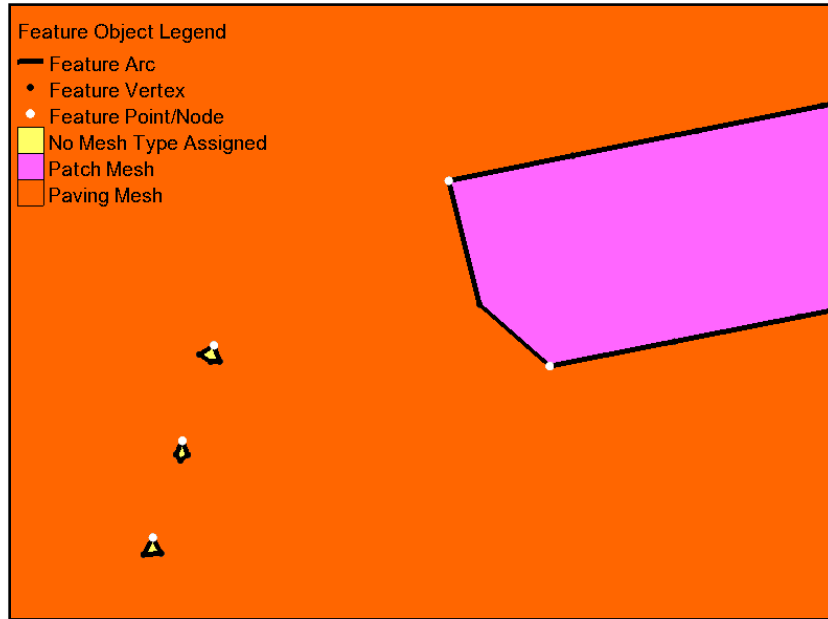


Figure 29: Assigned mesh types and legend. A zoomed-in view of the piers and the end of the eastern road.



5. Assigning Materials

One final polygon attribute to discuss is the assignment of materials data. For SRH-2D, a separate SRH-2D Materials coverage defines the materials for each mesh node. The option in the dialog to specify materials for feature polygons in this coverage is dimmed and is not available for SRH-2D.

6. Generating the Mesh

So far, only a preview of the meshing of individual polygons has been viewed. The entire mesh will now be created using the “instructions” stored as parameters for each polygon:

- R-click on the “MeshGen” coverage in the *Project Explorer* and select *Zoom to Coverage*.

- Make sure no polygons are selected.
- R-click on the “MeshGen” coverage and choose the command *Covert | Map → 2D Mesh*. The *2D Mesh Options* dialog appears.
- Leave the default setting and click OK.
- Specify the *Mesh Name* as “Lakina Mesh” and click OK. SMS generates the elements of the mesh and interpolates the elevations to the nodes.
- To view the mesh, un-select “Map Data” in the *Project Explorer* and click on “Lakina Mesh” coverage to activate the layer.
- Select the *Display Options*  tool and make sure *2D Mesh* is highlighted. Be sure *Nodes* and *Contours* is un-selected and *Elements* is selected . Click OK to exit.
- Toggle off the Lakina_13.tif image to better view the mesh.
- Figure 30 shows how the mesh may look.
- SAVE Project .

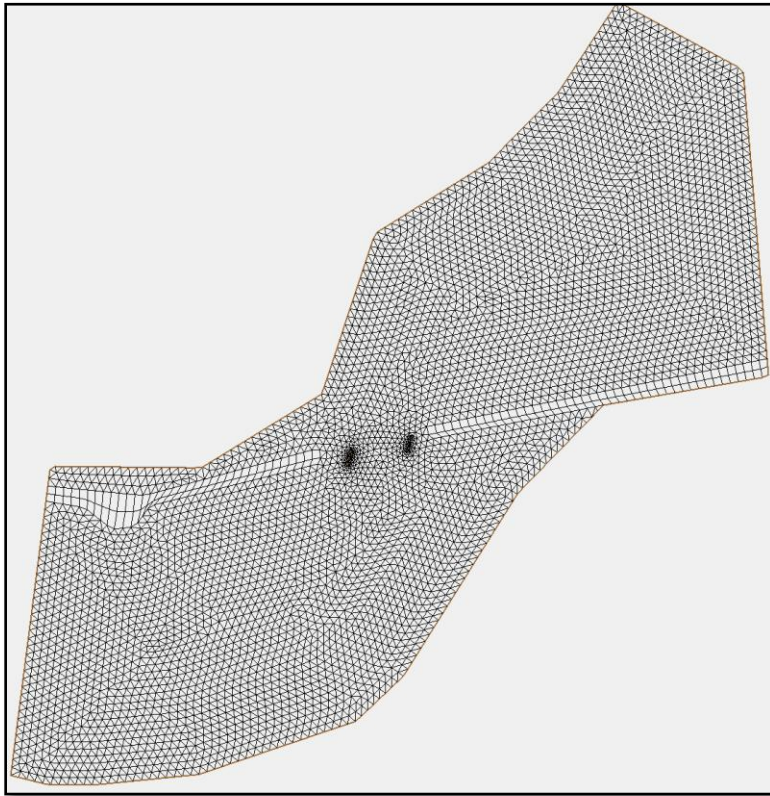


Figure 30: Lakina River mesh.


7. Evaluating the Mesh

After creating a mesh, it is a good idea to evaluate it for quality and to be sure that it was created as intended. Two separate checks should be made in reviewing meshes.

7.1. Mesh Quality

First, visually inspect the mesh to be sure that the elements look reasonable and that they were created as desired. SMS also provides an option to detect areas that are outside the mesh quality guidelines. These options may not identify all problems, and all identified issues may not need to be corrected. However, they will show potential problem areas for the mesh.

The *Mesh Quality* options in SMS display potential problems with individual elements. To turn on the *Mesh Quality* options:


- Select the *Display Options*  tool and make sure *2D Mesh* is highlighted.
- Toggle on the *Mesh quality* option.
 - Click the Options button to the right of the *Mesh quality* option.
 - The *Element Quality Checks* dialog controls the thresholds of what is defined as a good or a bad element. Turn off the *Maximum slope* option. This generally only applies to a model limited to subcritical flow, such as an old RMA2 model.
 - Change the *Maximum interior angle* to 110 degrees.
 - Click OK twice to exit both dialogs.

Elements that violate the specified criteria are now highlighted with a color for each mesh quality option. The most common problems are area change and element interior angles. Once SMS has highlighted potential problems, it is up to the user to either fix or ignore the warning.

There are no hard-and-fast rules when it comes to element quality. The real measure is what solutions the engine can generate for the given mesh. For this case, some issues occur. These issues could be addressed by adjusting the meshing parameters and vertex spacing on the individual polygons.



7.2. Elevation contours

It is a good idea to review the elevations for the mesh to be sure that the generated mesh reasonably represents the underlying background elevation data.

- Select the *Display Options*  tool and make sure *2D Mesh* is highlighted.

- Turn off the *Mesh quality* option and turn on the *Contours*.
 - Select the *Contours* tab and be sure *Color Fill* is selected. Click the *Color Ramp* button and select *Reverse* if necessary to display the lower elevations as blue. Click OK. Un-select *Specify a range* and make the *Transparency* "0."
- Click OK to exit the dialog. Color elevation contours will be displayed.

Check the contours to be sure the elevations are properly represented. If a polygon is not with the underlying scatter set, zero elevations will be assigned and will be evident. It will be clear if some polygons were not assigned to interpolate from the scatter set.

- Select the *Zoom*  tool and zoom into the piers to make sure no elevation contours (color) exist.
- SAVE Project .

8. Conclusion

This concludes the Geometry modeling exercise. This exercise has illustrated some of the features SMS provides for mesh generation for a model domain definition.


Modeling Exercise #5 – Model Simulation

SRH-2D Simulation Setup and Model Run

1. Introduction

All the components needed for the SRH-2D model have now been created. These include a mesh, boundary conditions, materials, and monitor points.

We will begin with data from the previous exercise. To ensure consistency, read in a set of completed files from the end of the previous exercise. To do this:

- Open SMS and select Open .
- Navigate to the “SMS Modeling Exercises\Exercise 4 – Generating a Mesh” directory.
- Select the file named “Lakina River Mesh.sms.” and then select *Open*.

If it asks, “Do you want to delete existing data?” click Yes. Select *No*, if asked if you would like to generate image pyramids.

2. Creating a Simulation

An SRH-2D simulation will now be created:

- R-click in the blank area at the bottom of the *Project Explorer* and select *New Simulation | SRH-2D*.
- R-click the “Sim” coverage and select *Rename*. Rename the coverage to “Q2.”

3. Linking Components

Links will now be created to assign the components to the simulation. Typically, for an SRH-2D simulation, a mesh will be linked to define the geometry. Coverages (layers) will also be linked that specify the boundary conditions, the materials, and the monitor points for the simulation. Because simulations contain links to SMS objects, objects can be shared among multiple simulations.

- Create a link to the mesh by dragging the mesh named “Lakina Mesh” in the *Project Explorer* onto the simulation “Q2.” This is done by clicking on the mesh item in the

Project Explorer and dragging it underneath the simulation. A heavy black line will appear to the right, as shown in Figure 31A.

- Next, add boundary conditions, materials, and monitor points coverages to the simulation. Click and drag the “BC,” “Materials,” and “Monitor Points” coverages into the simulation as was done with the mesh. No other item will be linked in the simulation. When complete, the “Simulation Data” in the *Project Explorer* should appear as shown in Figure 31B.

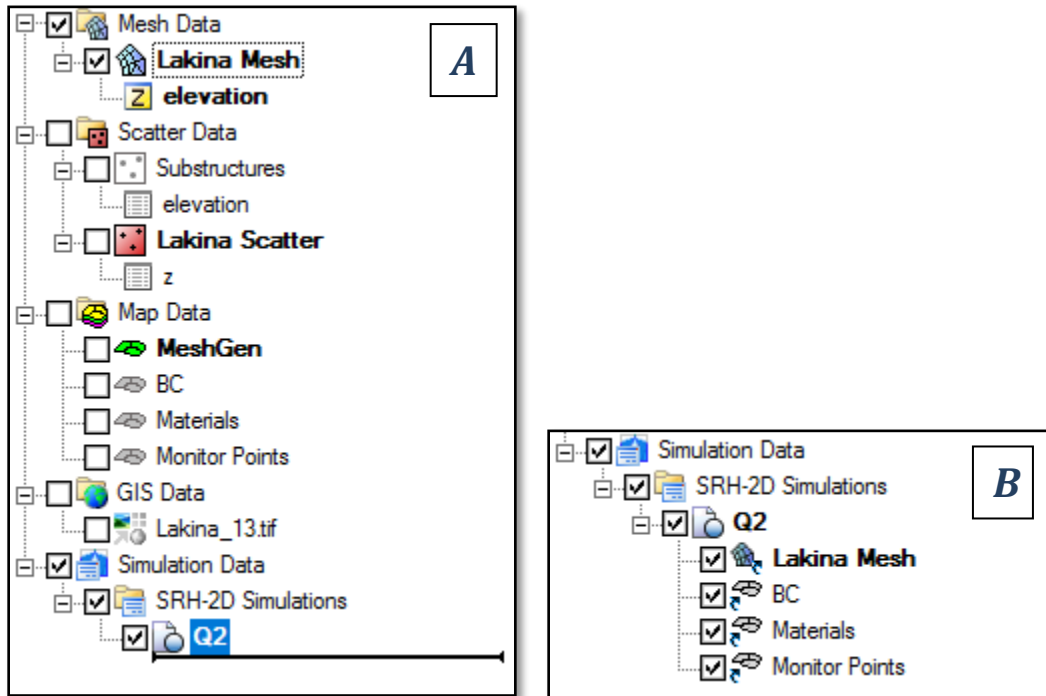


Figure 31: A) Project Explorer illustrating heavy black line when dragging and dropping the mesh. B) Linked coverages.

As shown above, the components in the simulation have a small arrow next to the icon indicating that these objects are just links and not the actual object. Therefore, when the objects are modified, the simulation links back to the updated object. When components are modified, they do not need to be “relinked” (dragged) to the simulation.

4. Define Model Control

The final step before running the model is to specify the model control parameters. In the model control, we specify the solution type, run time, time step, initial conditions, turbulence options, and output options. In this section, we will review and set each of the model control parameters and options. To do this:

- R-click on the “Q2” simulation in the *Project Explorer* and select *Model Control* to launch the *Model Control* dialog. There are three tabs in this dialog: *General*, *Flow*, and *Output*.


4.1. General Tab

- For *Simulation Description*, enter “2-year flood.” This is descriptive text that only appears in the output file.
- For *Case Name*, enter “Q2.” This name will be used for the prefix for the results file names in the folder where the file results are stored.
- Be sure the checkbox for *Temperature Modeling* is not checked.
- For *Start Time*, leave the value at the default of 0 hours.
- For *Time Step*, specify 1 second. The time step is the most critical parameter affecting model stability. A rule of thumb is that time step should be set such that water does not move across more than one element in a single time step. It is, therefore, dependent on both water velocity and element resolution. Experience is required to determine appropriate time steps. Usually a time step between 1 and 10 seconds is specified, and can be reduced if the model becomes unstable.
- For *Total Simulation Time*, specify 1.25 hour. A time should be specified that allows for the entire hydrograph to propagate to the downstream boundary for an unsteady run, or for the simulated steady-state flow to reach equilibrium at the downstream boundary. Results and monitor points can be used to verify these conditions. Be sure that the flow values specified in the table for the boundary conditions cover enough time for the *Total Simulation Time*.
- Specify *Dry* in the drop-down box for *Initial Condition*. This option defines how the initial water level is set for running the model. Most models are run beginning with a dry domain.

4.2. Flow Tab

- Select the *Flow* tab.
- Leave the default turbulence parameters in the *Flow* tab. SRH-2D uses a global turbulence model with a default *Parabolic* turbulence of 0.7.

4.3. Output Tab

- In the *Output* tab, make sure the *Results Output Unit* is set to English, and specify the *Results Output Frequency* as 0.0167 hours.
- Click OK to exit the *Model Control* dialog.
- SAVE Project .

5. Running the Model

The SRH-2D model simulation is now ready to run. To do so:

- R-click on the simulation “Q2” and select *Save, Export and Launch SRH-2D*.
- A message may appear notifying you that the BC and Materials coverage will be renumbered. Click OK.

SMS launches the model wrapper and displays the screen output for the numerical model. SRH-Pre requires only a second or two to run. Once it has completed, SMS will automatically launch SRH-2D. Once the SRH-2D run begins, you will see a model wrapper consisting of three DOS windows. The first is simply a title graphic for SRH-2D including some version information. This window can be minimized. The second window is Residual Monitor. This plots the changes in residuals for the solution procedure. It can give some indication of model stability, but mostly will indicate how far the model is progressing. The third window plots the changes in water level for the monitor points. This can be used to see changes at the inflow and outflow locations and, for this model, can give an indication that the model has reached steady state.

