Hydraulic Analysis – Yankton County, SD

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APPROVALS

This document requires the approval of the following persons:

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CLIENT DISTRIBUTION

Name	Title/Organization	Location

Table of Contents

Figures..... page

Tables .... page

01 Introduction

1.1 Purpose and Scope of Study

As part of the FY2017 FEMA Region VIII Task Order, this study is being performed to upgrade existing two-dimensional (2D) Base Level Engineering (BLE) models for selected flooding sources to establish Zone AE Special Flood Hazard Areas (SFHAs). The original 2D BLE models were developed in 2016 for 27 Eastern South Dakota Counties. Based on feedback during the discovery and community outreach process, specific reaches were defined for upgrade to a Zone AE product through enhancements to the original BLE models. The primary purpose of this study is to

- Establish water surface elevations for the 10-, 4-, 2-, 1-, 1-percent minus, 1-percent plus, and 0.2-percent annual exceedance probability flood events;
- Establish the 1-, and 0.2-percent annual exceedance probability floodplain and floodway boundaries.

This report details the enhancement process and results for 6 scoped reaches within Yankton County, South Dakota. The organization of the report is as follows:

- 1 Introduction
  - Purpose and Scope of Study
- 2 Study Background
  - Study Area
  - Terrain
  - BLE Enhancement Process
  - Initial BLE Assessment
  - Survey
- 3 Model Development
  - Geometry and Model Layout
  - Boundary Conditions
  - Hydrology
  - Manning's Roughness Coefficients
  - Breaklines
  - Hydraulic Structures
  - Computational Parameters
  - Results Verification
  - Model Challenges
  - Floodway Development
- 4 Study Results
  - Floodplain Boundary
  - Floodway

02 Study Background

2.1 Study Area

Yankton County is located in southeast South Dakota within the James River basin. Six reaches were identified within Yankton County for enhancement to Zone AE products using 2D methodologies. Details of each reach are provided in Table 1 and the locations within Yankton County are shown in Figure 1-Figure 4

Table 1: 2D Enhanced Flood Sources within Yankton County

Flooding Source	Downstream Limit	Upstream Limit	Length (mi)	Floodway (Y/N)	Zone shown on FIRM	Date of Analysis	Modeling Method
Unnamed Stream/Ditch in Y1	Just downstream of 437th St.	Starting southwest of 436 Ave. and 306 St	2.05	N	AE	2017	HEC-RAS 2D
Hillcrest Golf Course Stream in Y2	Bill Baggs Rd and Highway 50	Highway 81	3.62	N	AE	2017	HEC-RAS 2D
Marne Creek in Y3	Missouri River	W 23st St.	2.96	Y	AE	2017	HEC-RAS 2D
Marne Creek in Y4	Just downstream of W 23rd St	Highway 50	2.1	Y	AE	2017	HEC-RAS 2D
Unnamed Stream/Ditch in Y5	Just downstream of W 25th St	W 39th St.	1.4	N	AE	2017	HEC-RAS 2D
Unnamed Stream/Ditch in Y6	Mission Hill City Limit	Mission Hill City Limit	0.91	Y	AE	2017	HEC-RAS 2D
Unnamed Creek in Irene (T1)	Irene City Limit	Irene City Limit	0.67	Y	AE	2018	HEC-RAS 2D

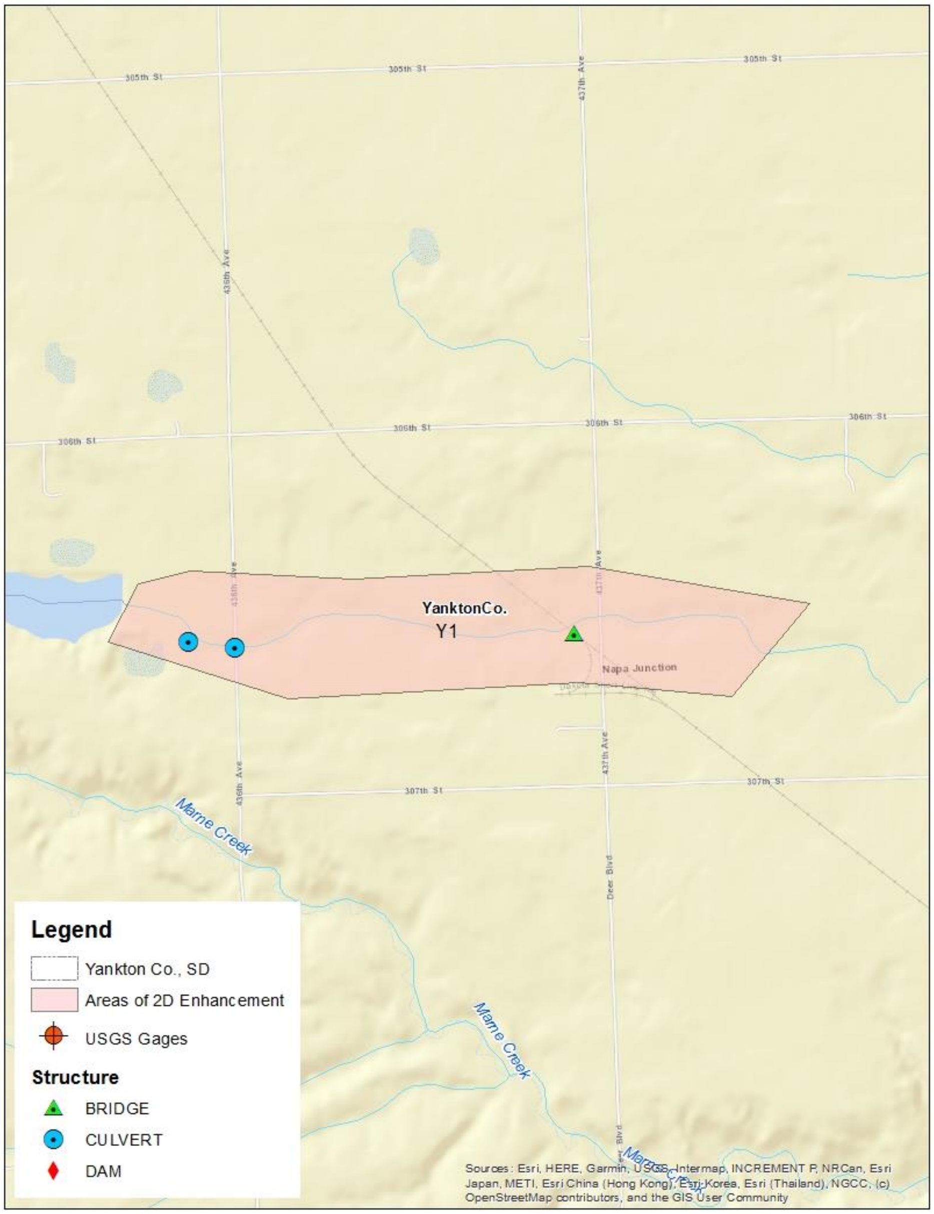

Figure 1: Enhancement Study Area – Unnamed Stream/Ditch in Y1

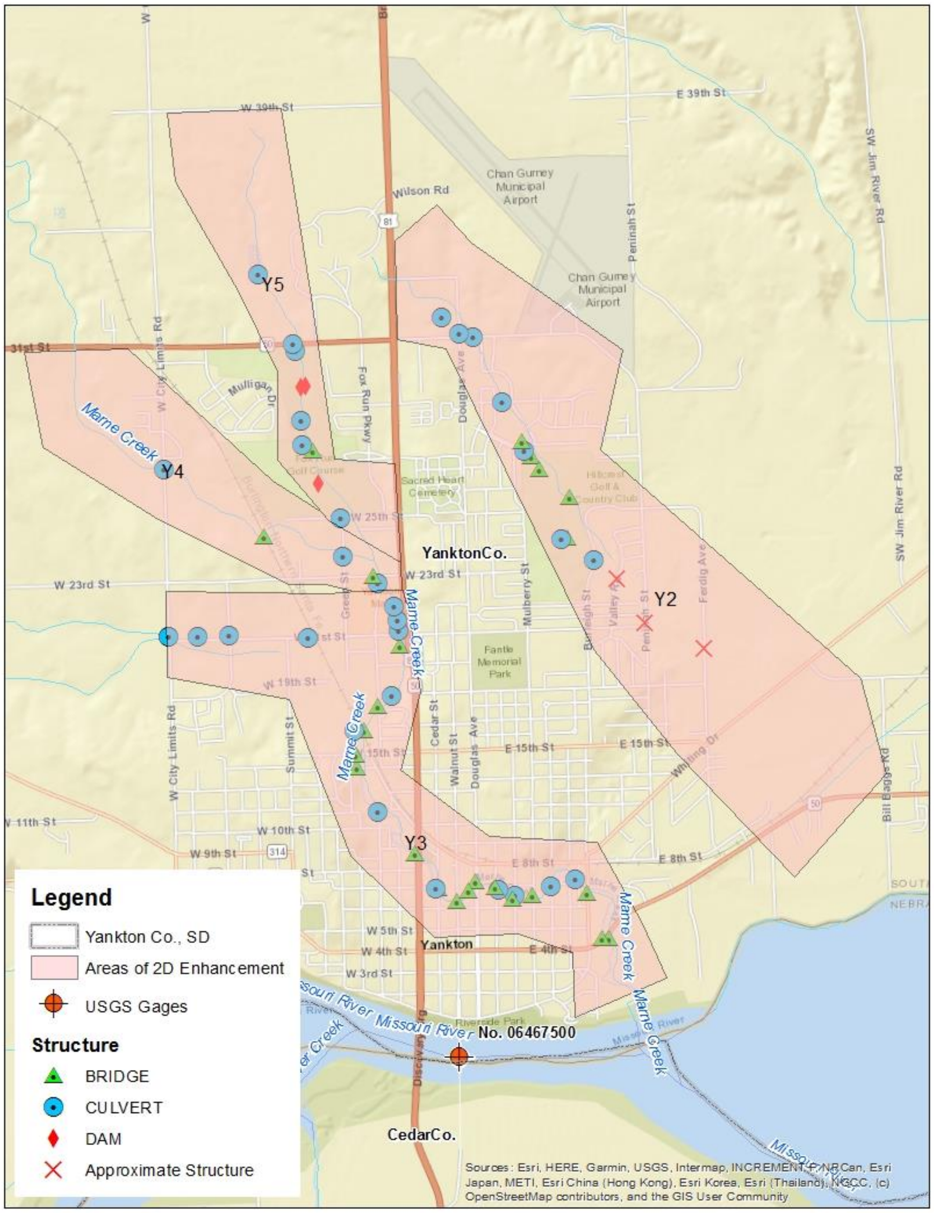

Figure 2: Enhancement Study Area – Marne Creek & Hillcrest Golf Course Stream (Y2-Y5)

Figure 3: Enhancement Study Area – Unnamed Stream/Ditch in Mission Hill, SD (Y6)