- Move and resize such that the second and third windows are visible as shown in Figure 32.

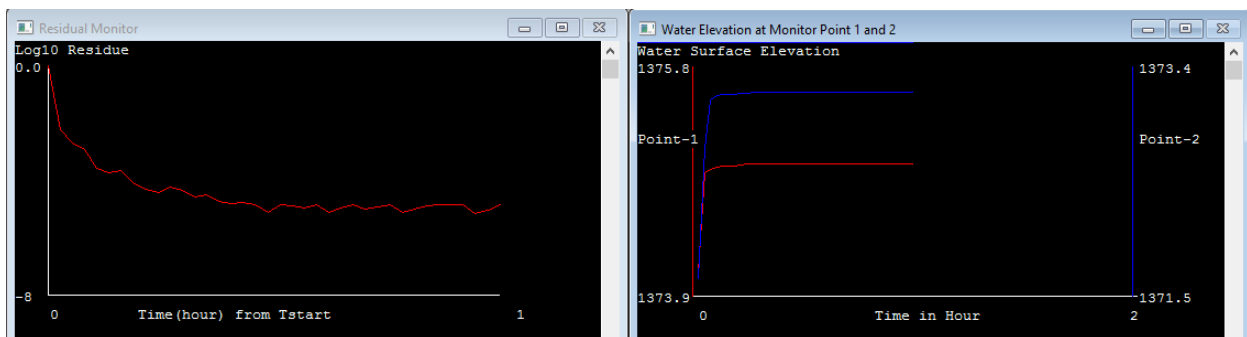
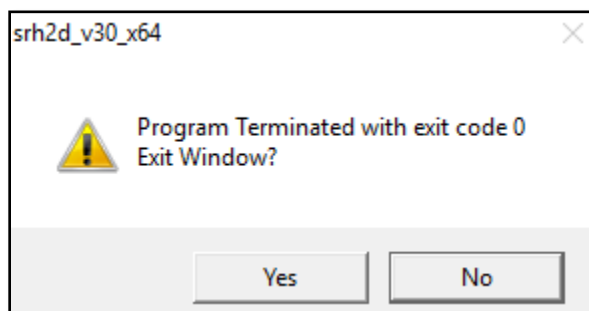


Figure 32: SRH-2D model wrapper

If the model successfully runs to completion, SRH-2D will display the dialog below.




- Click *Yes* to close the SRH-2D model wrapper.
- Click *Exit* to close the SMS model wrapper.


During the model run, SRH-2D writes out several files in the same folder where the SRH-2D model inputs are written out. Most of those files are *Restart files*, written out at each time step. The model results are stored in a ZMDF file, which can be loaded into SMS for further visualization. The model results should automatically be read in.

6. Post-Processing

When SMS finishes reading the solution files, several datasets are added under the Mesh Data folder in the Project Explorer. The solutions datasets include computed depths and velocities, water surface elevations, Froude number for each node, and each time step in the mesh. Contour and vector display of these datasets can be generated.

To update the display settings for dataset viewing:

- Select the *Display Options*  tool and make sure *2D Mesh* is highlighted.
- Click the *All Off* button at the bottom of the window and then select *Mesh boundary*, *Contours*, and *Vectors*.
- Click on the *Contours* tab:
 - Make sure the *Contour method* is *Color Fill*.
 - Select *Specify a range* and enter a *Min*: 0.1 and *Max*: 10.
 - Un-select the *Fill below* and *Fill above*.
- Click on the *Vectors* tab.
 - In the *Vector Display Placement and Filter* section, select *on a grid* from the drop-down menu.
 - For the *Origin* select *Relative to bed* in the drop-down box and enter 10.0 for the *Offset*.
- Click OK to exit the *Display Options* dialog.
- Select the *Lakina_13.tif* image to turn it on.
- Click on the *Water_Depth_ft* dataset in the *Project Explorer* to activate it.

- Below the *Project Explorer* is a *Timeset window*. Select the initial time set (i.e., 0 00:00:01). Since the project started dry, there will be little if any water shown flowing into the mesh at the upstream boundary. Use the arrow keys on the keyboard to scroll down through the time steps to observe the flow into the model domain over time (Figure 33).
- Leaving the solution at the last time step, alternately select the *Water Depth*, *Velocity magnitude*, and *Froude number* datasets in the *Project Explore*.
- Continue to explore the solution datasets by changing display options as desired.
- SAVE Project .

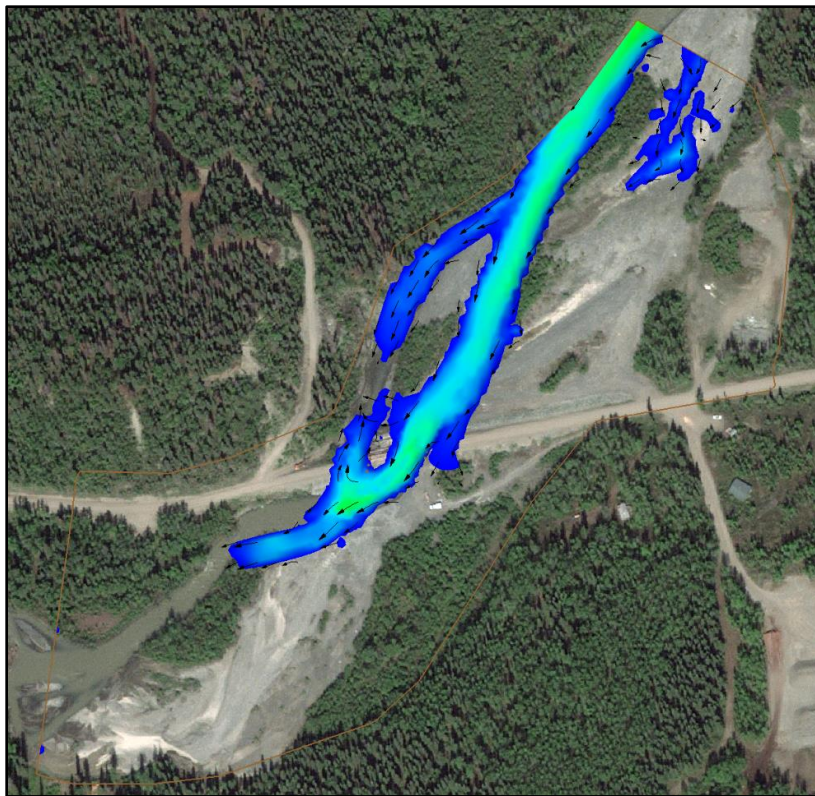


Figure 33: Water depth 3 minutes into the simulation.

7. Map Export


Once a desired map display has been created, it can easily be exported:

- Select *File | Save As*.
- Enter a name of your choice.
- Change the *Save As type* to *JPEG Image Files (*.jpg)*.

- Click Save.
- The model then exports an image file that can be opened in other image views.

8. Create Profile Plots

It is often useful to create profile plots of the datasets to represent or show the data. This is done using arcs in an observation coverage in the *Map* module.

- R-click on the “Map Data” and create a new Observation type coverage named “Observation.”
- Select the new observation coverage in the *Project Explorer*.
- Using the *Create Feature Arc*  tool, create an arc down the center of the reach from the downstream boundary to the upstream boundary.
- Select *Display | Plot Wizard* menu command to launch the *Plot Wizard*, then select the *Observation Profile* option. Click *Next*.
- Be sure Arc 1 is checked in the *Coverage* sections.
- Under *Datasets*, select *Specified*. Select the elevation and Water_Elev_ft datasets.
- Leave the *Time steps* option as *Active* and click *Finish*. A profile plot of the water surface elevation along with the ground elevation will be displayed (Figure 34).
- Practice creating additional profile arcs and plots for any location and any dataset.

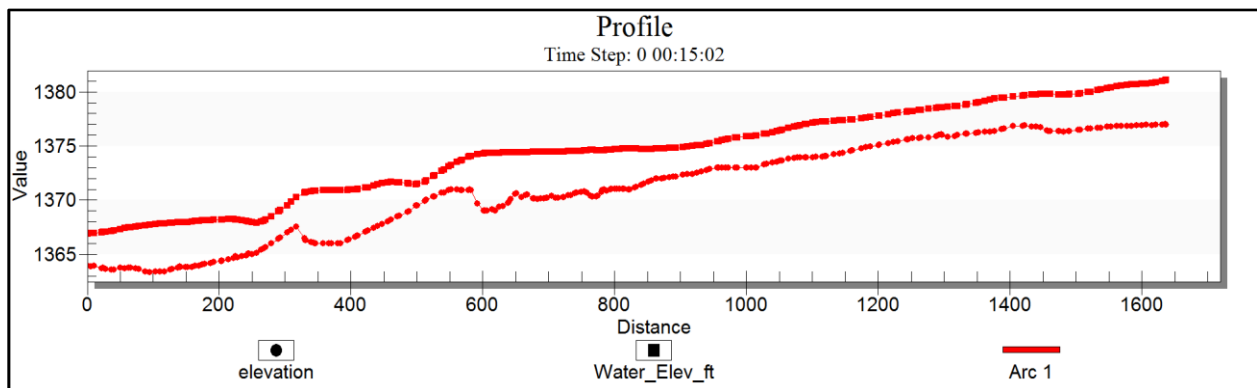


Figure 34: A profile plot of the water surface elevation along with the ground elevation.

9. Create Animation

A film loop (animation) can be created showing a flow trace of the solutions:

- R-click on *Lakina Mesh* | *Zoom to Mesh*. This will also activate the *Mesh* menu options.
- Select *Data* | *Film Loop* menu command.
- Check *Create AVI File* option, then click on the browse button. Specify a name of “LakinaRiver” for the filename of the AVI file. Click Save.
- Select the *Flow Trace* option, then click *Next*.
- Click *Next* | *Next* | *Finish* to accept the default *Display Options*. A flow trace animation will be created and should run in the *Play AVI Application* (Figure 35). This animation will be saved in a file named as specified and can be played in a PowerPoint presentation or other media player.
- Zoom into a specific area and create a new animation. Experiment with the different options for creating animations by creating more versions.





Figure 35: Lakina River film loop.

10. Conclusion

This workshop provided a basic introduction for setting up and running an SRH-2D simulation. Different post-processing methods were also evaluated.

2D Hydraulic Modeling of Rivers Using HEC RAS-2D

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Modeling Exercise #1 – ArcMap

Developing a Terrain Model

1. Introduction

HEC has added the ability to perform two-dimensional (2D) hydrodynamic routing within the unsteady flow analysis portion of HEC-RAS. Users can now perform one-dimensional (1D) unsteady flow modeling, two-dimensional (2D) unsteady flow modeling (Saint Venant equations or Diffusion Wave equations), as well as combined 1D and 2D unsteady flow routing. The 2D flow areas in HEC-RAS can be used in number of ways. The following are exercises based on the same Lakina River dataset that was used in the SMS workshop. The idea is to develop two different hydrological models using the same data, so a comparison can be made.

2. Developing a Terrain Model

It is essential to have a detailed and accurate terrain model in order to create a detailed and accurate hydraulics model. The quality of the terrain data can be a limiting factor in the quality of the hydraulics model the user can create. Terrain data come from many different sources, formats, and levels of detail. Currently, HEC-RAS uses gridded data for terrain modeling. It is up to the user to gather data from multiple sources, create a good terrain model, and convert/export it into a gridded data format that can be read in by HEC-RAS.

It is necessary to create a terrain model before the user can perform any HEC-RAS model computations that contain 2D flow areas. This section of the workshop describes how to create a terrain model in ArcGIS. For details on creating terrain models with HEC-RAS Mapper, please review the chapter on HEC-RAS Mapper in the HEC-RAS User's manual.

3. ArcGIS

If your computer is not equipped with ArcMap, follow the directions for the remainder of the *ArcMap* exercise.

- Launch ArcMap from the desktop icon, start menu, or from file browser, Select *New Map | Blank Map*.
- Save file: *File | Save As* and name it Lakina River Workshop.



4. Setting the Projection

The instructions below describe how to set the projection.

- *View | Data Frame Properties* to open the Data Frame Properties dialog.
- Click on *Projected Coordinate System | State Plane | NAD1983 (2011)(US Feet) | NAD_1983_2011_StatePlane_Alaska_2_FIPS_5002_Feet*
 - Then click *OK* to exit.

5. Background Image



To load the Lakina River aerial photo:

- Select *File | Add Data | Add Data* or use the *Add Data* Shortcut tool . Select the Lakina_13 image in the “Workshop\DOT Images\Lakina River\Lakina_13 World” folder.
 - ArcMap will automatically use the created World File.
 - Click *Add*.
- No, do not Pyramid build. Click *No*.
- An *Unknown Spatial Reference* message will appear. Click *OK* to exit.
- SAVE Project .

6. Digital Elevation Data

To load the elevation data:

6.1. AutoCAD Survey Data


- Use the *Add Data* Shortcut tool . Attempt to add the Lakina River XML data in the “Workshop\DOT Scatter Data\XML” folder.
 - GIS does not recognize XML formats, so let’s try the AutoCAD file.
- Use the *Add Data* Shortcut tool . Select the file LakinaRiver.dwg in the “Workshop\DOT Scatter Data\AutoCAD” folder.

- An *Unknown Spatial Reference* message will appear. Click *OK* to exit. The AutoCAD data should appear and aligned with the Lakina aerial photo.

The elevation data need to be extracted as a shapefile:


- In the TOC, click the “+” symbol next to “LakinaRiver.dwg Group Layer” to expand the layers.
- R-click on the *Point* layer | *Data* | *Export Data* to open the Export Data dialog.
 - Make sure *All features* is selected in the *Export* drop-down menu and *this layer’s source data* is selected.
 - For the *Output feature class*: navigate to where you want to save the shapefile and name it “LakinaRiverAutoCAD.”
 - Click *OK*.
- A message appears asking, “Do you want to add the exported data to the map as a layer?” Select *Yes*.
- Now we can remove the AutoCAD Layer:
 - In the TOC, R-click “LakinaRiver.dwg Group Layer” | *Remove*.

The Lakina River scatter data should be the only thing left.

- R-click on the *LakinaRiverAutoCAD* shapefile layer in TOC |  *Zoom to Layer*.