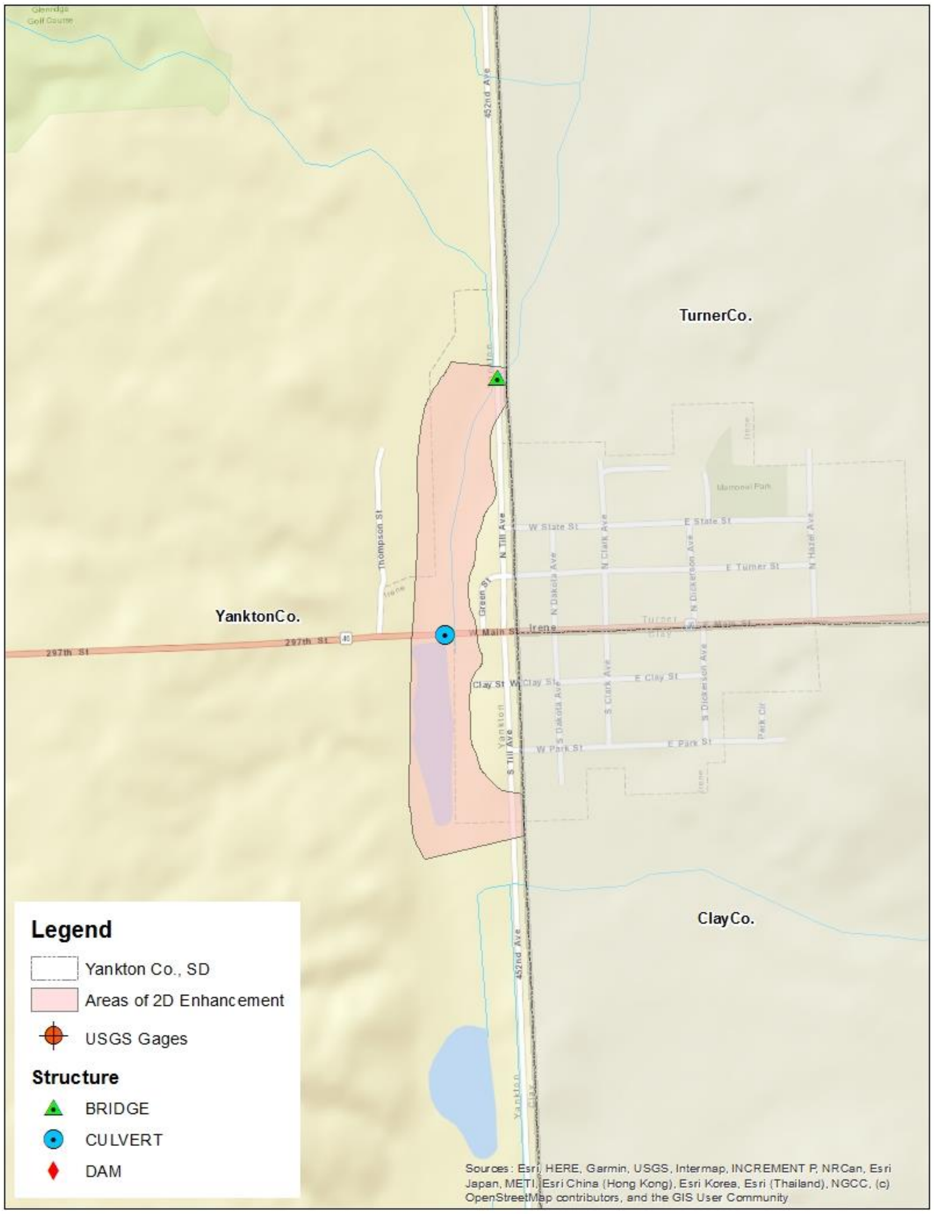

Figure 4: Enhancement Study Area – Unnamed Creek in Irene, SD

2.1.1 Principal Flood Problems

Per the Effective (07/06/2010) Flood Insurance Study (FIS) Report for Yankton County: A portion of Mission Hill is subject to flooding from the Unnamed Stream. The stream is intermittent, only having water when it rains or during snowmelt. The most recent flood was on May 22, 1966. During that flood, nine homes in Mission Hill sustained severe damages to the structures and contents.

A portion of Yankton is subject to flooding from Marne Creek, Marne Creek North, and Marne Creek Tributary. Flooding in the Marne Creek watershed is generally caused by intense thunderstorms that occur in the basin. The flood of record on Marne Creek occurred on June 16, 1957, with a discharge of approximately 4,400 cubic feet per second (cfs), which is greater than the 1%-annual-chance event. The stream is not gaged but the USGS estimated this flood to have a discharge of 4,450 cfs at Yankton.

The James River originates in Wells County of central North Dakota and meanders widely in a south-southeasterly direction across South Dakota until it joins the Missouri River approximately 5 miles below the City of Yankton. The James River is the longest prairie stream within the Missouri River drainage, and 474 of its total miles are in South Dakota. The James River has the flattest gradient of any river its length in North America, dropping only about 135 feet across its entire path through South Dakota. The upper James River in South Dakota even flows through areas in which no channel is well-defined, resulting in reverse flow due to tributaries with drastically higher bed slopes. The Yankton County area has better drainage, however, as the James River valley is incised into glacial drift and bluffs extend up to 200 feet above the channel.

Early spring snowmelt causes the majority of floods in the James River basin though rainfall has caused significant flooding as well, primarily in the downstream area which includes Yankton County. Major floods occurred along the James River in 1881, 1888, 1897, 1920, 1922, 1942, 1943, 1950, 1952, 1962, 1969, 1984, 1986, 1993 through 1997, and 2001. The lower basin also has several smaller tributaries patterned for quick concentration of runoff, which cumulatively exacerbate flood events. Another issue in Yankton County specifically is bank collapse and high velocities causing bank failures and scour. Flood hydrographs of the James River, except for a few miles below the mouths of major tributaries, are characterized by slow rises, long flat peaks, and extremely prolonged recession periods, sometimes resulting in flood durations of more than a month.

Flooding caused by the Missouri River has been limited by the building of Gavins Point Dam. Flooding is caused by the release of water from the dam due to the low lying areas of Yankton along the Missouri River flood plain.

2.1.2 Previous Studies

Table 2 provides a summary of previous studies leveraged for the reaches enhanced by 2D methods

Table 2: Summary of Previous Studies Leverage

Previous Study	Contractor	Date Completed	Effected Reaches
James River Feasibility Study/Environmental Impact Statement South Dakota	U.S. Army Corps of Engineers – Omaha District Northwestern Division	September 2008	James River

Previous Study	Contractor	Date Completed	Effected Reaches
Yankton FIS Report	Henningson, Durham & Richardson (HDR, Inc.)	September 2010	Y3, Y4, Y6
Eastern South Dakota 2D BLE	Compass PTS JV	January 2017	Y1-Y6, T1

2.2 Terrain

The primary source elevation data for Yankton County are DEMs derived from the 2012 Eastern South Dakota LiDAR collection. Only points classified as "ground" points (i.e., bare earth) were imported from the LiDAR and used for development of the project DEMs. Bare-earth LiDAR data are typically made by filtering non-ground returns (e.g. buildings, vegetation, etc.) from the raw laser returns. Table 3 lists the source data used to compile the engineering DEM for Yankton County. Figure 5 depicts the extent of the data defined in Table 3.

Table 3: Yankton County Source Terrain Data

Year	Description	Data Type	Data Accuracy	Source/Owner
2012	Eastern South Dakota	Airborne LiDAR	12.8 cm	FEMA/SDSLI/USGS

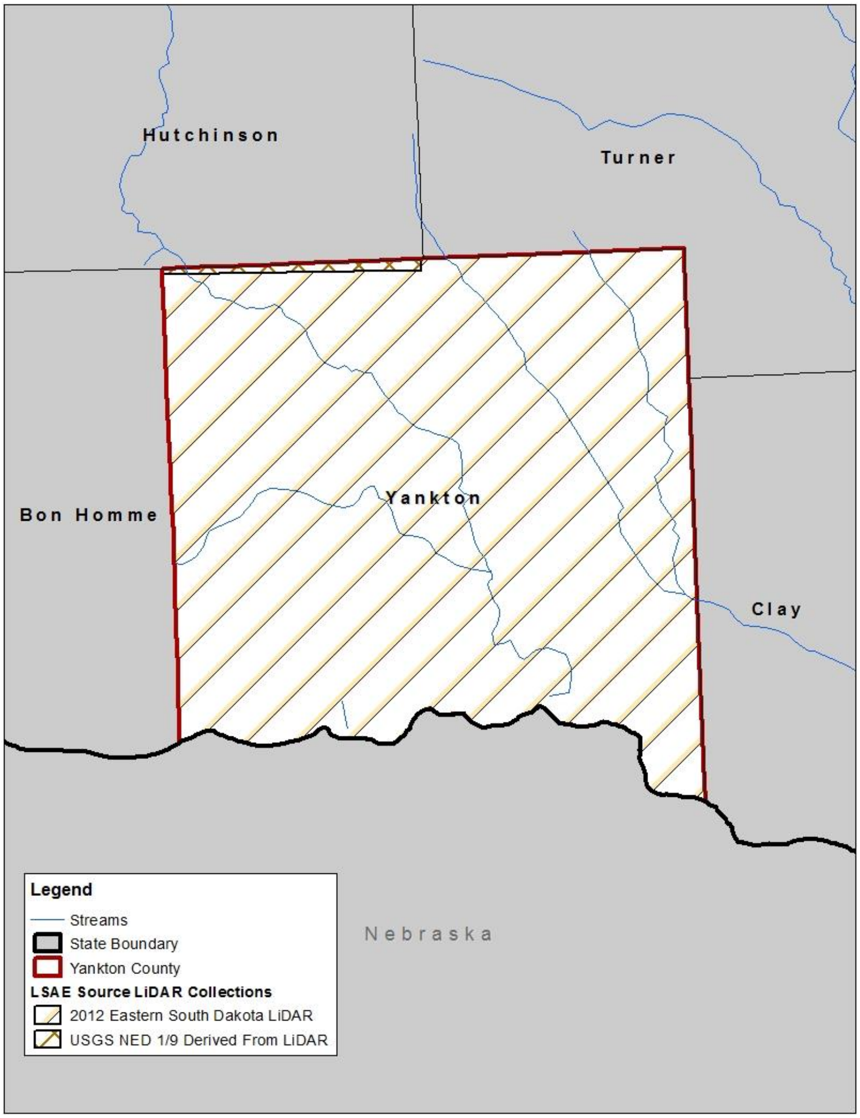

Figure 5: Yankton County Source Terrain Data

2.2.1 2012 Eastern South Dakota LiDAR

The source topographic data were processed for an area covering Yankton County and contributing drainage areas for the SD LSAE modeling efforts. The topographic data for Yankton County was projected horizontally, as needed, to North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS) South Dakota South in feet (SDS-SPC83). All topographic data were adjusted vertically, as needed, to NAVD88 in feet. Compass used a combination of ArcGIS and other software tools to apply any vertical datum shifts and\or any horizontal projection transformations to the topographic data.

2.3 BLE Enhancement Process

The Eastern South Dakota BLE models were used as the starting point for this study. Through various model upgrades, the scoped reaches were “enhanced” from a Zone A, regulatory-ready product, to a Zone AE detailed study product. The original BLE study consisted of 25 watershed scale BLE models that cover the eastern 27 counties in South Dakota. The models were defined along hydrologic basin boundaries, rather than political boundaries, therefore, in some cases multiple models encompass individual counties. The enhancement process included an initial assessment of the BLE models containing enhancement reaches, model domain and hydrologic adjustments if/as necessary, mesh refinements, hydraulic structure implementation, Manning’s n spatial updates, and model execution and calibration. Each of these steps is illustrated in the work flow diagram shown in Figure 6 and described in the subsections below.