This should reveal that extra points are present. To remove these extra points:

- Make sure the *Editor Toolbars* is activated.
- From the *Editor* drop-down menu, select *Start Editing*. Click *Continue* if a *Spatial Reference Does Not Match Data Frame* message appears.
 - R-click the *LakinaRiverAutoCAD* shapefile layer in TOC | *Open Attribute Table*.
 - R-click on *Elevation* column | *Sort Ascending*.
 - Select all rows with “0” *Elevation* values by holding *Shift* down. There should be roughly 547 rows with 0 elevation. The selected rows should turn blue.
 - R-click far left edge of selected rows | *Delete Selected*.
 - Close *Attribute Table* | *Stop editing* and *Save*
- From the *Editor* drop-down menu, select *Stop Editing* | Click *Yes* to save your edits.


- R-click on the *LakinaRiverAutoCAD* shapefile layer in TOC |  *Zoom to Layer*.

Only the elevation data should now be present and aligned with the background image.

6.2. XML Survey Data

Unfortunately, the AutoCAD survey dataset does not include as much detail (number of survey points) as the XML file that was used in SMS, and ArcMap does not see XML files.

We can export the XML data from SMS to a .txt file and then import it into GIS. To do this:

- Launch SMS from the desktop icon, start menu, or from file browser.
- Select Open  and navigate to “SMS Modeling Exercises\Exercise 1 – Background Data A” directory.
- Select the file named “Lakina River.sms,” then select *Open*.
- Turn on the *Lakina Scatter* in the *Project Explorer* and click on the layer to activate it.
- *File | Save As*
 - Navigate to where you want to save the file.
 - For *File name*, enter “Lakina River XML.”
 - In the *Save As type* drop-down menu, select “Tabular Data Files (*.txt).”
 - Click Save. This should open the *Export Tabular File* dialog.
 - Because the Lakina Scatter includes x, y, and z data, the *Number of Columns* should have a 3 next to it.
 - Change the *Delimiter* to *Comma* using the drop-down menu.
 - Click on the *Data* button under *Column 1* and select *x location*.
 - *Repeat for Columns 2 and 3* using the following:
 - Column 1 = x location
 - Column 2 = y location
 - Column 3 = z location
 - Click OK to exit.
- Close SMS.

In order to bring in the *Lakina River XML.txt* file into GIS, we first need to add column headings. To do this:

- Use Excel to open the *Lakina River XML.txt* file | *Comma* delimiter. Change the column headings to x, y, z | save as an Excel Workbook.

The *Lakina River XML.xlsx* file can now be added into ArcMap.

- Back in ArcMap, select *File* | *Add Data* | *Add XY Data*.
 - In the *Choose a table...* drop-down menu find *Lakina River XML.xlsx*.
 - There should only be one sheet named '*Lakina River XML\$*.' Select it and click *Add*.
 - Make sure that the *X Field* is "x," *Y Field* is "y," and *Z Field* is "z."
- Click OK.
 - A message saying *Table Does Not Have Object-ID Field* pops up. Click OK to exit.

Notice the XML derived scatter set has more data points. Let's make this layer a shapefile:

- R-click on the '*Lakina River XML\$*' Events layer | *Data* | *Export Data* to open the Export Data dialog.
 - Make sure *All features* is selected in the *Export* drop-down menu and *this layer's source data* is selected.
 - For the *Output feature class*: navigate to where you want to save the shapefile and name it "LakinaRiverXML." Click *Save*.
 - Click OK.
- A message appears asking, "Do you want to add the exported data to the map as a layer?" Select *Yes*.
- Now we can remove the '*Lakina River XML\$*' Events and *LakinaRiverAutoCAD* layers:
 - In the TOC, R-click on both layers | *Remove*

The Lakina River XML scatter data should be the only thing left.

- SAVE Project .

7. Adding Pier Locations into Terrain Data Using ArcMap

Current version limitations of the 2D modeling capabilities in HEC-RAS: Cannot use the HEC-RAS bridge modeling capabilities inside of a 2D flow area.

An alternative option is to simply modify the terrain to include the bridge embankments, abutments, and even piers. This requires a little work in ArcMap by manually editing the terrain to include those features.

During the SMS modeling exercises, bridge pier locations were needed. We cut out the mesh around the piers, and the model treated the boundary conditions as a vertical wall. For HEC-RAS, we need the pier elevations, so the information can be added to the terrain.

- In Excel, navigate to *Workshop\Bridge Data* and open the *LakinaPiers* file.
- For the pier elevations (z column), the height of the bridge deck was entered, which is 1389 feet.

Because we are adding much higher elevation points into the middle of the channel, this will greatly affect the surrounding area when the TIN is developed. To eliminate a “cone” effect around the piers, ground elevation points need to be positioned around the base of the piers.

Three additional columns were added to the Excel file with pier surrounding “base” points. The “base” points were positions 1.5 feet from all of the 6 pier centers, because the piers are 3 feet in diameter, in the north, east, south and west directions. The “base” elevations were estimated from the nearest by survey points. To add in the “Pier” and “Base” elevation data:



- Close *Excel*.
- In ArcMap select *File | Add Data | Add XY Data*.
 - In the *Choose a table...* drop-down menu, navigate to *Workshop\Bridge Data* and select *LakinaPiers\$*. Click Add.
 - Make sure that the *X Field* is “x,” *Y Field* is “y,” *Z Field* is “z.”
- Click OK.
- Repeat to add the base elevation points, but make sure the *X Field* is “xbase,” *Y Field* is “ybase,” *Z Field* is “zbase.” Click OK | OK
- Turn off the *LakinaRiverXML* layer in the TOC.
- R-click on the *LakinaPeir\$ Events* layer in TOC |  *Zoom to Layer* (Figure 1).




Figure 1: Zoomed-in view of the bridge piers and base elevation points.

The 6 piers should be plotted and all with 4 surrounding “base” elevation points. To make the newly added layers shapefiles, do each of the following sets for both of the *LakinaPier\$ Events* layers:

- R-click on the *LakinaPier\$ Events* layer | *Data* | *Export Data* to open the Export Data dialog.
- Make sure *All features* is selected in the *Export* drop-down menu and *this layer's source data* is selected.
 - For the *Output feature class*: navigate to where you want to save the shapefile and name the piers points “LakinaPier” and the base points “LakinaPierBase.” Click *Save*.
 - Click *OK*.
 - A message appears asking “Do you want to add the exported data to the map as a layer?” Select *Yes*.
 - In the TOC, R-click on *LakinaPier\$ Events* layer | *Remove*.
- SAVE Project .

8. Create TIN

To create in TIN using ArcMap:

- Click on the *ArcToolbox*  | *3D Analyst Tools* | *Data Management* | *TIN* | *double-click Create TIN* to open the *Create Tin* dialog.
- In the *Output TIN* drop-down, navigate to where you want to save the file and name it “LakinaTIN.” Click *Save*.

- For the *Coordinate System*, navigate to *Projected Coordinate System | State Plane | NAD1983 (2011)(US Feet) | NAD_1983_2011_StatePlane_Alaska_2_FIPS_5002_Feet*
 - Click OK
- Using the *Input Feature Class* drop-down menu, individually select *LakinaPerBase*, *LakinaPier*, and *LakinaRiverXML* (Figure 2). We are selecting all these layers because we want the TIN to be created using the points from the survey data, piers, and surrounding base points.
 - Click OK

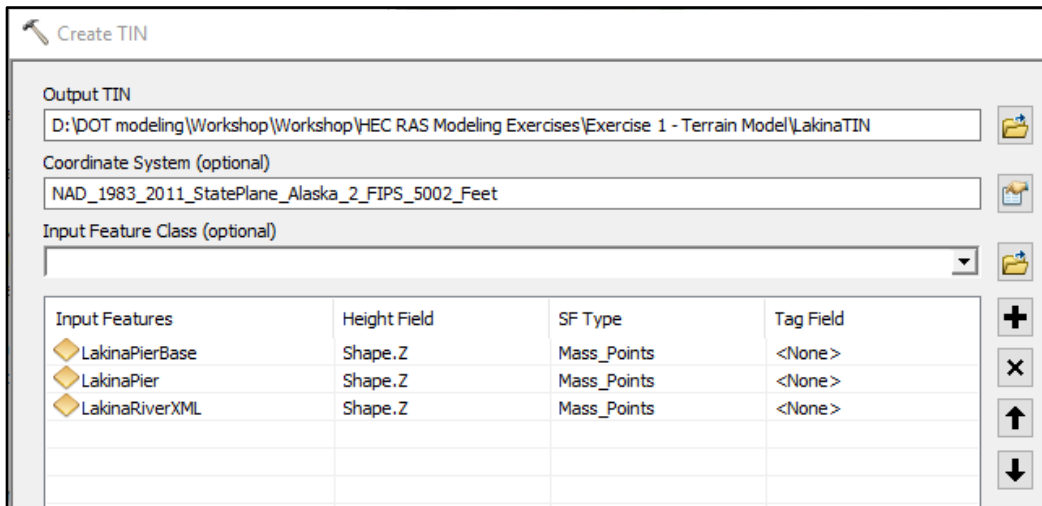



Figure 2: Create TIN dialog.

- Wait a minute as the TIN is created. When the TIN is complete, a little message will pop up in the lower right-hand corner. The TIN should also automatically show in the map.
- In the TOC, check the elevation ranges for the LakinaTIN. Make sure there are no 0 values.
- R-click on the *LakinaTIN* layer in TOC |  *Zoom to Layer* (Figure 3).

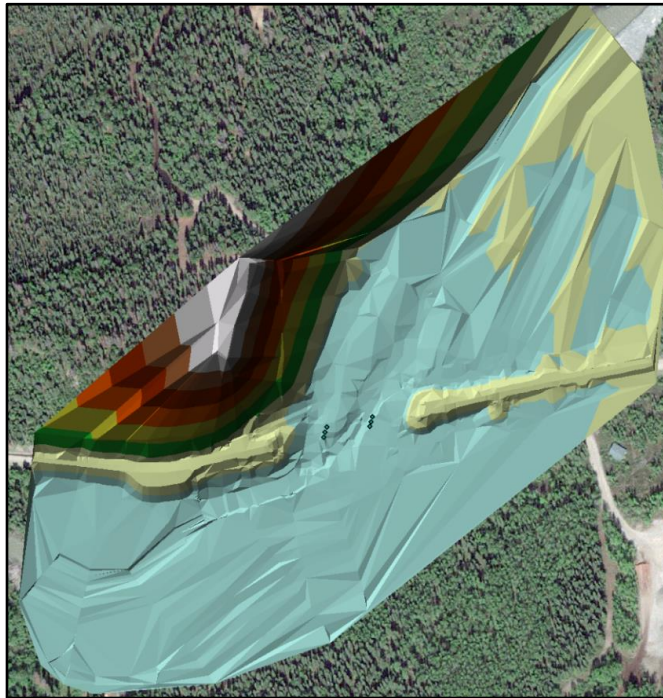


Figure 3: Lakina TIN.

9. Editing TIN

As a result of the triangulation process, the downstream boundary has an artificial lip at the end, which acts as a wall. This bogus boundary will cause the prevention of modeled flow.

- To edit the TIN, the TIN editor needs to be activated:
 - *Customize | Toolbars | TIN Editing.*
- Using the *TIN Editing* drop-down menu, select *Start Editing TIN* (Figure 4).

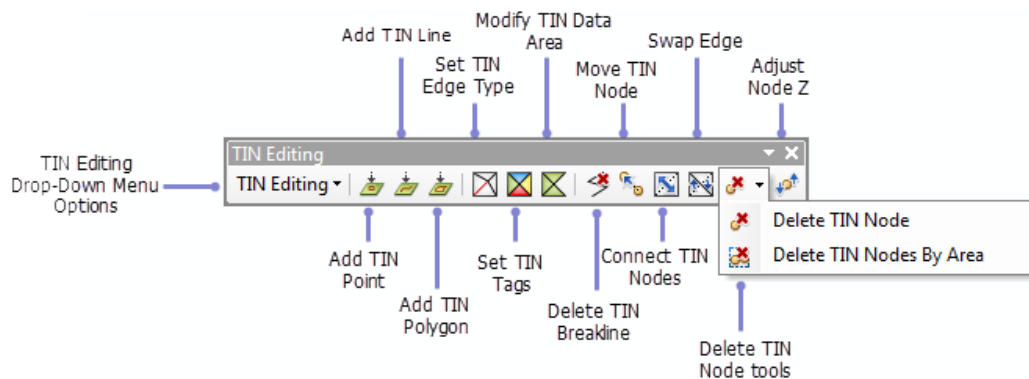




Figure 4: TIN editing toolbar tools. Image from “The interactive TIN Editing toolbar,” 2017, <http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tin/interactive-tin-editing-tools.htm>.

- Click on the *Modify TIN Data Area*  tool. The *Modify TIN Data Area* dialog window appears.
 - Set the *Selection* to *completely within polygon* from the drop-down menu. This allows you to manually modify the TIN triangles that are completely within a digitized polygon.
 - Set the *Mask* to *toggle current state* from the drop-down menu. This changes the TIN triangle(s) to either on or off depending on the current state.
- By clicking on the map, digitize a polygon around the artificial lip at the downstream boundary (Figure 5). Double-click to finish the digitized polygon. The triangles should immediately disappear.
- In the *TIN Editing* drop-down menu, select *Stop Editing TIN* | click *Yes* to save the edits to the Lakina TIN.
- SAVE Project .

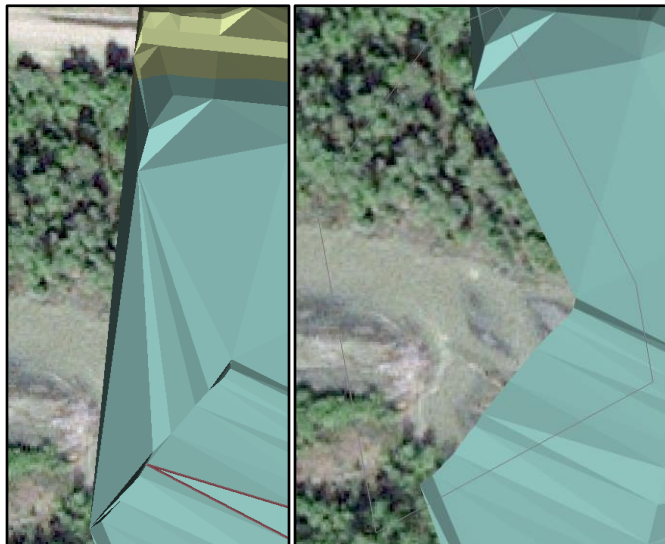


Figure 5: Downstream boundary triangles before and after turning them off.

9.1. Breaklines

Breaklines are also added using the TIN Editing tool. We will add breaklines to the whitish diagonal channels as we did in the SMS exercises (Figure 6A).

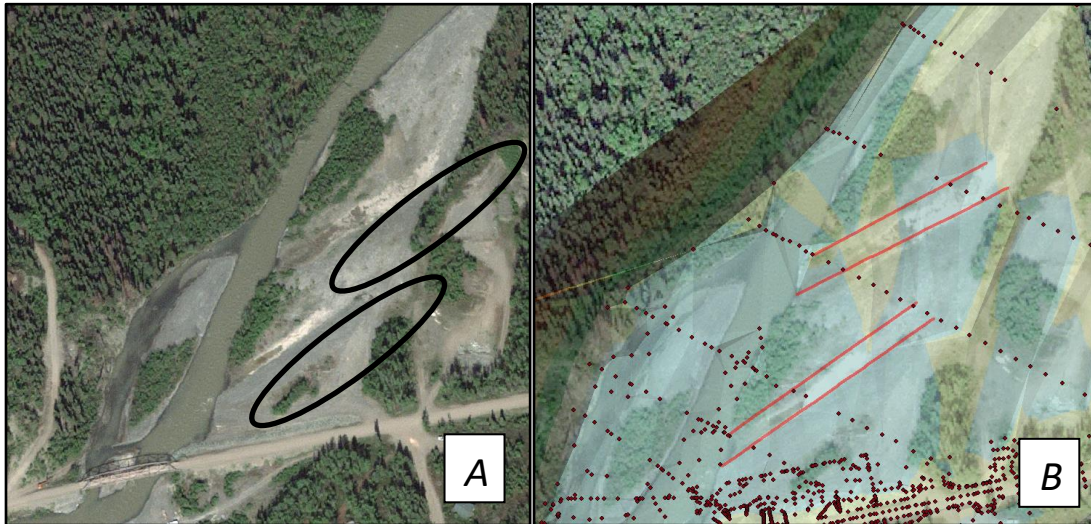





Figure 6: A) Diagonal channels highlighted with circles. B) Breaklines for the diagonal channels.


- Toggle on the *LakinaRiverXML* layer so the survey points are visible, and zoom into the whitish diagonal channels
- Using the *TIN Editing* drop-down menu, select *Start Editing TIN*.
- Click on the *Add TIN Line*  tool, which adds new breaklines to a TIN. The *Add TIN Line* dialog window appears.
 - Set the *Line type* to *soft line* from the drop-down menu.
 - *Line type* — The type of breakline to be created, either hard or soft. Hard and soft qualifiers for line and polygon feature types are used to indicate whether a distinct break in slope occurs on the surface at the location. A hard line is a distinct break in slope, while a soft line is represented on the surface as a more gradual change in slope.
 - Set the *Height source* to *From Surface* from the drop-down menu.
 - The elevation of the digitized line is interpolated from the selected locations on the surface.
- Double-click on the *LakinaTIN* layer in the TOC. Click the *Display* tab and enter 50% for the *Transparency*. The whitish diagonal channels should now be more visible.
- Draw in breaklines on either side of the whitish diagonal channels (Figure 6B). You do not have to click on a vertex like you do in SMS. The triangulations will automatically adjust as the breaklines are added.
- In the *TIN Editing* drop-down menu, select *Stop Editing TIN* | click *Yes* to save the edits to the Lakina TIN.
- SAVE Project .

10. Create Raster from TIN

You can convert a TIN to a raster to use in surface modeling. This conversion can be done using the *Tin to Raster (3D Analyst) geo-processing tool*. The raster is created by interpolating its cell values from the elevation of the input TIN at the specified sampling distance.

- Click on the *ArcToolbox*  | *3D Analyst Tools* | *Conversion* | *From TIN* | *double-click TIN to Raster* to open the *TIN to Raster* dialog.
- For the *Input TIN*, select *LakinaTIN* from the drop-down menu.
- In the *Output Raster* drop-down, navigate to where you want to save the file and name it “LakinaRaster.”
- Leave the *Output Data Type* as *FLOAT*.
- Leave the *Method* as *LINEAR*.
- Change the *Sampling Distance* to *CELLSIZE* using the drop-down menu.
- Click OK.
- Wait a minute as the Raster is created. When the Raster is complete, a little message will pop up in the lower right-hand corner. The TIN should also automatically show up in the map (Figure 7).

The raster now needs to be exported as a TIFF file:

- R-click *lakinaraster* in TOC | *Data* | *Export Data* to open the *Export Raster Data* dialog.
 - For the *Location*, navigate to where you want to save it.
 - Make sure that *TIFF* is selected in the *Format* drop-down menu.
 - The *Name* should automatically populate as *lakinaraster1.tif*.
 - Click Save.
 - An *Output Raster* message should appear asking, “Would you like to add the exported data to the map as a Layer?” Click *Yes*, and the TIFF file should plot.
- SAVE Project .

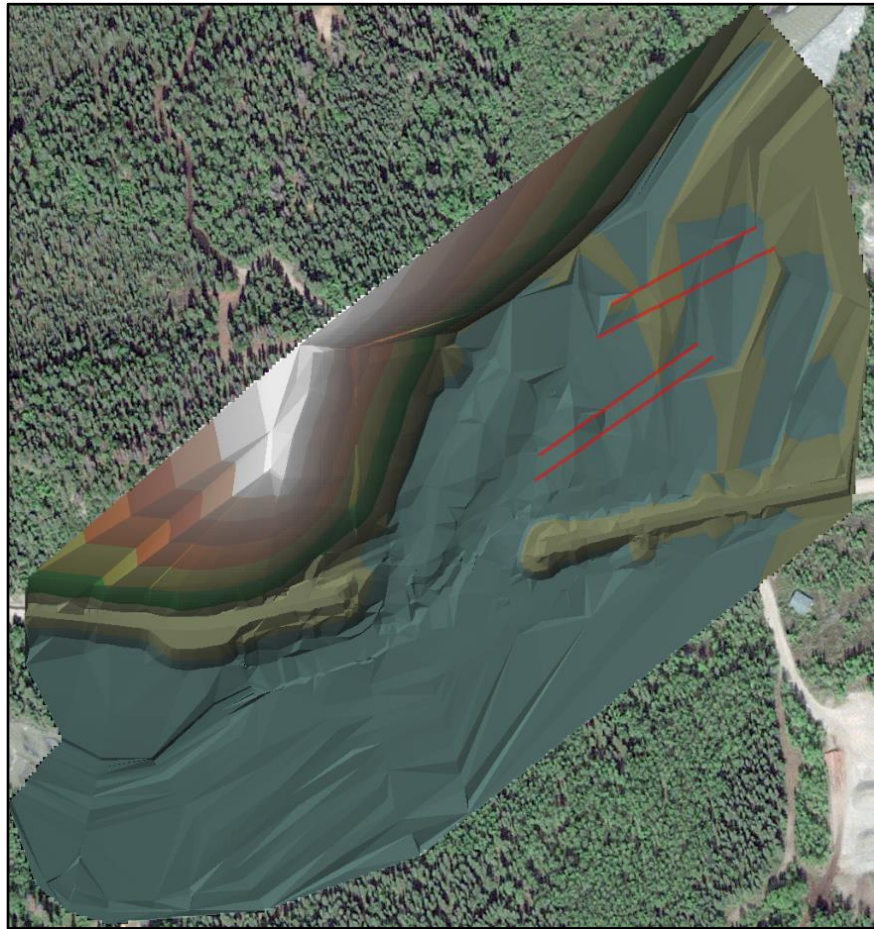


Figure 7: Lakina River raster, TIN, and breaklines.

11. Conclusion

We have finished developing a terrain model in ArcMap. The terrain model is a requirement for 2D modeling, as it is used to establish the geometric and hydraulic properties of the 2D cells and cell faces. A terrain model is also needed in order to perform any inundation mapping in HEC-RAS Mapper. The terrain model can now be imported into HEC-RAS.

Modeling Exercise #2 – Background Data

Gathering Data

1. Introduction

Currently, HEC-RAS uses gridded data for terrain modeling. In the previous exercise, a terrain model was created and exported, so the gridded data can be read in by HEC-RAS.

Launch HEC-RAS 5.0.3 from the desktop icon, start menu, or from file browser. HEC-RAS will open the “main window” menu bar (Figure 8).

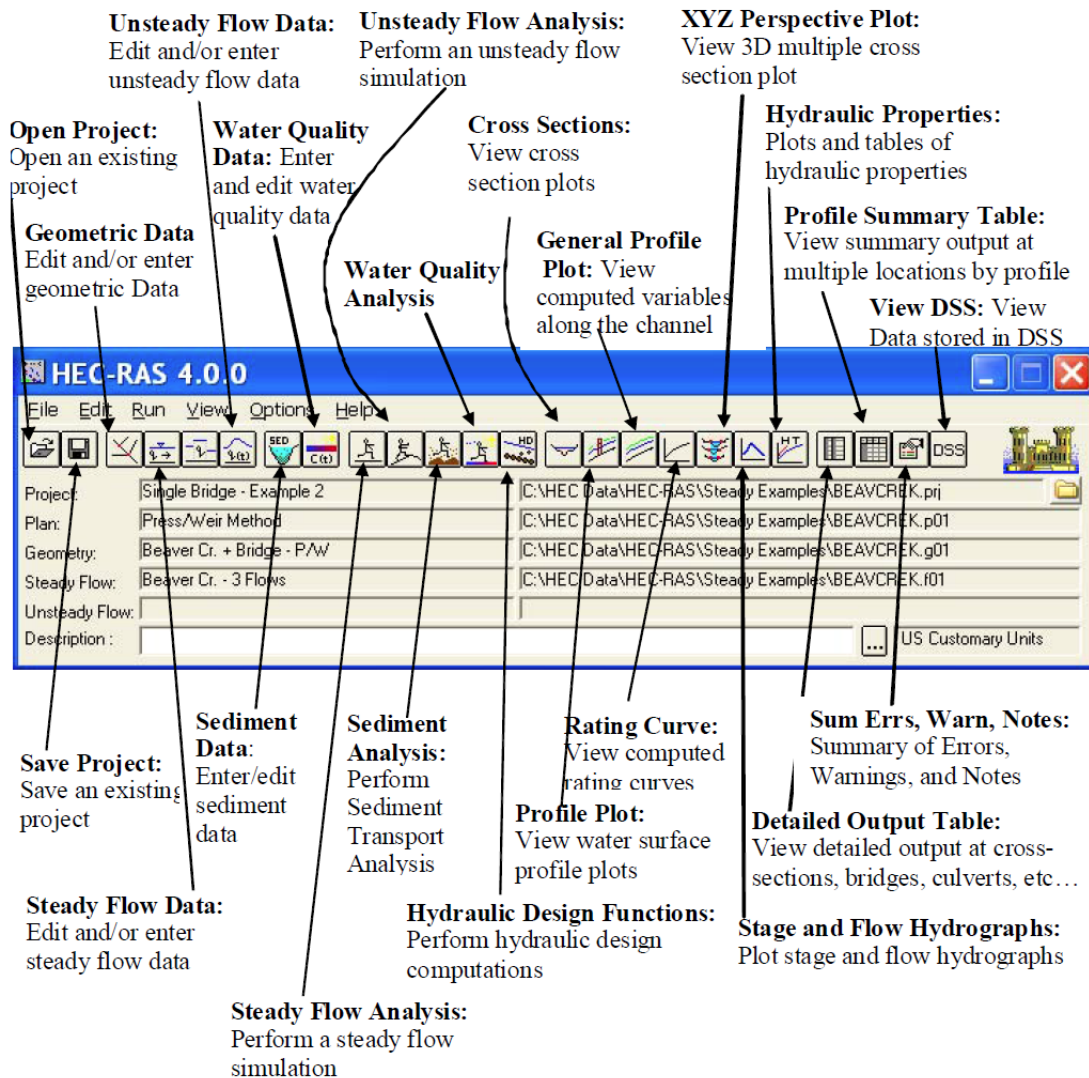


Figure 8: HEC-RAS main window. Image from HEC-RAS_4.1_Users_Manual.

Save the project:

- Select *File | Save Project As...*

- In the *Save Project As* dialog, navigate to where you want to save the file and enter a name of “LakinaRiver” and OK.
- In the HEC-RAS Main Window, the *Project* should have populated with *LakinaRiver*.

2. Setting the Spatial Reference Projection

The data specific spatial coordinate projection can be set using the RAS Mapper dialog.

- To open RAS Mapper, press the *RAS Mapper* button  on the HEC-RAS Main Window.

To set the spatial reference system for the project:

- Select the *Tools / Set Projection for Project* menu item from the RAS Mapper menu bar. When the Set Projection option is selected, a dialog window will appear.

To set the spatial reference system (coordinate system), we need to browse and select an existing “.prj” file (ESRI projection file) that contains the correct coordinate system. If ArcGIS is installed on the computer, the user can browse to the ArcGIS directory that contains a listing of all the available coordinate systems and select the appropriate one.

For this Lakina River example, the ArcGIS projection file (*.prj) has been saved in the *Workshop\ESRI projection file* folder.

- Navigate to the *Workshop\ESRI projection file* folder and select:
 - NAD_1983_2011_StatePlane_Alaska_2_FIPS_5002_Feet


3. Loading the Terrain Model

The next step is to load the terrain model that was created in Exercise #1.

- In RAS Mapper, select the *Tools | New Terrain...*

At this time, RAS Mapper can import terrain data that is in the floating point grid format (*.flt); GeoTIFF (*.tif) format...

- Use the Plus (+) button to get a file chooser, then select the *lakinaraster1.tif* terrain layer from the *Workshop\HEC-RAS Modeling Exercises\Exercise 2 - Background Data* folder. Click Open.

- Press the *Create* button to create the new Terrain Layer. Once the *Create* button is pressed, RAS Mapper will convert the grids into the GeoTIFF (*.tif) file format. Close the *Creating Terrain* dialog when the *Terrain Complete* appears.
 - Select *Terrains* to turn in on and R-click on *Terrain | Zoom to layer* (Figure 9).
- *Save Project*  in the HEC-RAS Main Window.