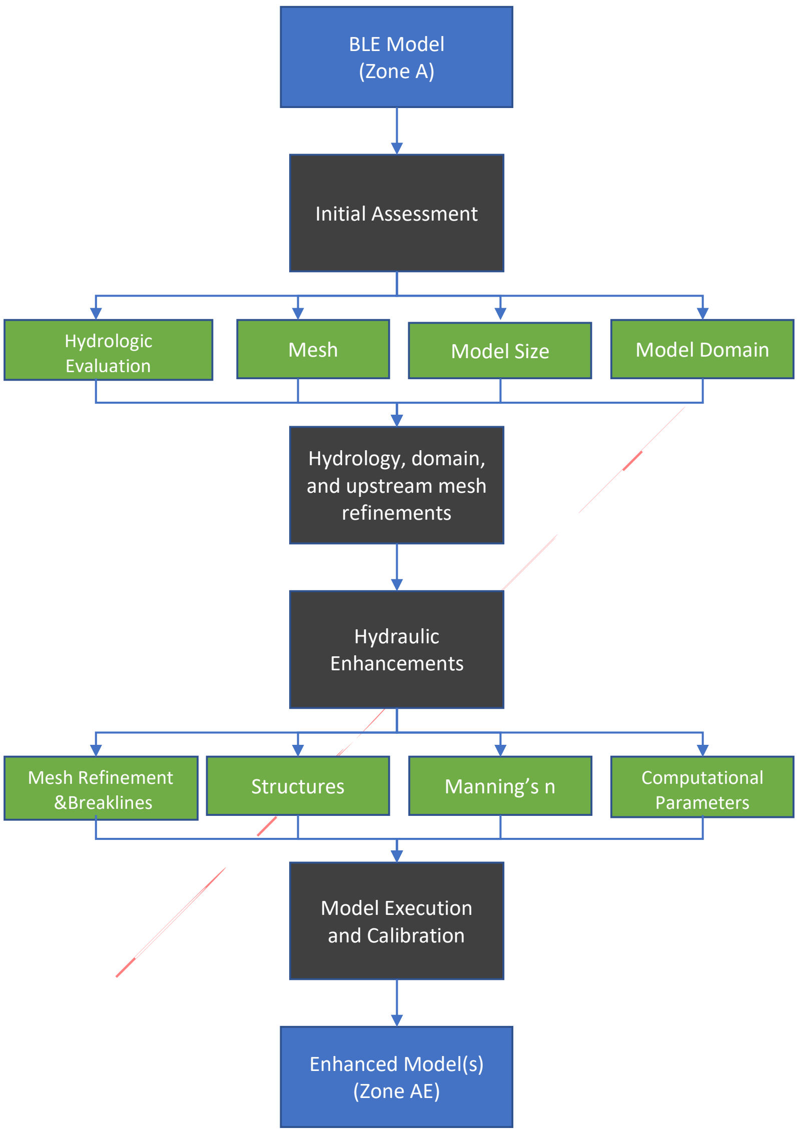

Figure 6: 2D Enhancement Workflow

2.4 Initial BLE Model Assessment

2.4.1 Model Size, Domain, and Mesh Assessment

The Eastern South Dakota 2D BLE models generally have between 800,000 and 1,200,000 grid cells, pushing the limits of HEC-RAS 5.0 functionality. Working with models this large can often be inefficient and in some cases may cease from a program memory overload during model runs if additional refinements are added. For these reasons, the BLE models containing enhancement reaches were evaluated to check for functionality prior to moving forward with the full model domain.

Enhancement reaches within Yankton County are contained within Work Area 10, which is approximately 948 square-miles and contains 692,004 grid cells. Based on initial mesh refinements and preliminary model runs, it was determined that Work Area 10 could be carried forward efficiently into the enhancement process.

Following the general functionality assessment, the domain was checked to ensure all upstream contributing drainage area was included in the model through either rain-on-grid or external inflow hydrographs. This was confirmed for Work Area 10.

Finally, the BLE model grid cell mesh was assessed to determine the level of detail applied to the model upstream of the enhancement reaches by evaluating application of breaklines used to represent embankments and structures (offset breaklines). Results were used to identify unreasonable backwater where embankments were represented, but structures at stream crossings were not, this process is discussed in additional detail in the next section as it relates to representing hydrology for each enhancement reach.

2.4.2 Hydrologic Assessment

Each enhancement reach was assessed independently to determine if the BLE hydrology was reasonable per FEMA guidance General Hydrologic Considerations, February 2018. Upon conclusion of this hydrologic verification it was decided if the BLE hydrology could be carried forward into the enhancement reaches. Gage data and/or regional regression equations were used to calculate target values and the associated one-standard error of prediction (1-SEP) band, as a reference range for acceptable peak flows at each reach. The BLE peak flows were then extracted at each enhancement reach for comparison to the 1-SEP band, as shown in

Table 4 -Table 10. The BLE peak flows were also compared against other available sources such as effective flood insurance study reports and USGS Scientific Investigation Reports if the data was available.

The SEP band for regional regression equations in this area is relatively wide (plus/minus 81%) for the 1% annual exceedance probability event (AEP), indicating the need for additional review of the BLE results where flows are near the limits of the 1-SEP bounds. In many cases, the review revealed poorly represented structures and embankments in the contributing basin BLE model mesh.

Table 11 provides a summary of the hydrologic assessments for the enhanced flooding sources in this county.

Table 4: Y1 Stream Flow Verification

Flooding Source	Contributing Drainage Area (mi²)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Unnamed Stream/Ditch at Y1	*	*	*	*	Effective FIS 7/06/2010
Unnamed Stream/Ditch at Y1	3.18	616	*	*	StreamStats
Unnamed Stream/Ditch at Y1	3.18	523	155	792	2D BLE Model
Unnamed Stream/Ditch at Y1	3.18	495	210	1,030	Enhanced 2D Model

* Data not available

Table 5: Y2 Stream Flow Verification

Flooding Source	Contributing Drainage Area (mi²)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Hillcrest Golf Course Stream	*	*	*	*	Effective FIS 7/06/2010
Hillcrest Golf Course Stream	2.13	486	*	*	StreamStats
Hillcrest Golf Course Stream	2.13	686	184	1,350	2D BLE Model
Hillcrest Golf Course Stream	2.13	580	161	1,710	Enhanced 2D Model

* Data not available

Table 6: Marne Creek Y3 Flow Verification

Flooding Source	Contributing Drainage Area (mi²)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Marne Creek at Confluence w/ Missouri River	33	4,100	*	*	Effective FIS 7/06/2010

Flooding Source	Contributing Drainage Area (mi^2)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Marne Creek North Above Confluence with Marne Creek Tributary	20.5	3,300	*	*	
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	7.2	1,900	*	*	
Marne Creek at Confluence w/ Missouri River	31.05	2,590	*	*	StreamStats
Marne Creek North Above Confluence with Marne Creek Tributary	22.51	2,120	*	*	
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	7.35	1,050	*	*	
Marne Creek at Confluence w/ Missouri River	31.05	4,570	1,460	12,000	2D BLE Model
Marne Creek North Above Confluence with Marne Creek Tributary	22.51	3,210	1,170	8,350	
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	7.35	1,030	407	2,610	
Marne Creek at Confluence w/ Missouri River	31.05	4,300	596**	8,750**	Enhanced 2D Model
Marne Creek North Above Confluence with Marne Creek Tributary	22.51	3,230	84**	7,700**	
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	7.35	1,590	23**	3,120**	

* Data not available

** Data not final

Table 7: Marne Creek Y4 Flow Verification

Flooding Source	Contributing Drainage Area (mi^2)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Marne Creek at 23rd Street	*	*	*	*	Effective FIS 7/06/2010
Marne Creek at 23rd Street	22.03	2,090	*	*	StreamStats
Marne Creek at 23rd Street	22.03	2,510	1,040	5,350	2D BLE Model
Marne Creek at 23rd Street	22.03	2,040	105**	4,500**	Enhanced 2D Model

* Data not available

** Data not final

Table 8: Y5 Flow Verification

Flooding Source	Contributing Drainage Area (mi^2)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Unnamed Stream/Ditch at 25th Street	*	*	*	*	Effective FIS 7/06/2010
Unnamed Stream/Ditch at 25th Street	1.2	337	*	*	StreamStats
Unnamed Stream/Ditch at 25th Street	1.2	207	58	521	2D BLE Model
Unnamed Stream/Ditch at 25th Street	1.2	192	1**	619**	Enhanced 2D Model

* Data not available

** Data not final

Table 9: Y6 Flow Verification

Flooding Source	Contributing Drainage Area (mi^2)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Unnamed Stream/Ditch at Nichols St	6.00	1,700	*	*	Effective FIS 7/06/2010
Unnamed Stream/Ditch at Nichols St	6.00	984	*	*	StreamStats
Unnamed Stream/Ditch at Nichols St	6.00	720	176	2,290	2D BLE Model
Unnamed Stream/Ditch at Nichols St	6.00	1,770	893	4,040	Enhanced 2D Model

* Data not available

Table 10: Irene (T1) Flow Verification

Flooding Source	Contributing Drainage Area (mi^2)	1% AEP (cfs)	1% AEP - (cfs)	1% AEP + (cfs)	Data Source
Unnamed Creek in Irene	*	*	*	*	Effective FIS 7/06/2010
Unnamed Creek in Irene	0.49	197	*	*	StreamStats
Unnamed Creek in Irene	0.49	68	33	293	2D BLE Model
Unnamed Creek in Irene	0.49	77	55	421	Enhanced 2D Model

* Data not available

Table 11: BLE Hydrologic Assessment Summary

Flooding Source	1% AEP Hydrologic Assessment	Revision Description
Unnamed Stream/Ditch in Y1	Reasonable	N/A
Hillcrest Golf Course Stream	Reasonable	N/A
Marne Creek at Confluence w/ Missouri River	Reasonable	N/A
Marne Creek North Above Confluence with Marne Creek Tributary	Reasonable	N/A
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	Reasonable	N/A
Marne Creek at 23rd Street	Reasonable	N/A
Unnamed Stream/Ditch at 25th Street	Reasonable	N/A
Unnamed Stream/Ditch at Nichols St	Reasonable	N/A
Unnamed Creek in Irene, SD	Reasonable	N/A

2.5 Survey

The inclusion of structure data is one of the key components to elevating the leveraged BLE studies from a Zone A ready product to Zone AE. By definition, Zone AE is the special flood hazard area (SFHA) shown on a Flood Insurance Rate Maps (FIRMs) representing areas inundated by the 1% annual exceedance probability flooding, for which base flood elevations (BFEs) have been determined.

Per FEMA Guidance, General Hydraulic Considerations, November 2016, a base level study typically entails using topographic data, typically without bathymetry or bridge/culvert dimensions, to conduct approximate hydrologic and hydraulic analyses. An enhanced analysis on the other hand, entails topographic data, channel bathymetry (if available), and bridge/culvert opening geometry to conduct detailed hydrologic and hydraulic analyses and floodplain mapping. Structure data can include: information from national, state or other data sources.

Rapid field surveys were performed to collect data for hydraulic structures along and within adjacent floodplains of the enhancement reaches. Rapid field survey techniques are intended to provide key dimension and elevation data for hydraulic structures including, inverts, low chord, top of deck, abutments, guard rails, hydraulic width, and culvert and pier dimensions. A level survey was performed at each structure with shots tied back to a reference shot (typically top of road shot or other fixed elevation) that could easily be tied back to the LiDAR to convert the level shots to elevations. The reference elevations were checked by the modeling team to ensure they were correctly pulled from the LiDAR. All elevation data used the NAVD88 vertical datum.

Compass performed 78 rapid field structure surveys in Yankton County, South Dakota. Only structures within the enhancement reaches were inserted into the HEC-RAS model. Table 12 provides summary information for each structure surveyed and Figure 7 shows the locations. The original survey data for each structure are included in Section 07 Appendix. Section 3.6 2D Flow Area Hydraulic Structures of this document describes the process of incorporating these structure data into the models.

Table 12: Structure Survey Data Summary

Reach Name	Structure Name	Structure Type	Survey Date	Notes
Reach Y1	LDS_UNT69_01	Bridge	November 2017	LDS_UNT69_02: Surveyed invert is below the DEM elevation; offset breakline placed on 437th Ave at apparent missing culvert
	LDS_UNT69_02	Culvert		
	LDS_UNT69_03	Culvert		
Reach Y2	LDS_UNT70_01	Bridge	November 2017	One structure at end of reach not surveyed—estimated from aerial imagery and terrain. LDS_UNT75_04 surveyed invert is below the DEM elevation.
	LDS_UNT70_03	Bridge		
	LDS_UNT70_05	Bridge		
	LDS_UNT70_07	Culvert		
	LDS_UNT70_08	Bridge		
	LDS_UNT70_09	Culvert		
	LDS_UNT70_10	Culvert		
	LDS_UNT75_03	Bridge		
	LDS_UNT75_04	Culvert		
	LDS_UNT75_52	Culvert		

Reach Name	Structure Name	Structure Type	Survey Date	Notes
	LDS_UNT75_54	Culvert		
	LDS_UNT75_55	Culvert		
	Unknown_structure	Culvert		
	Valley_Rd_approx	Culvert	Not surveyed. Dimensions provided by the city of Yankton	Structure inverts were approximated from terrain
	Peninah_St_approx	Culvert		
	Ferdig_St_approx	Culvert		
Reach Y3	LDS_MC_01	Bridge	November 2017	N/A
	LDS_MC_02	Bridge		
	LDS_MC_03	Bridge		
	LDS_MC_04	Culvert		
	LDS_MC_05	Culvert		
	LDS_MC_06	Bridge		
	LDS_MC_07	Culvert		
	LDS_MC_07.2	Bridge		
	LDS_MC_08	Culvert		
	LDS_MC_09	Bridge		
	LDS_MC_10	Bridge		
	LDS_MC_11	Bridge		
	LDS_MC_12	Bridge		
	LDS_MC_13	Bridge		
	LDS_MC_13.2	Culvert		
	LDS_MC_14	Bridge		
	LDS_MC_16	Culvert		

Reach Name	Structure Name	Structure Type	Survey Date	Notes
	LDS_MC_17	Bridge		
	LDS_MC_18	Bridge		
	LDS_MC_19	Bridge		
	LDS_MC_20	Bridge		
	LDS_MC_21	Culvert		
	LDS_MC_22	Bridge		
	LDS_MC_23	Culvert		
	LDS_MC_24	Culvert		
	LDS_MC_25	Culvert		
	LDS_UNT71_0.5	Culvert		
	LDS_UNT71_01	Culvert		
	LDS_UNT71_02	Culvert		
	LDS_UNT71_03	Culvert		
	LDS_UNT71_04	Culvert		
Reach Y4	LDS_MC_26	Culvert	November 2017	N/A
	LDS_MC_27	Bridge		
	LDS_MC_28	Culvert		
	LDS_MC_29	Bridge		
	LDS_MC_30	Culvert		
Reach Y5	LDS_UNT78_01	Culvert	November 2017	N/A
	LDS_UNT78_02	Dam		
	LDS_UNT78_02.5	Dam		
	LDS_UNT78_03	Bridge		

Reach Name	Structure Name	Structure Type	Survey Date	Notes
	LDS_UNT78_04	Culvert		
	LDS_UNT78_05	Culvert		
	LDS_UNT78_06	Dam		
	LDS_UNT78_06.1	Dam		
	LDS_UNT78_07	Culvert		
	LDS_UNT78_08	Culvert		
	LDS_UNT78_09	Culvert		
Reach Y6	Y6_Unknown1	Culvert	N/A	Not surveyed. Estimated from aerial imagery, terrain, and Yankton County, SD Effective FIS Report.
	Y6_Unknown2	Culvert		
	Y6_Unknown3	Culvert		
Irene Reach	LDS_UC_11	Culvert	November 2018	New reach identified in FY18 as part of Yankton County; culvert is mostly blocked
	LDS_UC_12	Bridge		

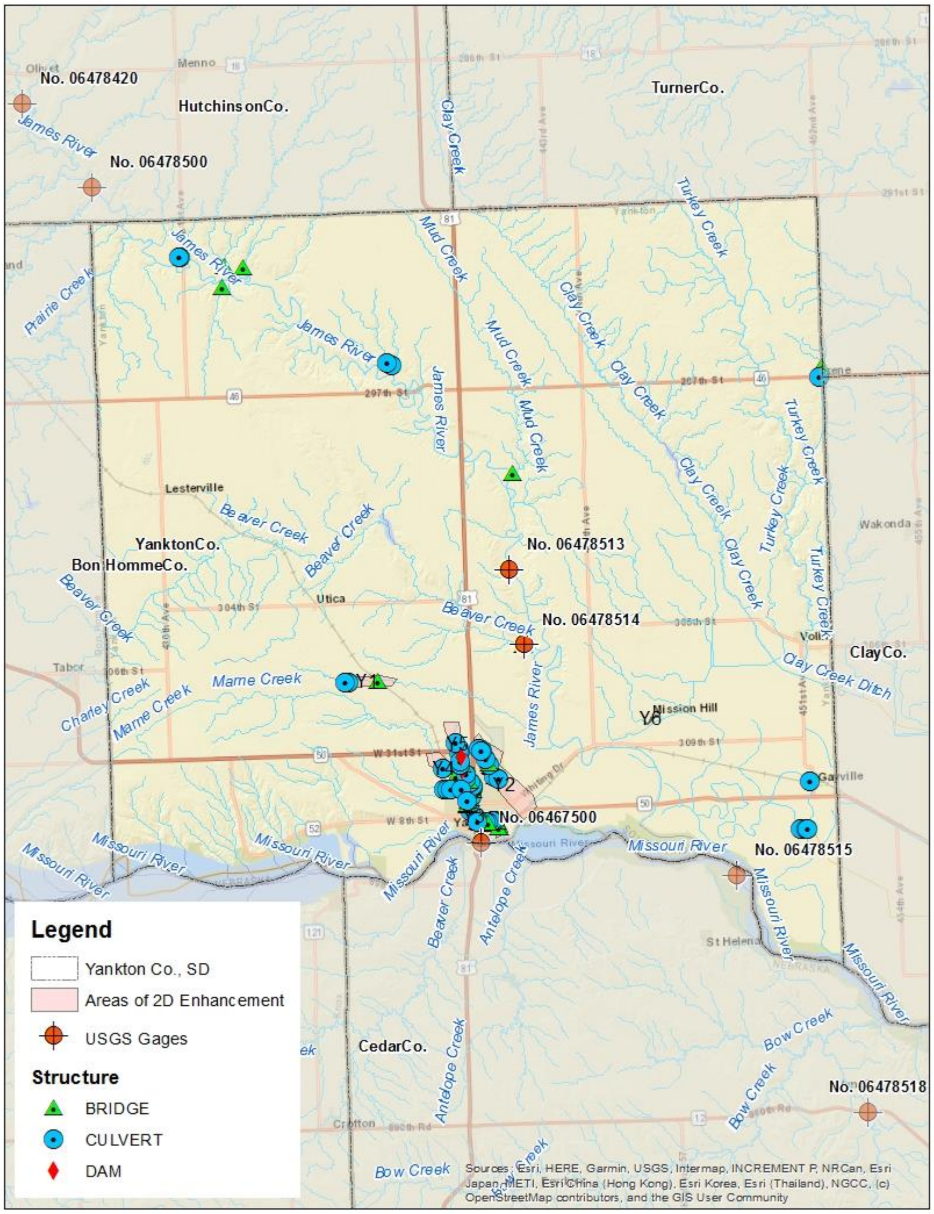

Figure 7: Structures Surveyed for Yankton Co., SD

03 Enhancement Model Development

3.1 Model and Geometry Layout

Table 13 provides a list of basic 2D model specifications for reaches enhanced by 2D methods in this county.

Table 13: Basic 2D Model Geometry Specifications

Model Name	No. of cells	Nominal Grid Cell size	Upstream Drainage Area (mi^2)	Enhanced Reaches	Enhanced Cells	Min-Max Breakline Cell Spacing	No. Structures	Modeling Considerations
Work Area 10	692,004	200-FT x 200-FT	1.57	Reach Y1	2D mesh enhanced along: major stream centerlines, transportation centerlines, water bodies	100-200	68	Reach Y3 upstream drainage area accounts for two inflows from Marne Creek and Marne Creek Tributary
			0.79	Reach Y2		50-200		
			29.86	Reach Y3		50-200		
			19.55	Reach Y4		50-200		
			0.46	Reach Y5		100-200		
			6.25	Reach Y6		100-200		
			0.04	Irene Reach (T1)		50-200		

3.2 Boundary Conditions

Boundary conditions were used to define inflows, rain-on-grid precipitation expressed as an excess rainfall hyetograph, and outflows to the 2D model domain(s) for the enhancement reaches within Yankton County. This model maintained the large-scale BLE domain, therefore, the boundaries are defined at the watershed scale, including inflow hydrographs from James River and the Missouri River. The external hydrographs and the rain-on-grid data are discussed in detail in Section 3.3.1 and 3.3.2.

Outflow boundaries were defined using normal depth at the BLE boundaries. Work Area 10 is where the James River meets the Missouri River and, thus, the only outflow boundary is the Missouri River.

3.3 Hydrology

3.3.1 Rain-on-Grid

As discussed in Section 2.4, the BLE hydrology was deemed reasonable to carry forward into this study for the Yankton County enhancement reaches. HEC-HMS version 4.2 was used to apply the SCS Curve Number method to calculate losses and define excess precipitation for each model work area. Temporal distributions of point rainfall totals were defined using 24-hour, SCS Type II storm distributions.

Initial Curve Numbers were computed by intersecting the National Land Cover Dataset (NLCD) 2011 coverage and NRCS soils data (assuming Antecedent Runoff Condition II) based on the matrix presented below in Table 14.

Table 14: Land Use-Soils-CN Matrix for Computing Initial Curve Numbers

LU_GridCode	NLCD LU Description	Hydrologic Soil Group			
		A	B	C	D
11	Open Water	99	99	99	99
21	Developed Open Space	49	69	79	84
22	Developed Low Intensity	61	75	83	87
23	Developed Medium Intensity	81	88	91	93
24	Developed High Intensity	89	92	94	95
31	Barren Land	39	61	74	80
41	Deciduous Forest	30	55	70	77
42	Evergreen Forest	30	55	70	77
43	Mixed Forest	30	55	70	77
52	Shrub Scrub	30	48	65	73
71	Herbaceous	49	62	74	85
81	Hay Pasture	39	61	74	84
82	Cultivated Crops	51	67	76	80
90	Woody Wetlands	72	80	87	93
95	Emergent Herbaceous Wetlands	72	80	87	93

NRCS rainfall-runoff methods were used to define excess precipitation applied to the 2D mesh, including CNs for defining rainfall losses. No routing was considered in the rainfall-runoff modeling. Table 15 provides the NOAA Atlas 14 Precipitation Frequency Estimates used for determining excess precipitation within HEC-HMS.

Table 15: NOAA Atlas 14 Precipitation Frequency Estimates

Percent (AEP)	Precipitation Depth (in)
10	3.84
4	4.64
2	5.29
1	5.97
0.2	7.68
1% Minus	5.17
1% Plus	6.76

The Work Area 10 CN was adjusted 0% and new excess precipitation hyetographs were calculated during the BLE calibration process. The final BLE excess precipitation hyetographs were applied to the 2D mesh for this study and are shown in Figure 8 and .