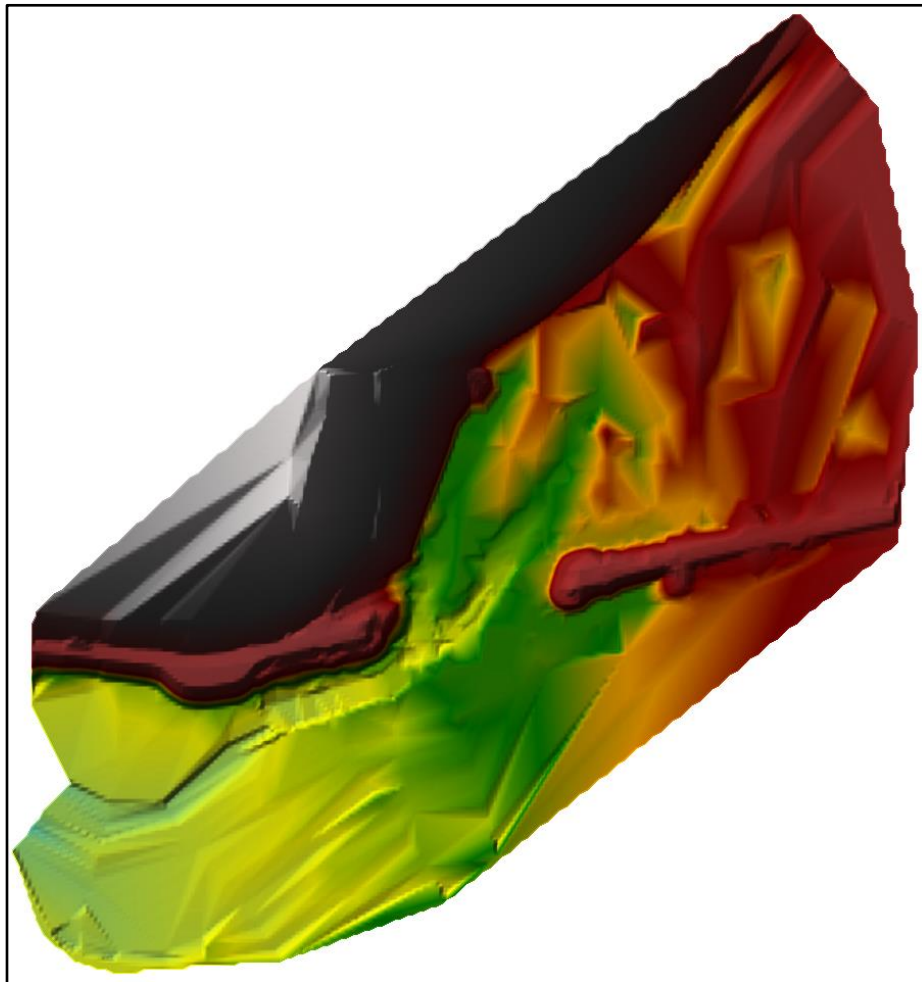


Figure 9: Lakina terrain layer in RAS Mapper.

Once the terrain model is created, the user can enhance the look of the terrain data by R-clicking on the terrain layer and selecting *Layer Properties*. The *Layer Properties* window (Figure 10) allows the user to select and control the Surface Color Ramp; Transparency; Create and plot Contour Lines; and shade the terrain using a Hill Shading algorithm (Hill Shading makes the visualization of the terrain much more realistic and semi 3D).

Note: After a Terrain dataset is created, the user will be able to display this terrain layer as a background image in the HEC-RAS geometry editor. Terrain layers and any other Map Layers developed in RAS Mapper are available for display in the HEC-RAS Geometry editor.

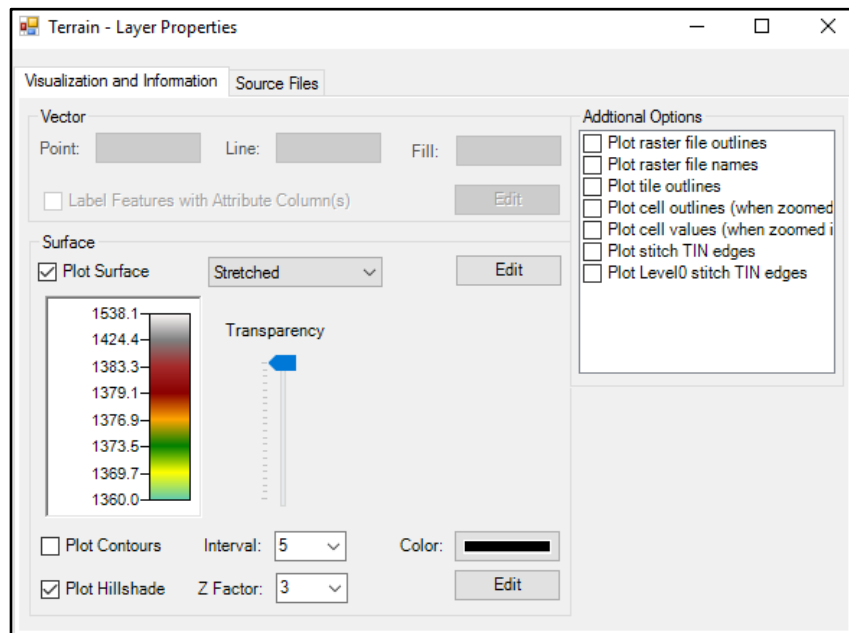



Figure 10: Layer properties window for the terrain data layer.

4. Background Image

The next step is to load the Lakina River aerial:

- In RAS Mapper, select the *Tools | Add Map Layer*
 - Change file type to “images” in the drop-down menu in the bottom right-hand corner
 - Navigate to *Workshop\DOT Images\Lakina River\Lakina_13 World* and select *Lakina_13*. Click *Open*.
 - RAS Mapper will automatically use the created World File.
- R-click the *Lakina_13* image in the TOC | *Image Display Properties*
 - In the pop-up window, make the transparency ~50%. Click *OK*.

The background image and terrain layer should both be visible.

- Close RAS Mapper.
- *Save Project*  in the HEC-RAS Main Window.

5. Conclusion

The background data, including the ArcMap Terrain Model and aerial image have been read into HEC-RAS. It is now time to develop the 2D model.


Modeling Exercise #3 – Development of a 2D Model

Development of the 2D Computational Mesh

1. Introduction

The HEC-RAS 2D modeling software capability uses a Finite-Volume solution scheme. This algorithm was developed to allow for the use of a structured or unstructured computational mesh. This means that the computational mesh can be a mixture of 3-sided, 4-sided, 5-sided, etc., computational cells (HEC-RAS has a maximum of 8 sides in a computational cell). However, the user will most likely select a nominal grid resolution to use (e.g., 200 x 200 ft cells), and the automated tools within HEC-RAS will build the computational mesh. After the initial mesh is built, the user can refine the grid with breaklines and the mesh editing tools. A 2D computational mesh is developed in HEC-RAS by doing the following sets.

To ensure consistency, read in a set of completed files from the end of Exercise #2.


- Open HEC-RAS and select Open 
- Navigate to “Workshop\HEC RAS Modeling Exercises\Exercise 2 - Background Data” directory
- Select the file named “LakinaRiver.” It should populate the *Title*. Click OK.

2. Drawing a Polygon Bounder for the 2D Area




The user must add a 2D flow area polygon to represent the boundary of the 2D area using the 2D flow area drawing tool in the Geometric Data editor (just as the user would create a Storage Area).

- Open the Geometric Data editor by clicking  in the HEC-RAS Main Window.

Use the background mapping button  on the HEC-RAS Geometry editor to turn on the terrain and other Map Layers if they existed, in order to visualize where the boundary of the 2D flow area should be drawn.

- Select *Lakina_13* Select *Plot Terrain*, click Close.
- If the Terrain layer is not visible, you will need to go to the Geometry editor’s *View* menu, then select *Set Schematic Plot Extents*. From this window, select the option called *Set to Computed Extents*. This option will reset the extents of the geometric data editor view window to the extents of the terrain model you created and associated to the geometry data.
- *File | Save Geometry As*

- In the *Save Geometry Data As* dialog, enter a *Title* of “LakinaGeo” and click OK.
- In the HEC-RAS Main Window, the *Geometry* should have populated with *LakinaGeo*.

To create the 2D flow area, use the 2D Flow Area tool  located along the top of the Geometry editor.

- To draw the boundary of the 2D flow area, begin by L-clicking to drop a point along the 2D flow area polygon boundary. Then continue to use the left mouse button to drop points in the 2D flow area boundary. As you run out of screen real estate, R-click to re-center the screen. This will give you more area to continue drawing the 2D flow area boundary. Double-click the left mouse button to finish creating the polygon (Figure 11).




Figure 11: Example 2D flow area polygon.

- Once the 2D area polygon is finished, the interface will ask the user for a Name to identify the 2D flow area. For this example, enter “2D Interior Area.”

Note: A 2D flow area must be drawn within the limits of the terrain model area being used for the study.

- R-click on the 2D flow area and select *View Options* to open the *Geometry Plot Options*.

- Un-select *Fill in Storage Area/2D Flow Areas*. Close the options window.
- *Save Project*  in the HEC-RAS Main Window.

3. Adding Breaklines Inside of the 2D Flow Area

Before the computational mesh is created, the user may want to add breaklines to enforce the mesh generation tools to align the computational cell faces along the breaklines. Breaklines can also be added after the main computational mesh is formed, and the mesh can be regenerated just around that breakline. In general, breaklines should be added to any location that is a barrier to flow, or controls flow/direction.

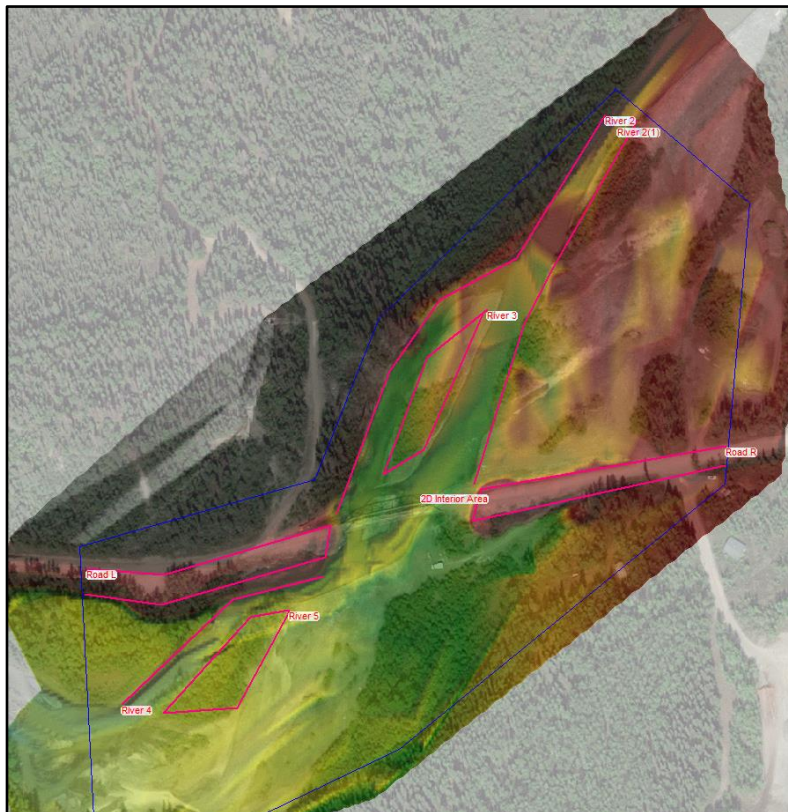




Figure 12: Example of breaklines.

To add breaklines by hand into a 2D flow area, select the 2D Area Breakline tool .

- L-click on the geometry window to start a breakline and to add additional points. Double-click to end a breakline. While drawing a breakline, you can R-click to re-center the screen in order to have more area for drawing the breakline.

- Once a breakline is drawn, the software will ask you to enter a name for the breakline. Enter whatever name you want.
- Quickly add breaklines along the roads, and any river channel you want to align the mesh faces along. Breaklines can also be placed along the main channel banks in order to keep flow in the channel until it gets high enough to overtop any high-ground berm along the main channel. An example of using breaklines within a 2D flow area is shown in Figure 12. Your breaklines do not have to match the image.
- *Save Project*  in the HEC-RAS Main Window.

After all the breaklines have been added, the computational mesh can be generated. Keep in mind the user can also add additional breaklines after the mesh has been generated, and the computational mesh can be refined around an individual breakline at any time.

4. Creating a Spatially Varied Manning's Roughness Layer

Since we already created a Manning's n coverage in the SMS, we are going to steal it and import it into HEC-RAS.

The SMS-derived Lakina River Material shapefile can be found in the *Workshop\HEC RAS Modeling Exercises\Exercise 3 – Mesh* folder. The shapefile has already been exported from SMS for this exercise, but if you wanted to do it yourself, the steps are below:

- In SMS | Click to highlight the *Materials* coverage in the *Project Explorer* | *File* | *Save As*.
 - Change the *Save As* type to *Shapefiles (*.shp)* in the drop-down menu.
 - Click *Save*
 - Select *Feature Polygons* | *Polygon Shapefile*

Open RAS mapper to read in the Lakina River Material shapefile

- Select *Tools* | *New Land Cover*
 - Click the “+” symbol and Navigate to the *Workshop\HEC RAS Modeling Exercises\Exercise 3 – Mesh* folder and select *LakinaLandUse_withN_values.shp* | *Open*.
 - Verify the following Manning's n values are entered:
 - Channel: 0.035
 - Road: 0.015
 - Trees 0.1

- Create!!!
- When the “Land Cover layer complete!” appears, close out of the dialog (Figure 13).






Figure 13: Land cover.

- To change Land Cover colors, R-click *LandCover* | *Image Display Properties*.
- Change to your desire.

Once you have created a Land Cover layer in the *.tif file format, you need to associate that data layer with the geometry file(s) you want to use it with.

- To associate the *Land Cover* layer, R-click on Geometries (on the top left-hand side of the RAS Mapper window) and select *Manage Geometry Associations*.
- Make sure that *Terrain* is Terrain, and *Land Cover* is Land Cover.

Once a Land Cover layer is associated with a geometry file, the user can then build a table of Land Cover versus Manning’s *n* values, which can then be used in defining roughness values for 2D flow areas.

- Open the Geometric Data editor by clicking  in the HEC-RAS Main Window.
- Use the background mapping button  on the HEC-RAS Geometry editor to turn on the *Land Cover*. Select *Land Cover*, then click *Close*.
- Click *Tables | Manning's n by Land Cover* (very bottom).
- Because we imported the Manning's *n* coverage, the Default values are already set for us. Click OK to exit.
- *Save Project*  in the HEC-RAS Main Window.

5. Creating the 2D Computation Mesh

The HEC-RAS terminology for describing the computational mesh for 2D modeling begins with the 2D flow area. The 2D flow area defines the boundary for which 2D computations will occur. A computational mesh (or computational grid) is created within the 2D flow area. Each cell within the computational mesh has the following three properties (

Figure 14):

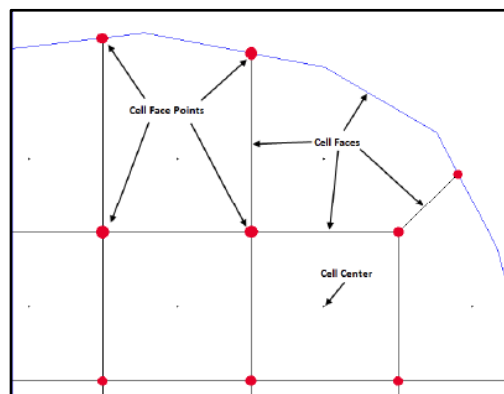



Figure 14: HEC-RAS 2D molding computation mesh terminology.
Image from HEC-RAS 5.0 2D Modeling User's Manual.