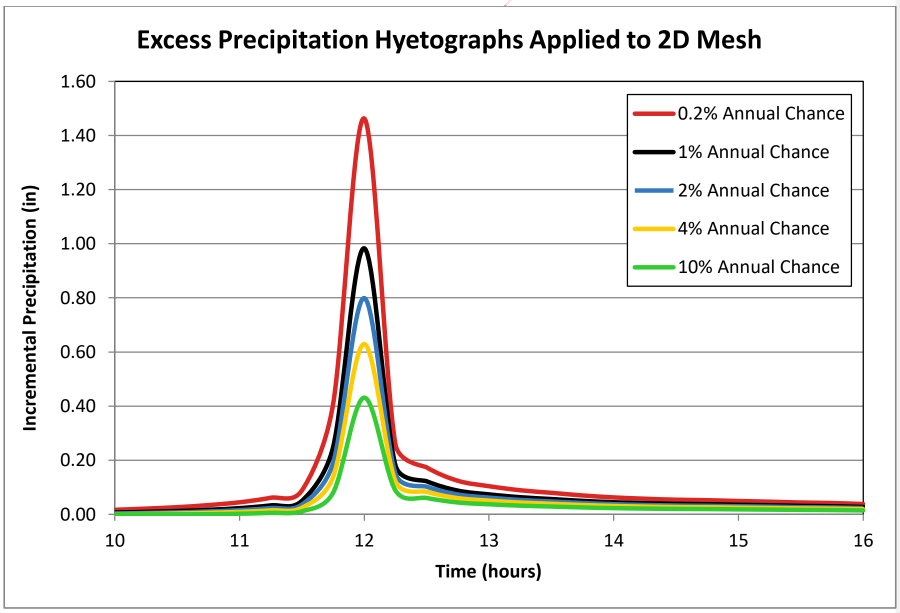

Figure 8: Work Area 10 Excess Precipitation Hyetographs

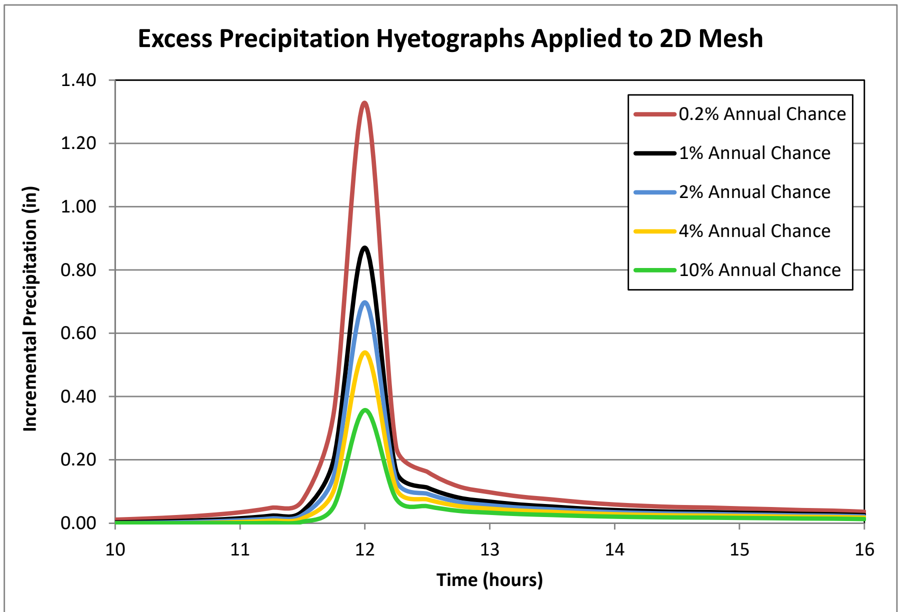

Figure 9: Marne Creek Clipped Model Excess Precipitation Hyetographs

3.3.2 Enhancement Reach Hydrographs

As described in Section 2.4.2, flow hydrographs were extracted at each enhancement reach to assess the hydrology and determine the applicability to this study. Detailed descriptions of the hydrology at all of Yankton County's enhancement reaches are provided in the subsections below.

3.3.3 Work Area 10 Enhancement Reaches

Work Area 10 has 7 enhancement reaches:

3.3.3.1 Enhancement Reach 1

Enhancement Reach 1 (Y1) is located on an unnamed stream/ditch starting southwest of 436th Ave and 306th St and extending past 437th Ave with a reach length of 2.05 mi. Y1 mostly consists of cropland. Three structures are located in this enhancement reach, including a pipe culvert under a small stream crossing, a culvert under 436th Ave with a surveyed inlet below DEM elevation, and a railroad bridge.

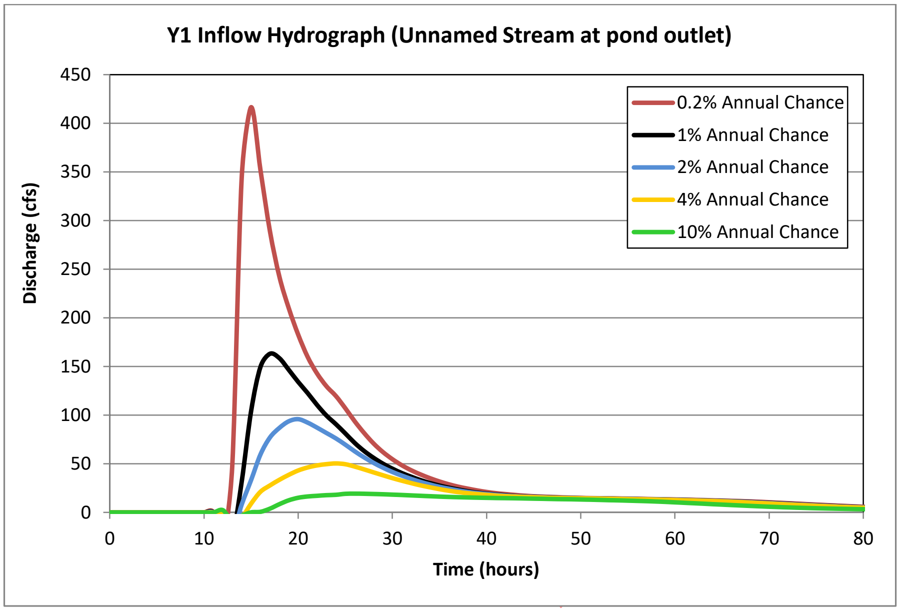

Figure 10: Inflow Hydrograph in Enhancement Reach 1

3.3.3.2 Enhancement Reach 2

Enhancement Reach 2 (Y2) is located on the Hillcrest Golf Course Stream from Highway 81 to Missouri River with a reach length of 3.62 mi. Y2 is located on a golf course and neighborhood with residential structures. In addition, a small airport is located just east of the reach. Thirteen structures are located in this enhancement reach, with one inlet surveyed below DEM elevation and one structure without survey data.

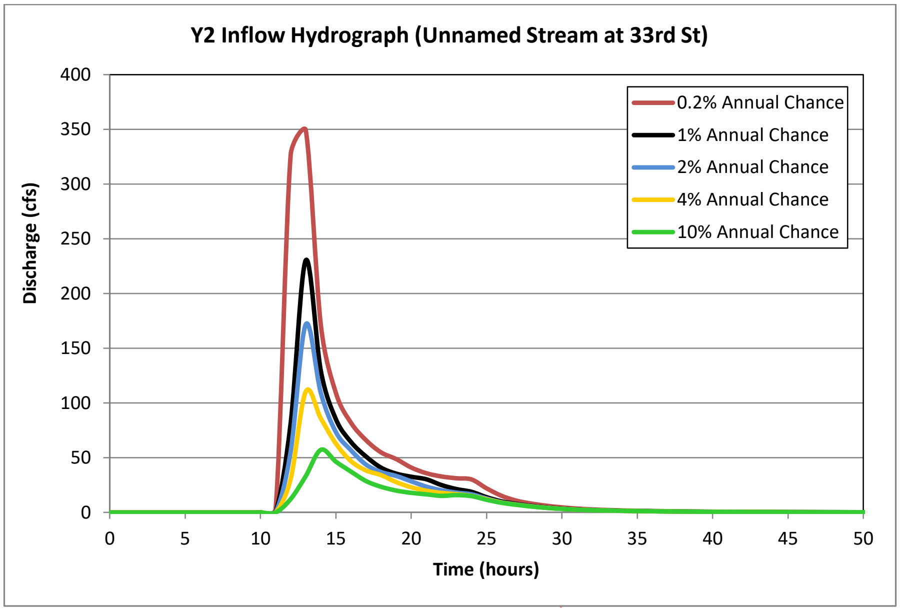

Figure 11: Inflow Hydrograph in Enhancement Reach 2

3.3.3.3 Enhancement Reach 3

Enhancement Reach 3 (Y3) is located on Marne Creek stretching from just south of W 23rd St to Missouri River with a reach length of 2.96 mi. Y3 is located in the city of Yankton where many buildings and a high population density are present. Thirty-one structures are located in this enhancement reach, with 16 bridges and 15 culverts. There are inflows into this enhancement reach from the northern part of Marne Creek and from a tributary.

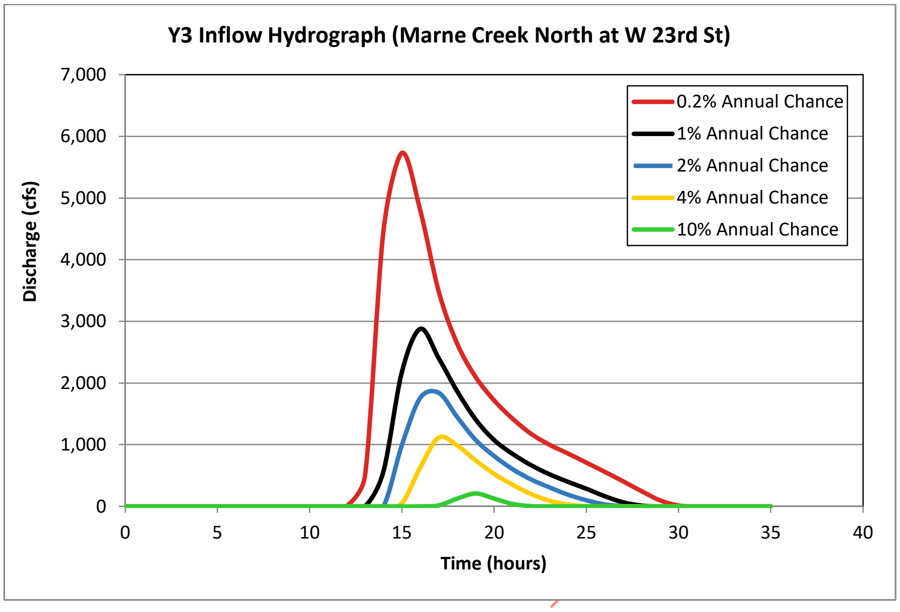

Figure 12: Inflow Hydrograph in Enhancement Reach 3

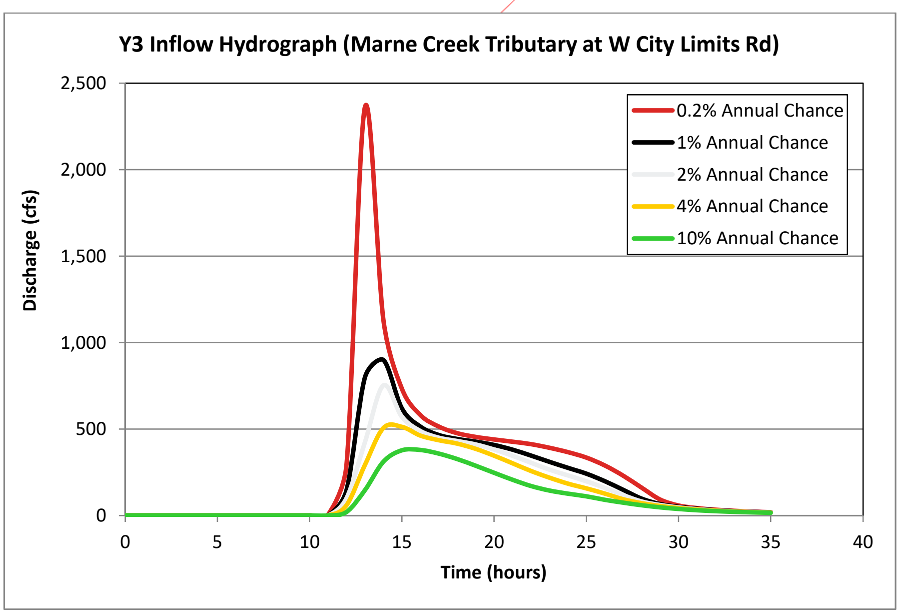

Figure 13: Inflow Hydrograph from Marne Creek Tributary

3.3.3.4 Enhancement Reach 4

Enhancement Reach 4 (Y4) is located on Marne Creek from Highway 50 to W 23rd St with a reach length of 2.1 mi. Five structures are located in this enhancement reach, including 2 bridges and 3 culverts. Y4 is located in the city of Yankton, where the south-most portion of the enhancement reach is made up of business buildings and the northeast portion has a few residential buildings. Otherwise, the majority of this reach consists of farmland with a couple of waterbodies present.

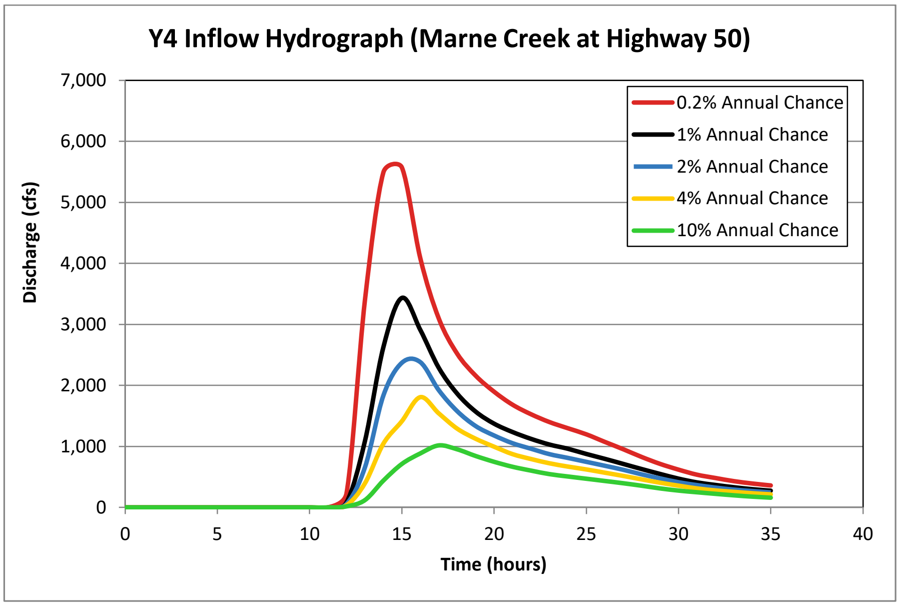

Figure 14: Inflow Hydrograph in Enhancement Reach 4

3.3.3.5 Enhancement Reach 5

Enhancement Reach 5 (Y5) is located on an unnamed stream/ditch from W 39th St to Yankton Mall with a reach length of 1.4 mi. Eleven structures are located in this enhancement reach, including 1 bridge, 6 culverts, and 4 dams. Y5 is located in the city of Yankton, where the south part of the enhancement reach is made up of business buildings but the majority of the reach is grass and water bodies.

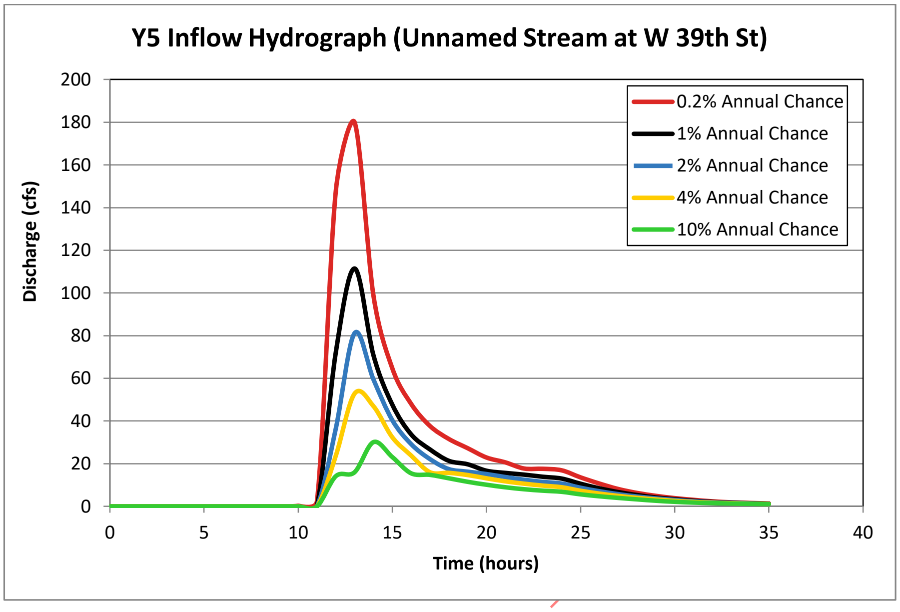

Figure 15: Inflow Hydrograph in Enhancement Reach 5

3.3.3.6 Enhancement Reach 6

Enhancement Reach 6 (Y6) is located on an Unnamed Stream/Ditch in the city limits of Mission Hill with a reach length of 0.91 mi. Three structures are located in this enhancement reach, none of which were surveyed and had to be estimated based on imagery and DEM.

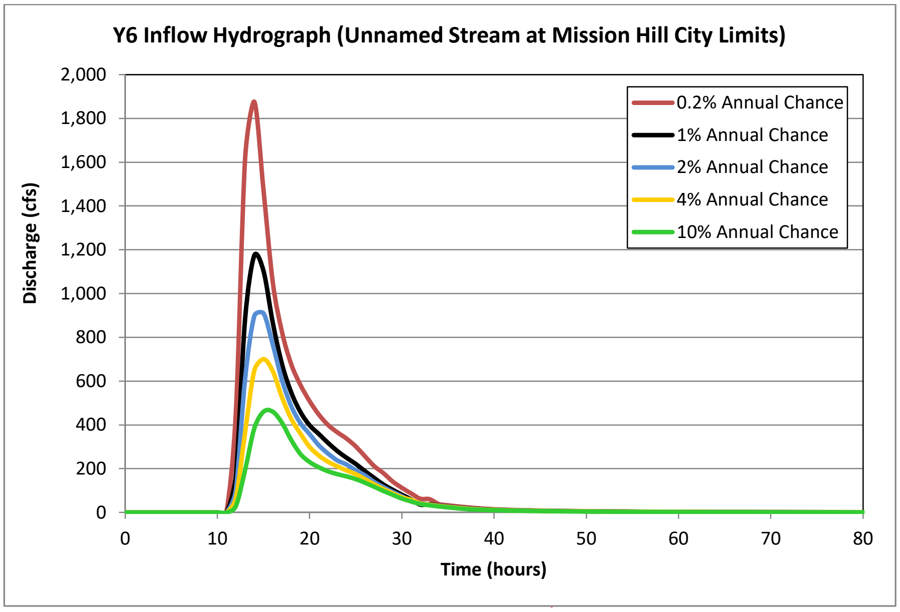

Figure 16: Inflow Hydrograph in Enhancement Reach 6

3.3.3.7 Enhancement Reach 7

Enhancement Reach 7 is located in Irene, SD and was originally identified in FY18 as T1 in Turner County. It has a reach length of 0.67 mi and two surveyed structures—one culvert and one bridge. The majority of the reach is classified as emergent herbaceous wetlands.

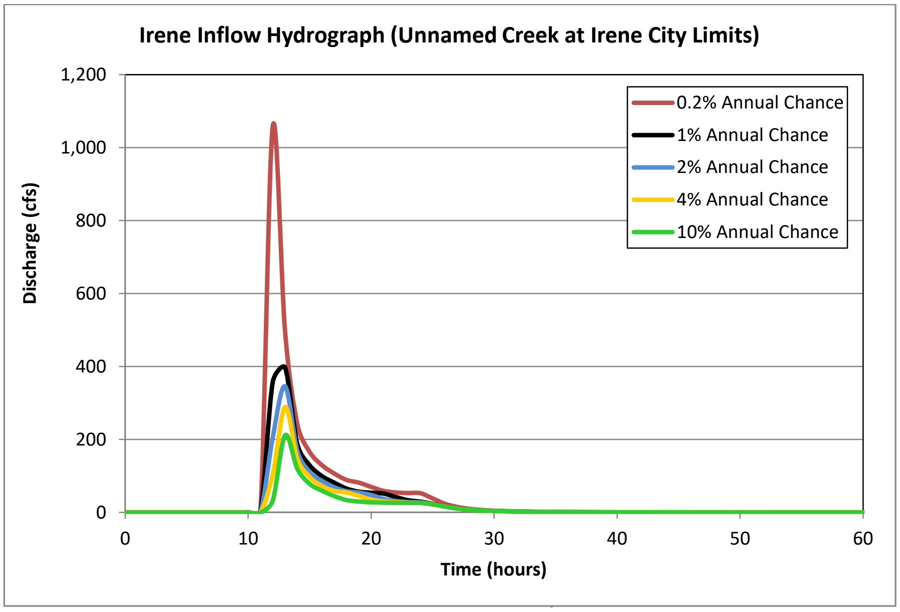

Figure 17: Inflow Hydrograph in Enhancement Reach 7

3.3.4 External Inflow Hydrographs

Incoming flow hydrographs from upstream of the 2D model domain were modeled with inflow hydrographs developed from the upstream BLE models or Bulletin 17B stream gage analyses, where data is available. Work area 10 has significant inflow from the James River and Missouri River.

Incoming flow from James River and Missouri River were modeled with inflow hydrographs developed from Bulletin 17B gage analysis. The following table shows the peak flows for the stream gages representing inflow drainage areas to the 2D computational mesh.

Table 16: Leveraged USGS Peak Streamflow Gage Analysis Results

USGS Stream Gage	Percent (AEP) Peak Flow (cfs)		
	1%-	1%	1%+
USGS 06478500 James River nr Scotland SD	36,023	45,414	59,155
USGS 06478513 James River nr Yankton SD	34,790	43,752	130,800
USGS 06467500 Missouri River at Yankton SD	79,750	86,330	95,030

A unit hydrograph for each stream gage was synthesized from historic records. Figure 18 - Figure 19 below show the inflow hydrographs for James River and Missouri River applied to the 2D computational mesh.

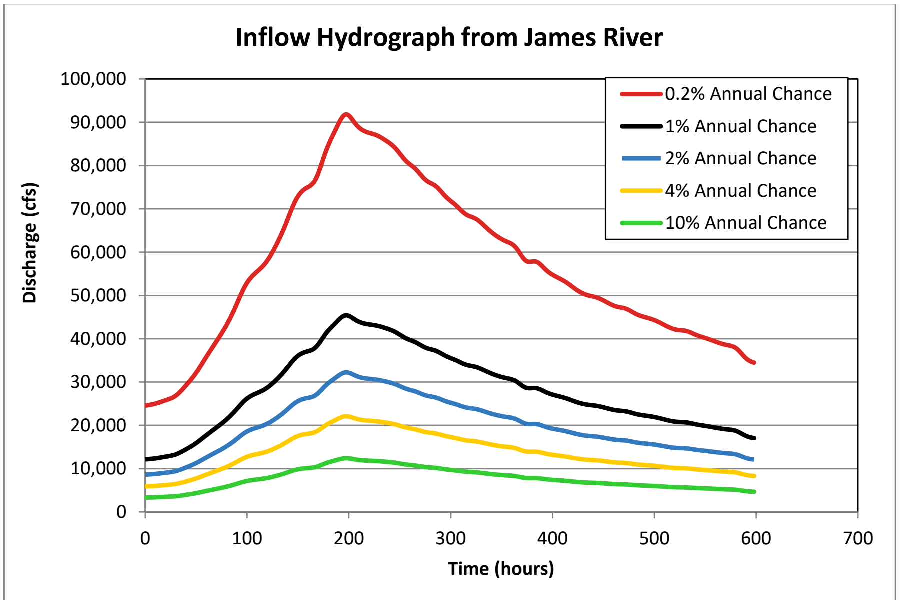

Figure 18: Inflow hydrographs from James River – Gage 06478500

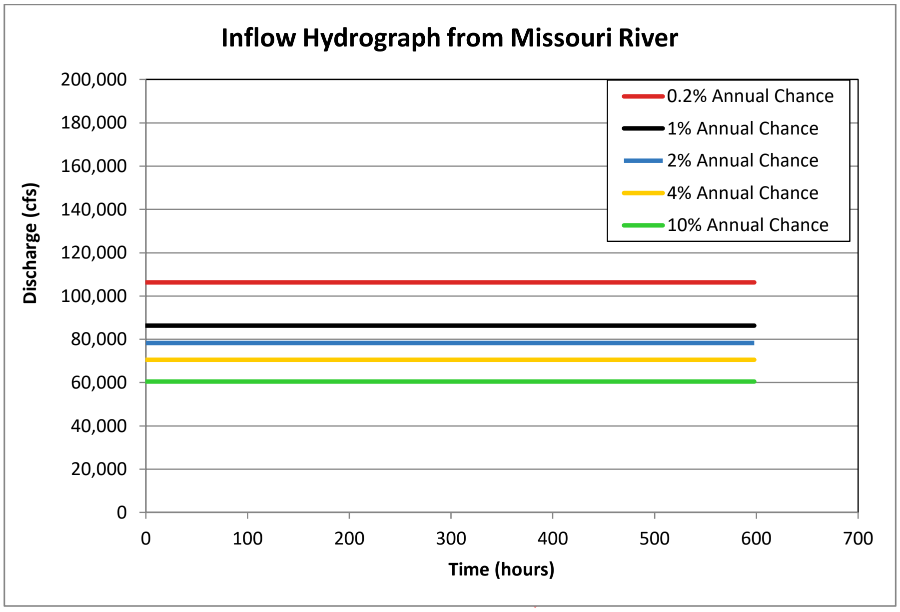

Figure 19: Inflow hydrographs from Missouri River – Gage 06467500

Inflow hydrographs were developed from a combination of gage analysis and dimensionless unit hydrographs and were used as boundary conditions to the 2D computational mesh.