- **Cell Center:** The computational center of the cell. This is where the water surface elevation is computed for the cell.
- **Cell Faces:** These are the cell boundary faces. Faces are generally straight lines, but they can also be multi-point lines, such as the outer boundary of the 2D flow area.
- **Cell Face Points:** The cell face points (FP) are the ends of the cell faces. The face point (FP) numbers for the outer boundary of the 2D flow area are used to hook the 2D flow area to a 1D elements and boundary conditions.

To create a 2D flow area computational mesh, select the 2D Flow Area  editor button on the left panel of the Geometric Data editor (under the Editors set of buttons on the left) to bring up the 2D Flow Area editor window (Figure 15):

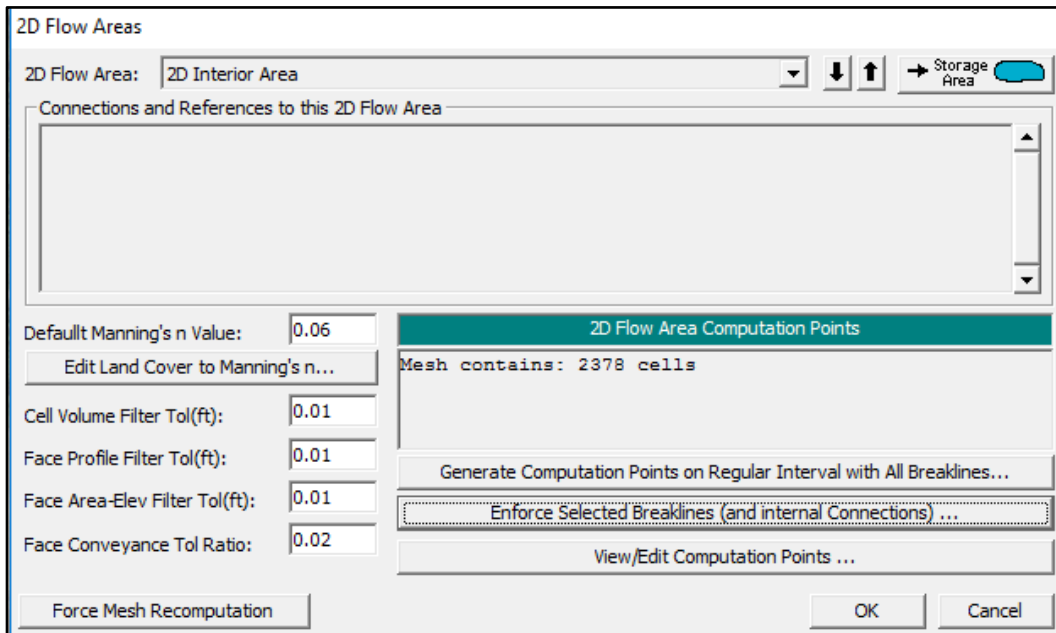


Figure 15: 2D flow area mesh generator editor.

The 2D Flow Area editor allows the user to select a nominal grid size for the initial generation of the 2D flow area computational mesh.

- To use this editor, first select the button labeled *Generate Computational points on regular Interval*. This will open a pop-up window that allows the user to enter a nominal cell size. The editor requires the user to enter a Computational Point Spacing in terms of DX and DY. Enter the following:
 - Spacing DX = 20
 - Spacing DY = 20
- This defines the spacing between the computational grid-cell centers. Click *Generate Points in 2D Flow Area*.

Since the user can enter breaklines, the mesh generation tools will automatically try to “snap” the cell faces to the breaklines. The cells formed around breaklines may not always have cell faces that are aligned perfectly with the breaklines. An additional option available is *Enforce Selected Breaklines*. The Enforce Selected Breaklines option will create cells that are aligned with the breaklines, which helps ensure that flow cannot go across that cells face until the water surface is higher than the terrain along that breakline.

- Select *Enforce Selected Breaklines (and internal Connections)*.
 - In the pop-up dialog *Select All | OK to exit*.

Default Manning's n Value: This field is used to enter a default Manning's n values that will be used for the cell outside of the *Land Cover Classification to Manning's*.


- Make sure the *Default Manning's n value* is 0.06.
- Also, click on the *Edit Land Classification to Manning's n* to verify that the correct classifications are entered. Click OK to exit.
- Leave *Tolerances (Tol)* as default values.

Now that the nominal grid size has been entered (20 ft x 20 ft), breaklines have been selected, the base Manning's n values have been verified and tolerances have been set, the mesh can be forced.

- Select Force Mesh Recomputation | OK.

When the OK button is selected, the software automatically creates the computational mesh and displays it in the Geometric Data Editor graphics window (Figure 16).

Cells around the breaklines and the 2D flow area boundary will typically be irregular in shape, in order to conform to the user-specified breaklines and boundary polygon. The mesh generation tools utilize the irregular boundary, as well as try to ensure that no cell is smaller in area than the nominal cell size.

- *Save Project*  in the HEC-RAS Main Window.

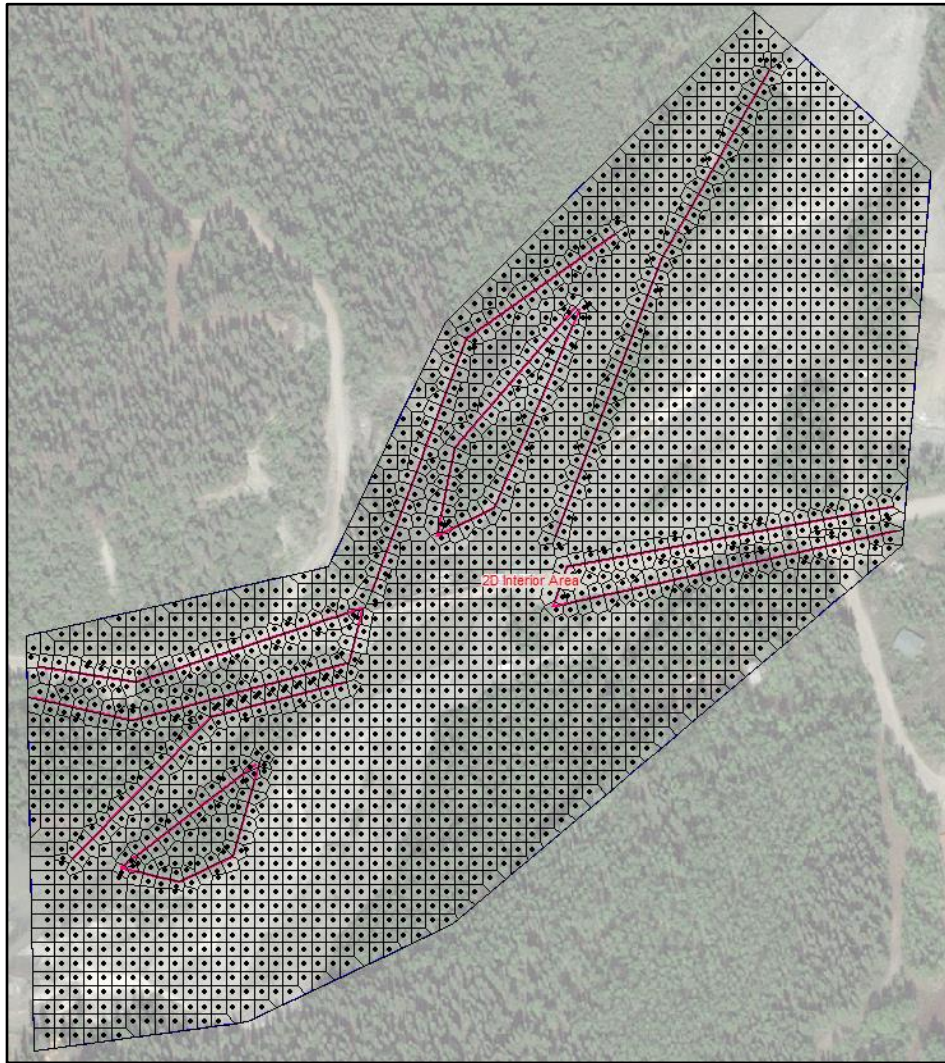


Figure 16: 2D computational mesh.

6. Potential Mesh Generation Problems

The automated mesh generation tool in HEC-RAS works well; however, nothing is perfect. On occasion a bad cell will be created due to the combination of the user-defined polygon boundary and the selected nominal cell size, or when the user is adding/modifying points inside of the polygon. After the mesh is made, the software automatically evaluates the mesh to find problem cells. If a problem cell is found, that cell's center is highlighted in a red color (Figure 17), and a red message will show up on the lower left corner of the geometric data window.

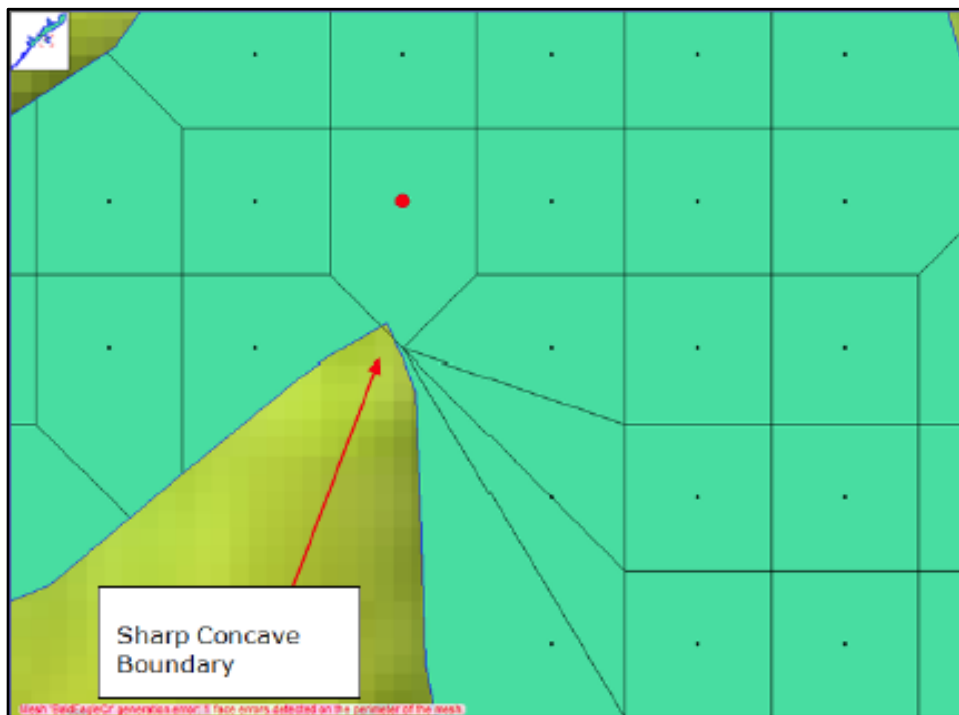



Figure 17: Example of a red cell center as a result of a sharp concave boundary. Image from HEC-RAS 5.0 2D Modeling User's Manual.

- Evaluate the Lakina River mesh to see if any problem cells (red cell centers) exist.

The HEC-RAS 2D Modeling User's Manual covers many of the reasons for why problem cells occur and how to fix the problem. Adding points is a simple hand-editing mesh manipulation tool that can fix most problems.

- Selects *Edit* then *Add Points*.
- L-click anywhere within the 2D flow area, a new cell center will be added, and the neighboring cells are changed (once the mesh is updated) (Figure 18).
- Quickly add a few new points.

The entire mesh only updates once the user has turned off the editing feature, which saves computational time in creating the new mesh.

- To turn off the editing feature, Selects *Edit* then *Add Points*.
- Close the *Geometric Data Editor* and *Save Project*  in the HEC-RAS Main Window.

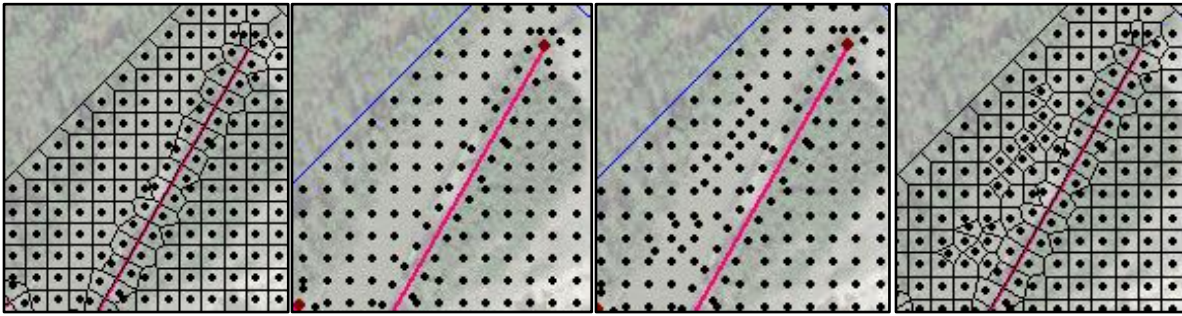


Figure 18: Example of new points being added. No points with cells, cells removed, points added, then mesh updated.

7. Running the 2D Geometric Preprocessor

This is the option to pre-process the 2D flow area computational cells and faces into detailed tables based on the underlying terrain data. Running the 2D Geometric preprocessor occurs in RAS Mapper.

- To open RAS Mapper, press the *RAS Mapper* button  on the HEC-RAS Main Window.

In the Geometry group, there will be a sub-layer called 2D flow area.

- Select *2D Flow* to turn on.
- R-click on the *2D Flow* sub-layer, then select *Compute 2D flow areas Hydraulic Tables*.
- R-click on the *2D Flow* sub-layer, then select one of the tables (i.e., Cell Volume vs. Elevation).
 - Take a minute to look at some of the tables.

8. External 2D Flow Area Boundary Conditions


Five types of external boundary conditions can be linked directly to the 2D flow areas. These boundary condition types are:

- Flow Hydrograph
- Stage Hydrograph
- Normal Depth
- Rating Curve
- Precipitation

The *Normal Depth* and *Rating Curve* boundary conditions can only be used at locations where flow will leave a 2D flow area. The flow and stage hydrograph boundary conditions can be used for putting flow into or taking flow out of a 2D flow area. For a *Flow Hydrograph*, positive flow values will send flow into a 2D flow area, and negative flow values will take flow out of a 2D area. For the *Stage Hydrograph*, stages higher than the ground/water surface in a 2D flow area will send flow in, and stages lower than the water surface in the 2D flow area will send flow out. If a cell is dry and the stage boundary condition is lower than the 2D flow area cell minimum elevation, then no flow will transfer. The Precipitation boundary condition can be applied directly to any 2D flow area as a time series of rainfall excesses.

For this example, a flow hydrograph boundary condition will be used to bring flow into the 2D area, while a normal depth boundary condition will be used for flow leaving the 2D area.

To add external boundary conditions to a 2D flow area:

- Open the *Geometry Data editor* by clicking  in the HEC-RAS Main Window.
- Select the tool (button) called SA/2D Area BC Lines.
- Draw a line along the outer boundaries of the 2D area to establish the location of the boundary condition (Figure 19).
- Start with the inflow boundary line along the top. Double-click to end the boundary condition line.
 - An interface will pop up asking you to enter a name; enter “LakinaInflow” and click OK.
- A red and black line should appear.
- Repeat this process to add an outflow boundary line along the bottom. Name it “OutFlow.”

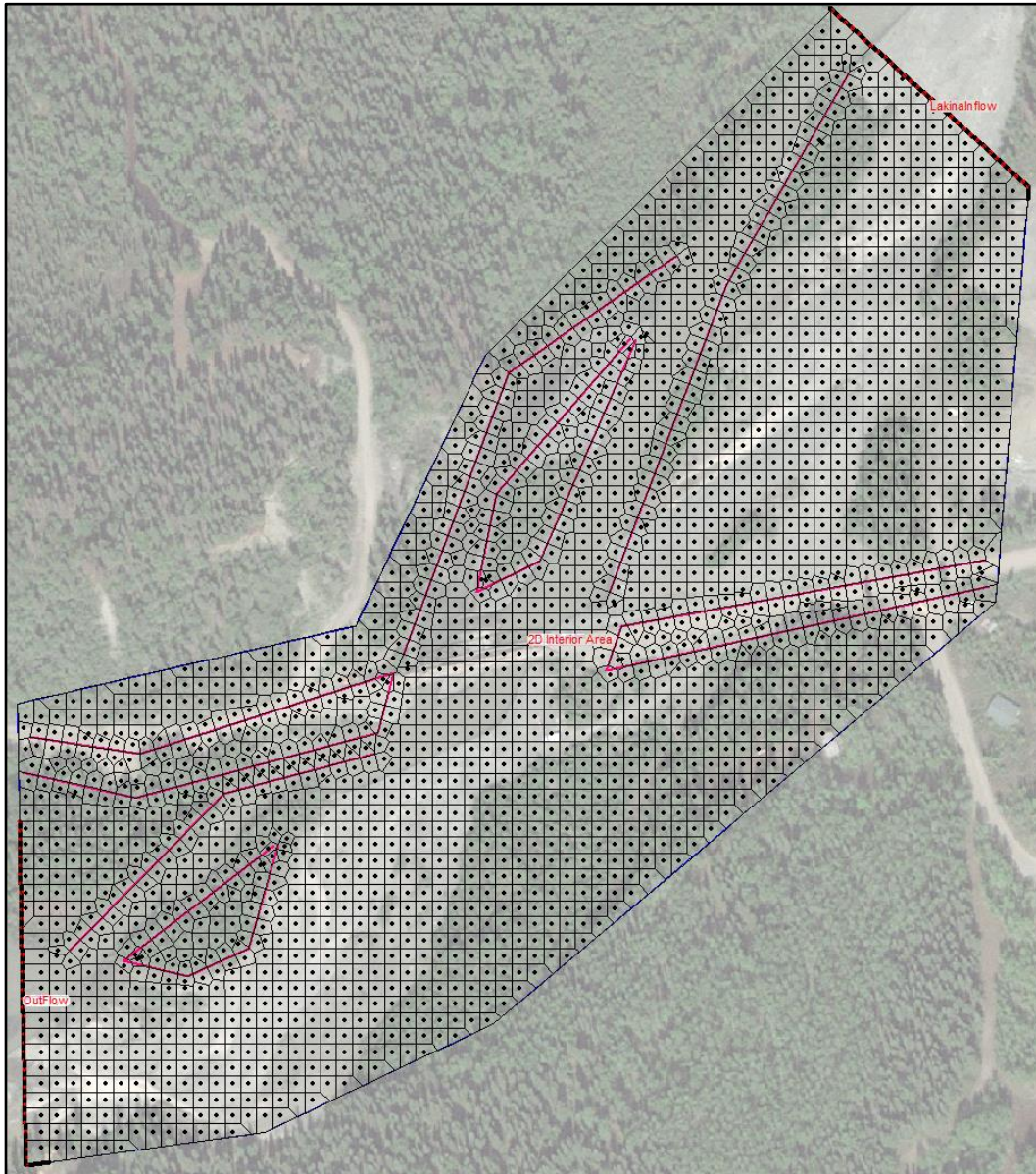



Figure 19: Inflow and outflow boundary conditions.

8.1. Unsteady Flow Data Editor

Once all of the 2D flow area boundary conditions have been identified (drawn with the SA/2D Area BC Lines tool), the boundary condition type and the boundary condition data are entered within the *Unsteady Flow Data editor*. The *Unsteady Flow Data editor* is where the user selects the type of boundary condition and enters that boundary conditions data.

- Select *View/Edit Unsteady Flow Data*  in the HEC-RAS main window to open the dialog (Figure 20A).

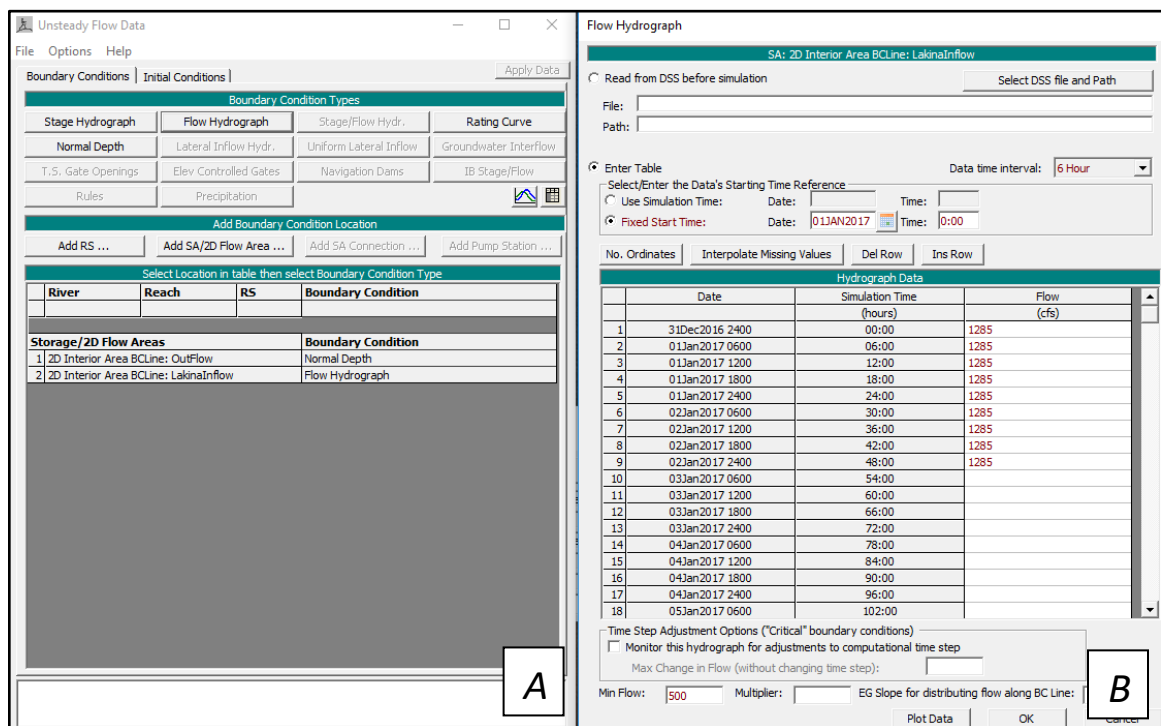



Figure 20: A) Unsteady flow data dialog. B) Flow hydrograph dialog.

Currently, none of the *Boundary Conditions Types* are activated. To activate them:

- Next to the *2D Interior Area BCLine: Outflow*, click in the blank space below *Boundary Condition*. Above, four *Boundary Conditions Types* should activate.
- For the *Outflow Boundary Conditions Type*, select *Normal Depth*. In the pop-up window, enter 0.01 for the *Friction Slope*. Click OK.
- Storage/2D Flow Area of interest ... *Boundary Condition*.
- Next to the *2D Interior Area BCLine: LakinaInflow*, click in the blank space below *Boundary Condition*.

The inflow for a 2-year flood for the Lakina River is 1285 cfs. During the next sets, a single discharge value will be used to populate a Flow Hydrograph.

- For the *Inflow Boundary Conditions Type*, select *Flow Hydrograph* (Figure 20B).
 - In the *Flow Hydrograph* dialog, select *Enter Table*.
 - Change the *Data time interval* to *6 hours* in the drop-down menu.
 - Select *Fixed Start Time*, and use the calendar to select 01JAN2016. Click OK.
 - Set the time to 0:00.
 - Enter 1285 cfs for a 48-hour period.

- Enter a *Min Flow: 0*.
 - Enter 0.01 for the *EG Slope for distributing flow along BC line*.
 - *OK* to exit.
- To save, select *File | Save Unsteady Flow Data*. Enter “LakinaUnsteady” for the *Title*. Click *OK*.
- In HEC-RAS main window, the *Unsteady Flow* should be populated with *LakinaUnsteady*.
- Close the *Unsteady Flow Data editor* and save the project  in the HEC-RAS Main Window.

Modeling Exercise #4 – Unsteady Flow Model


Unsteady Flow Simulation

1. Introduction

HEC-RAS has the ability to perform two-dimensional unsteady flow routing with either the full Saint Venant equations (with added terms for turbulence modeling and Coriolis effects) or the diffusion wave equations.


Within HEC-RAS, the diffusion wave equations are set as the default, and they are used for this exercise.

To ensure consistency, read in a set of completed files from the end of Exercise #3.

- Open HEC-RAS and select Open .
- Navigate to the “Workshop\HEC RAS Modeling Exercises\Exercise 3 - Mesh” directory.
- Select the file named “LakinaRiver.” It should populate the *Title*. Click OK.


2. Performing the Computations

To run the model, open the Unsteady Flow Analysis window:

- Select *Unsteady Flow Data*  in the HEC-RAS main window to open the dialog.
- Save the *Plan* by selecting *File | Save Plan As*. Enter “LakinaPlan” for the *Title* and click OK.
 - Enter “LakinaPlan” for the *short identifier* and click OK.
- Under *Programs to Run*, Select *Geometry Processor, Unsteady Flow Simulation, and Post Processor*.

The *Simulation Time* **MUST** be the same as the *Start Time* used in the *Unsteady Flow Data* editor.

- Using the calendar button, make the *Starting Date*: 01JAN2016 and enter a *Time*: 0:00.
- The *Ending Date* and *Time* depend on how long you want the model to run. For the exercise, set the *Ending Date*: 01JAN2016 and *Time*: 12:00.

- Set the *Computation Interval*: Between 30 and 1 seconds. For this exercise, try 1 sec.
- Set the *Hydrograph Output Interval*: 5 min.
- *Mapping Output Interval*: 1 min.
- Click Compute!!! The HEC-RAS Computations window should appear (Figure 21).
 - Hopefully, you get a **Finished Unsteady Flow Simulation**.
- Save the project  in the HEC-RAS Main Window.

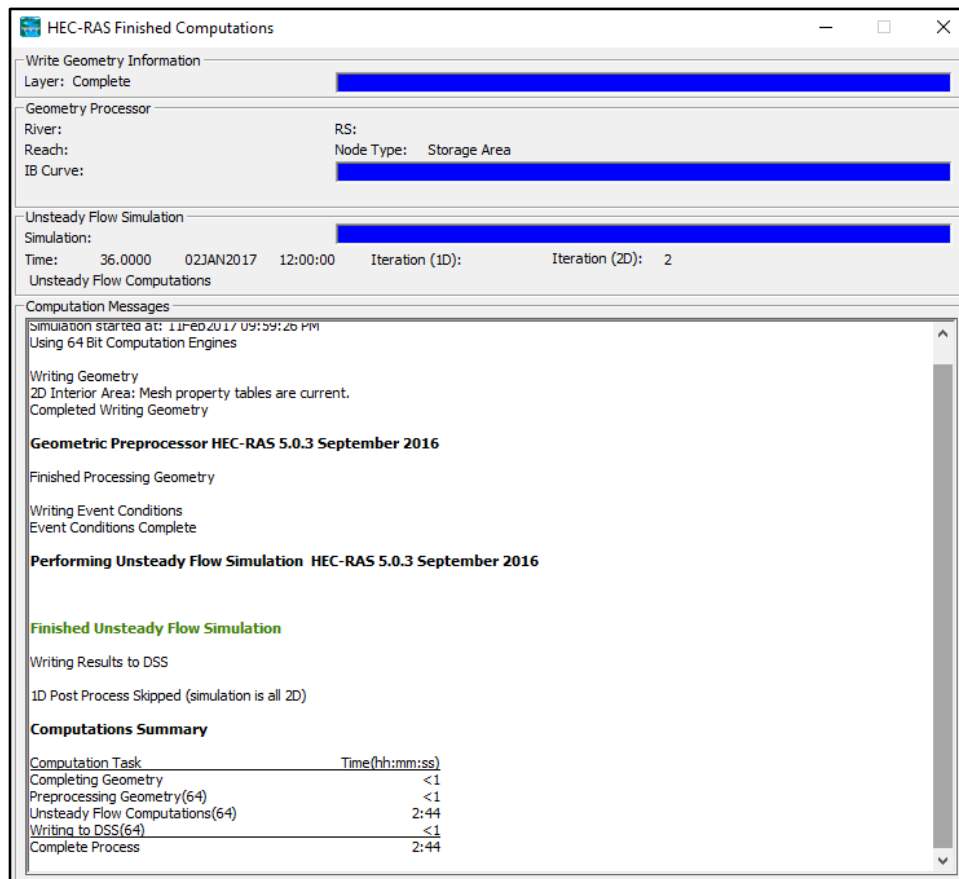


Figure 21: HEC-RAS computations window.


3. Viewing Output Using RAS Mapper

Once the user has completed an unsteady flow run of the model, the user can look at all of the 2D output results within RAS Mapper.