3.4 2D Area Roughness Coefficients

2D Flow Areas in HEC-RAS requires a spatially varied Manning's roughness layer. For this study and for the original BLE, the National Land Cover Database (NLCD) from 2011 served as the base spatial layer to define roughness coefficients associated with land characteristics. Table 17 details the land cover classifications and associated Manning's roughness coefficients in the enhancement areas.

Table 17: Manning's Roughness based on Land Cover Classification

NLCD Classification	Original Manning's Roughness		Enhanced Manning's Roughness			
	Normal	Source	Minimum	Normal	Maximum	Source
Open Water	0.03	Chow, 1959	0.025	0.040	0.05	Janssen, 2016
Developed, Open Space	0.013	Calenda, et al. 2005	0.03	0.040	0.05	Janssen, 2016
Developed, Low Intensity	0.05	Calenda, et al. 2005	0.06	0.08	0.12	Janssen, 2016[1]
Developed, Medium Intensity	0.075	Calenda, et al. 2005	0.08	0.100	0.14	Janssen, 2016[1]
Developed, High Intensity	0.1	Calenda, et al. 2005	0.12	0.150	0.20	Janssen, 2016

NLCD Classification	Original Manning's Roughness		Enhanced Manning's Roughness			
	Normal	Source	Minimum	Normal	Maximum	Source
Barren Land	0.03	Chow, 1959	0.023	0.025	0.030	Janssen, 2016
Deciduous Forest	0.12	Chow, 1959	0.100	0.160	0.16	Janssen, 2016
Evergreen Forest	0.12	Chow, 1959	0.100	0.160	0.16	Janssen, 2016
Mixed Forest	0.12	Chow, 1959	0.100	0.160	0.16	Janssen, 2016
Scrub/Shrub	0.05	Chow, 1959	0.07	0.100	0.16	Janssen, 2016
Grassland Herbaceous	0.03	Chow, 1959	0.025	0.035	0.050	Janssen, 2016
Pasture/Hay	0.04	Chow, 1959	0.025	0.030	0.050	Janssen, 2016
Cultivated Crops	0.035	Chow, 1959	0.025	0.035	0.050	Janssen, 2016
Woody Wetlands	0.1	Chow, 1959	0.045	0.120	0.15	Janssen, 2016
Emergent Herbaceous	0.1	Chow, 1959	0.05	0.070	0.085	Janssen, 2016

[1] Note that normal Manning's N values were corrected to better fit with classification (higher roughness with increased intensity)

Detailed polygons were defined inside the enhancement reaches to refine and supplement the base NLCD Manning's n regions. Figure 20 provides an example of the final Manning's n regions.

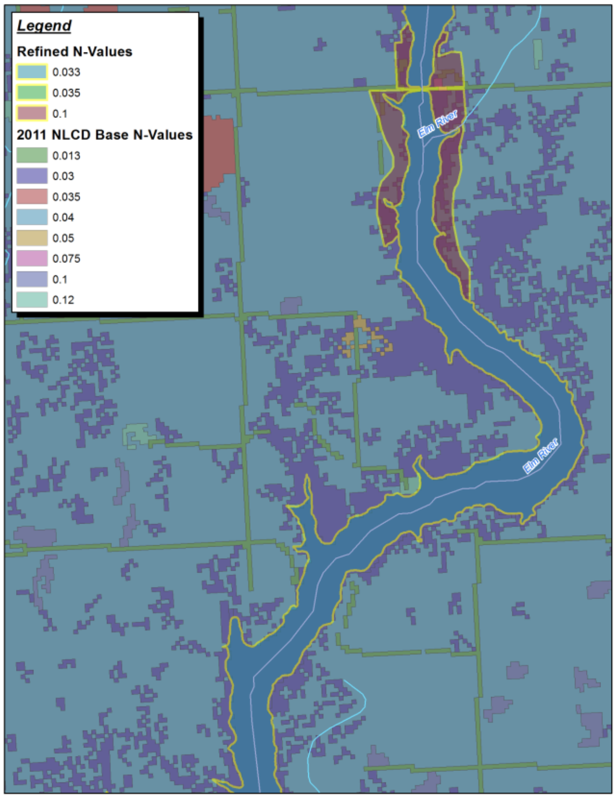

Figure 20: Manning's Roughness based on Land Cover Classification

3.5 Breaklines

Breaklines align grid cell faces and were used within the 2D mesh area to define prominent features including road embankments, natural high ground, hydraulic structures, or overland flow paths. Road embankments or other prominent topographic features were defined in GIS and imported into RAS5 as breaklines to ensure that water was not routed past roads without passing through a structure until it was deep enough to overtop the road. Additionally, breaklines were used to refine the mesh within the enhancement reaches to decrease cell size, increasing the hydraulic resolution. Figure 21-Figure 22 show examples of breaklines used to refine the mesh in a 2D Flow Area.

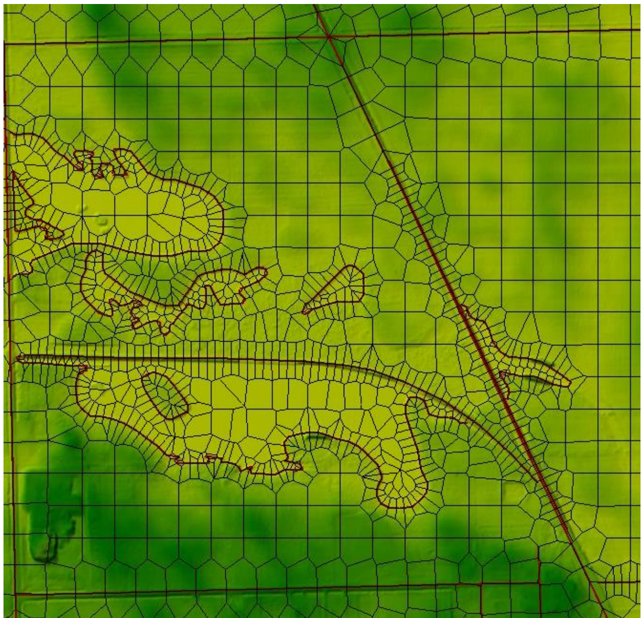

Figure 21: Sample of 2D Mesh Enhancement

The enhanced reaches in this project utilized several different breakline methods in order to enhance the detail of the 2D mesh. A classified slope polygon made from a slope raster using the underlying DEM was used to highlight water bodies, major stream corridors (with flat gradients), and various waterbodies/sloughs. Breaklines were added along stream centerlines and streambanks using stream shapefiles and stream flow paths generated using Arc Hydro or manual delineation. Contour shapefiles were created to capture areas such as road fills, bridge embankments, impoundment structures, and levees.

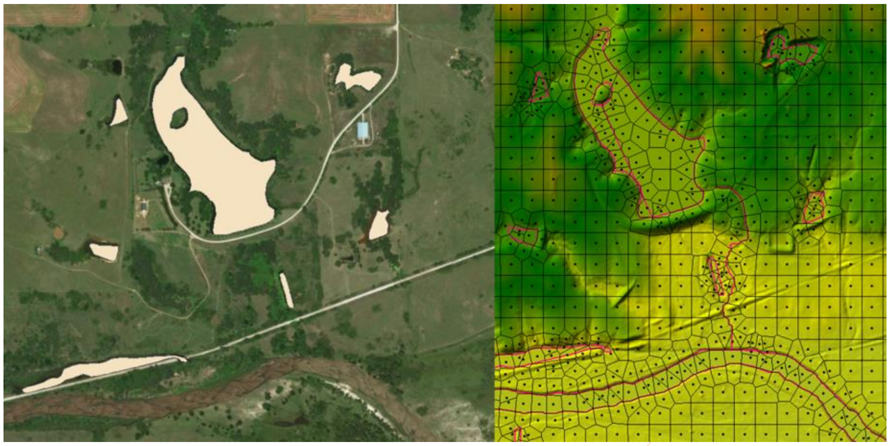

Figure 22: Classified Slope Polygons Used for Breaklines

3.6 2D Flow Area Hydraulic Structures

As described in Section 2.5 Survey, rapid field survey data were collected at all hydraulic structures for the enhancement reaches within Yankton County. The Zone AE 2D enhancement methodology incorporates the **W**atershed **I**nformation **S**yst**E**m (WISE) software as tool for cataloging and viewing the rapid field survey data.

Rapid field survey data is also commonly referred to as approximate survey or limited detail survey. Basic structure information is quickly collected in field. Each survey structure has a unique ID denoting the type survey, stream name, and structure count with respect to that stream. For example, LDS_MC_01 indicates that rapid field survey is of Limited Detail for Marne Creek and is structure number 1 on that reach.

3.6.1 Vertical Control Elevations

All rapid field survey data is tied back to a Vertical Control Elevation (VCE) shot. The global positioning system (GPS) coordinates for this VCE are collected in the field and the elevation is then extracted from the Digital Elevation Model (DEM) using Arc GIS. In addition to the VCE basic structure, measurements were collected on the upstream face of structures and cataloged into WISE's Open System Inventory. These field measurements utilized a level rod, survey wheel, wooden foldout ruler, and a hand level. Figure 23 provides a graphical illustration of the typical measurements collected for a culvert and how they tie back to the VCE shot. Structure elevations are calculated by the following equation: VCE + Backsight Height - Rod Height. For example, for structure:

LDS_ElmR_04
VCE: 1469.55 FT NAVD 88
Backsight: 5.0 FT
TOR Rod: 4.4 FT
Top of Road Elevation: 1469.55 + 5.0 – 4.4 = 1470.15 FT NAVD 88

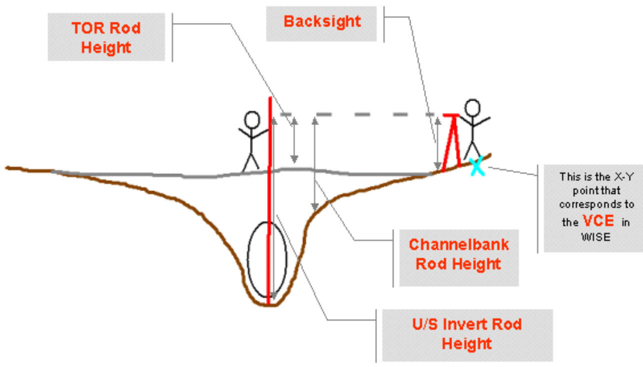

Figure 23: Rapid Field Survey – Typical Culvert Data Collection

Vertical Control Elevation shots were checked for consistency and reasonability. In some instances the VCE points collected in the field for bridges were taken on the bridge deck adjacent to the rod measurements. Most bridge decks, however, have been removed from DEMs derived from LiDAR data so when the elevation of these points was extracted from the DEM unrealistic structure elevation calculations were encountered. As shown in Figure 24 the VCE point is shown were a bridge would exist in the field but in the DEM derived from the LiDAR data it falls within the stream corridor. To mitigate this, a revised VCE point was manually selected to fall on the top of the road profile.