3.1. Animating Map Layer

Any Map Layer that is “Dynamic” can be animated in time. The animation control can be used to animate a single map layer or multiple map layers.

To animate a single map layer, turn that map layer on, then make it the active map layer (Layer will be highlighted in a magenta color). Once a layer is turned on and made the active layer, the animation control at the top of the map window can be used to animate that layer in time. The animation control has a play button, as well as Max and Min options.

- In RAS Mapper, turn on the *Results* in the TOC and select *Depth*. Then activate the depth layer by clicking on the *Depth*.
- Turn off the *Land Cover* and the *Geometries*.
- Above the map window, in the upper right-hand corner click the “>” next to the green play *Animation* button . Simulated water depth should emerge from the inflow boundary condition.
 - Click the “>” several times. Notice that the time shows below changes by 1:00 with every click (Figure 22).

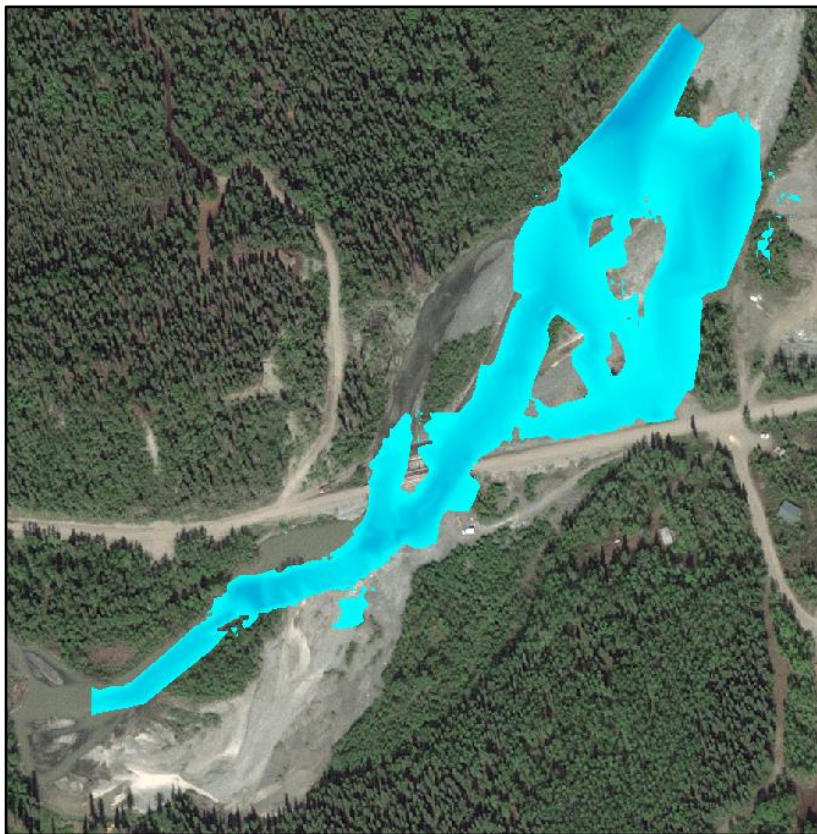




Figure 22: RAS Mapper with the *Depth* results displayed.

- Click the *Min* button to bring the simulation back to the beginning.
- Click the green play button  to watch a time lapse of the simulation. You can press the pause button at any time to stop the time lapse.

3.2. Plotting Velocity

RAS Mapper now has the ability to plot velocities spatially for 2D flow areas. Velocity is plotted with a color palette reflecting the magnitude of the velocity. Users can change the color palette, as well as the magnitude range for plotting the colors. Velocity vectors, which reflect the direction and magnitude of the velocity, can be added to the plot. Additionally, there is an option to turn on a particle tracing visualization, which allows for much greater understanding of the velocity flow field, in both magnitude and direction.

- Turn on the Velocity output layer and turn Depth off. Then activate the velocity layer by clicking on it.
- Click Min then select the green play *Animation* button  (Figure 23).

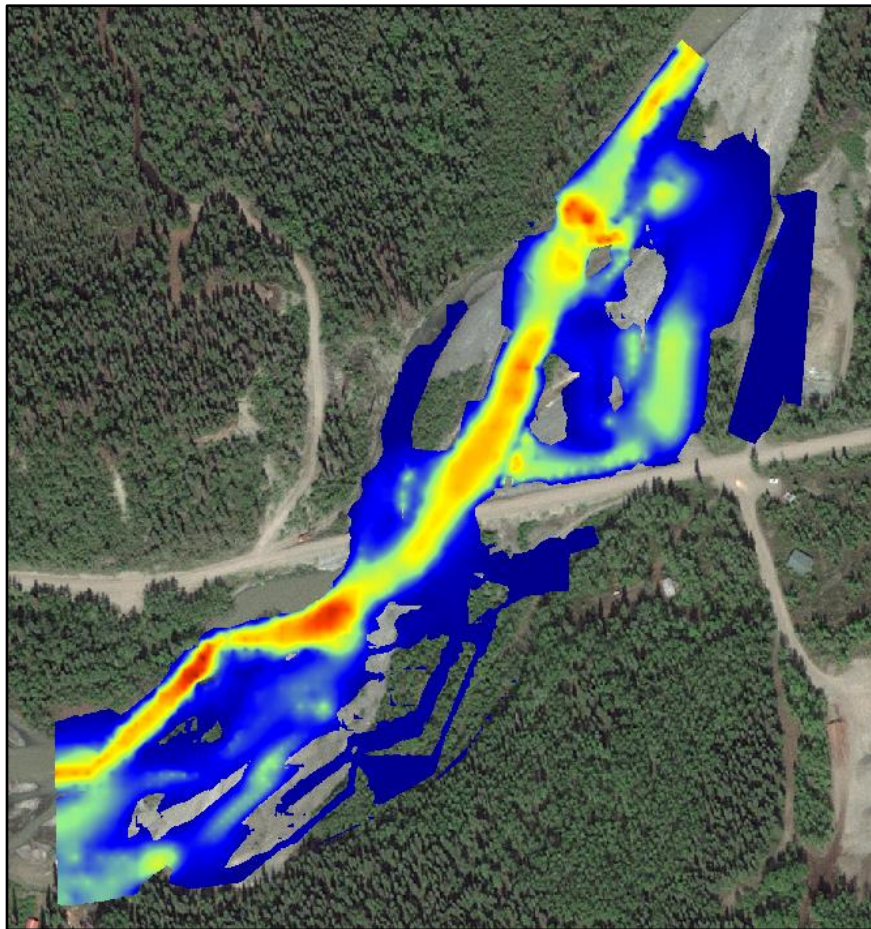




Figure 23: Color-based velocity plot.


In addition to color velocity plotting, RAS Mapper has the option to add velocity vectors and show particle traces on top of the map layers.

- To add velocity vectors, press the  *Static Velocity Arrows* button above the map window. This will turn on the velocity directions and magnitude arrows.
- To control the density of the arrows, select the *Velocity Setting*  button above the map window.

The *Velocity Map Parameters* settings window allows the user to control the spacing between arrows by selecting Spacing (pixel width for the spacing between arrows). When the arrows are turned on, they are displayed in the direction of the velocity. The magnitude of the velocity is reflected in the size of the arrows (i.e., larger arrows equate to higher velocity).

- Take a minute to become familiar with the parameters.

Another option for velocity plotting is the option called Particle Tracing. When this option is turned on, the user will see what appears to be particles of water moving through the flow field. This is a visualization of water particle movement to improve understanding of the velocity and the direction of the flow.

- To turn this option on, press the Particle Tracing  button.

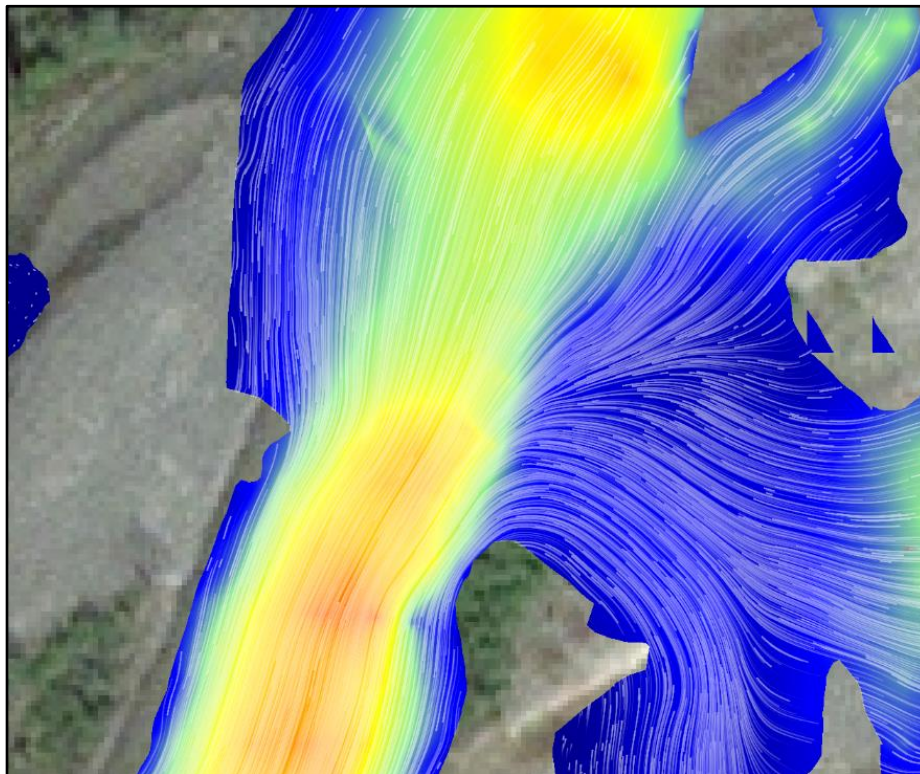


Figure 24: Particle tracing visualization option.

Once this option is turned on, from the *Velocity Map Parameters* window the user can change the parameters that control the particle tracing visualization. These parameters are:

- *Speed* (speed that the particles move. The speed is a relative speed; it is not the actual speed of the particles).

- *Density* (density of the particles).
- *Width* (how thick they appear).
- *Lifetime* (how long a particle trace will last).
- *Anti-Aliasing* (Yes, provides smoother lines for the particle traces, but takes more computer power).

4. Creating Static (Stored) Maps

The user can create a static map (map stored to the disk) at any time from RAS Mapper by selecting the *Tools | Manage Results Map* menu item. When this option is selected, the window shown in (Figure 25) will appear.

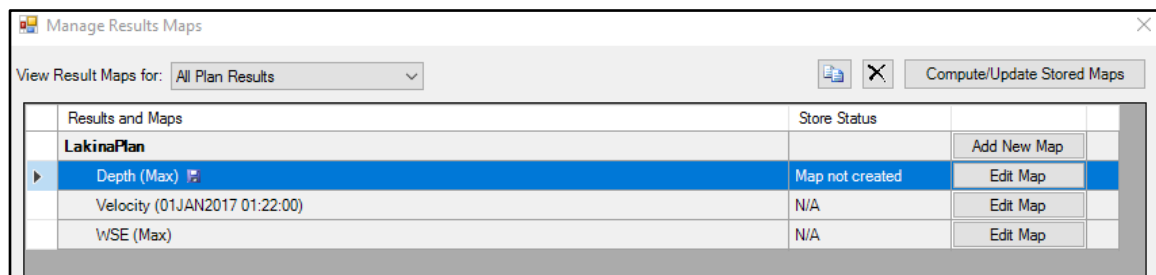


Figure 25: Results mapping window.

This editor will allow the user to create new map layers (Add New Map), as well as generate stored maps to a file (which can be used with HEC-FIA, or in a GIS).

- To create the stored map, first highlight the layer (i.e., *Depth*) to be created, then press the button labeled *Edit Map*.

A *Results Map Parameters* will appear (Figure 26).

- Select the time of interest. For this example, choose *Max*.
- Under the *Stored (Saved to disk)* options, select *Raster based on Terrain*.
 - *Save Map*
- To create the stored map, highlight the layer *Depth* to be created; then press the button labeled *Compute/Update Stored Maps* in the upper right corner.

This will start the process of creating/updating stored maps for the stored map layers. When this process is complete, there will be a subdirectory within the project directory that is labeled the same name as the RAS Plan Short ID. This folder will contain the results in a gridded file format.

The user can now import the file into GIS.

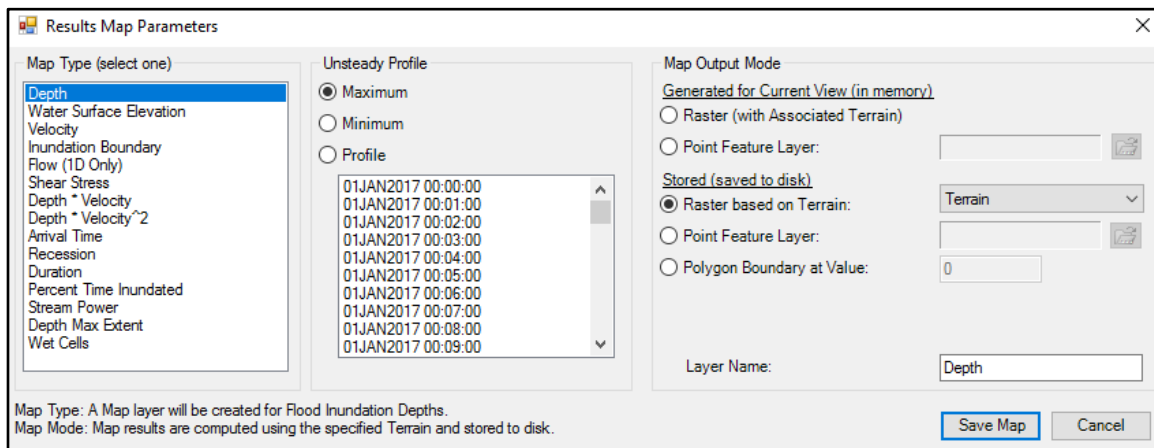


Figure 26: Results map parameters.

5. Time Series Output Plots and Tables

When Results Layer(s) are turned on for display, the user can also get time series plots and tables for those results layers.

- For example, if the *velocity* results map layer is turned on, R-click on the map window over that layer and an option for *Time Series Plots* will appear.
- Select *Velocity* and a plot will pop up.
 - Because our model has a constant discharge of 1258 cfs, it will reach a steady-state velocity and have a flat profile after an initial jump.

6. Conclusion

This workshop provided a basic introduction to setting up and running a HEC-RAS simulation. There are many ways to view the results, but they need to be saved and imported into another program to save them as an image.