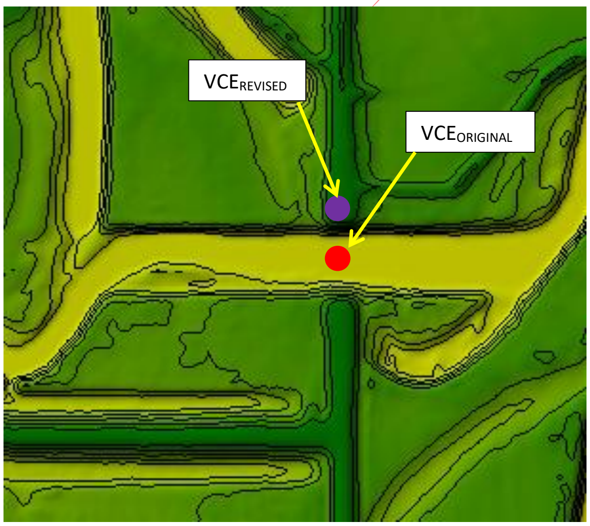

Figure 24: Vertical Control Elevation Shot

3.6.2 Types of Rapid Field Surveys

Rapid field survey data can either be in the form of bridges, culverts, or dams. Bridges will be surveyed by measuring:

- Deck thickness – Distance from top of crown of road to low chord (bottom of bridge opening)
- Top width – Distance between the top abutments (BEGIN and END)
- Toe width – Bottom of Abutments - Distance between the bottom abutments (TOES)
- Hydraulic width – Distance between US face and DS face of bridge (Outside to Outside)
- Number of piers
- Pier width
- Invert – Distance between the US bottom of channel and the VCE
- Channel top width – Top width of channel from channel bank to channel bank at structure
- Channel bottom width – Bottom width of channel at the structure
- Channel bank elevation – Distance from VCE to the channel bank (average the two CBs)

Figure 25 provides a graphical illustration of the typical measures taken at a bridge.

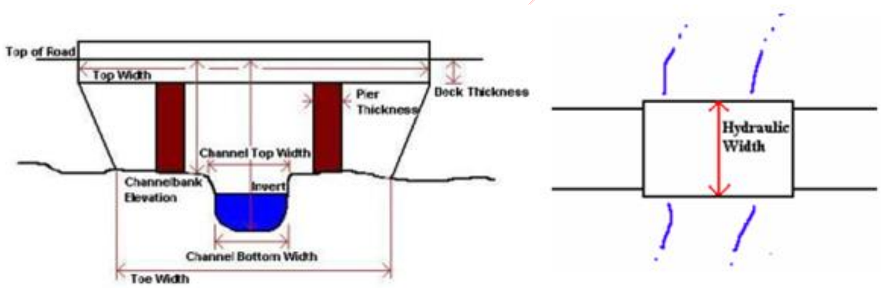

Figure 25: Rapid Field Survey - Bridge Rod Measurements & Hydraulic Width of Bridge

Culverts will be surveyed by measuring:

- Number of Barrels – Number of Boxes, Circular pipes, or Elliptical pipes
- Shape or Culvert type – Box, Circular, or Elliptical
- Rise – Height of Culvert or Diameter for a circular culvert
- Span – Width of Culvert
- Hydraulic width – Distance between US face and DS face of culvert
- Each Culvert Invert – Distance between the US bottom of Boxes, Circular pipes, or Elliptical pipes and the VCE
- Invert – Distance between the US bottom of channel and the VCE
- Channel top width – Top width of channel from channel bank to channel bank at structure

- Channel bottom width – Bottom width of channel at the structure
- Channel bank elevation – Distance from VCE to the channel bank (average the two CBs)

Figure 26 and Figure 27 provide a graphical illustration of the typical measurements taken at a culvert.

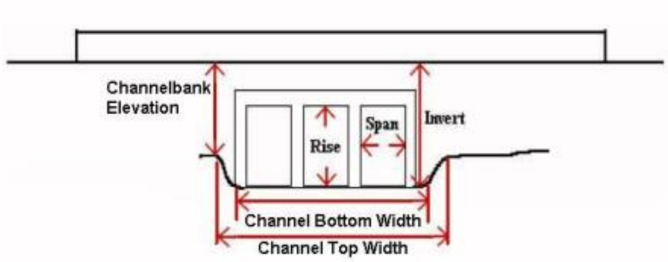

Figure 26: Rapid Field Survey - Culvert Rod Measurements

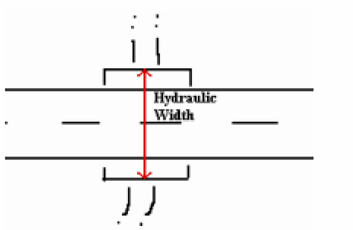

Figure 27: Rapid Field Survey – Hydraulic Width of Culvert

Dams will be surveyed by measuring:

- Type of Dam – Concrete Arch, Concrete Gravity, Earthfill, Masonry, RCC, Rockfill, Rubber, Timber Crib
- Material of Dam – Earthen, Concrete, Rock, Brick, Stone, Combination
- Hydraulic width – Distance of the top of dam
- Shape of Riser – Box or Circular
- Top Elevation – Elevation of the of riser
- Height – The distance between the top and bottom of riser
- Length – The dimension of the riser if a box
- Width – The dimension of the rise
- Out Shape – The shape of the exiting culvert of the riser downstream of the dam (Box or Circular)
- Out Top Elev – Elevation of the top of the exiting culvert on the downstream of the dam
- Out Rise – Height of Culvert or Diameter for a circular culvert
- Out Span – Width of Culvert
- Out Pipe Length – Distance from the riser to the outlet.
- Trash Rack Elevation – Elevation of top of the riser trash rack
- TR Len – Length of trash rack
- TR Width – Width of trash rack
- Riser Holes – Number of holes in the riser to help control water elevation

- Hole Spacing – The space between holes in riser
- Hole Shape – Shape of holes in the riser (Box or Circular)
- Hole Rise – Height of holes in riser
- Hole Span – Width of holes in riser
- Top Width – Width of the spillway at the top of dam elevation
- Bottom Width – Width of the spillway at the spillway crest elevation
- Crest Elevation – Elevation at the bottom of the spillway.
- Height – Height from the bottom to the top of the spillway

Section 07 Appendix contains a detailed list of the rapid field survey structures collected for this county.

3.6.3 Translating Field Survey Data to HEC-RAS Internal Connections

Once the field survey data has been collected and catalogued into WISE, the structure data is then added to the 2D domain in the form of an internal connection within the HEC-RAS geometry editor (See Figure 28-Figure 31). This allows flow that is normally impeded by the terrain (such as road fill) to pass freely through the structure simulating both pressure and overtopping.

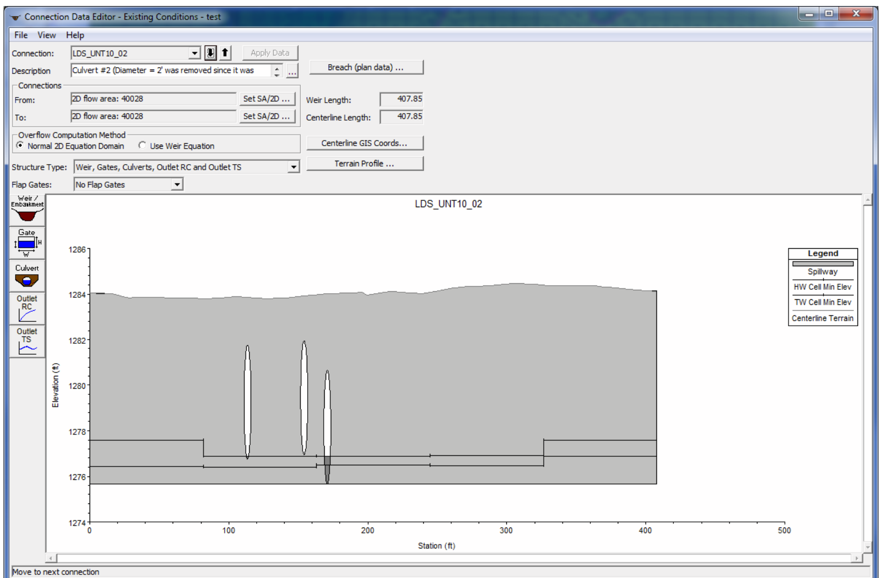

Figure 28: Typical Internal Connection – Culverts

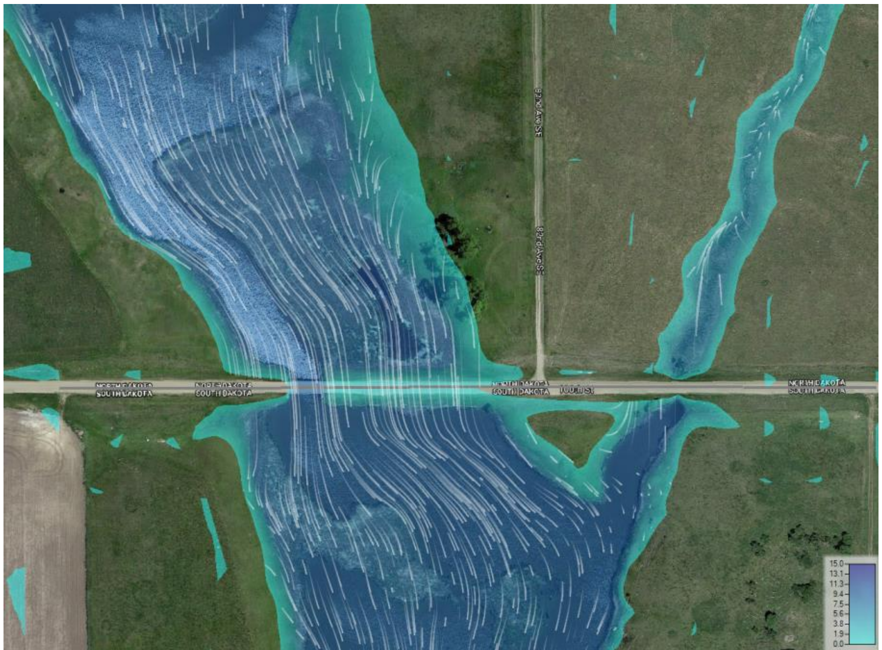

Figure 29: Simulated Bridge Overtopping & Culvert Pressure Flow

Figure 30: Simulated Bridge Pressure Flow

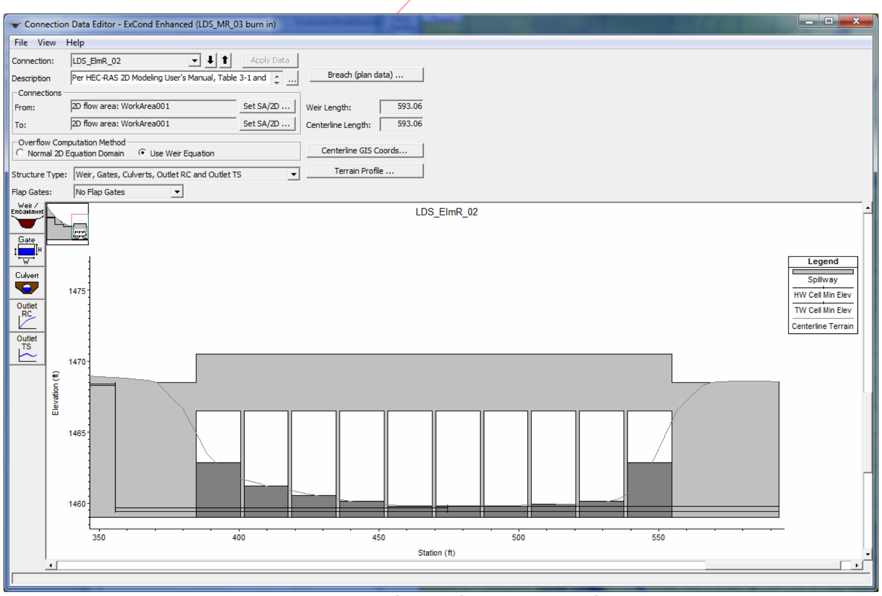

Figure 31: Typical Internal Connection - Bridge

Due to current software limitations within the HEC-RAS, all surveyed bridges such as LDS_ElmR_02 shown in Figure 32 have been modeled as either culverts or gates of equivalent dimensions. In most instances bridges were converted to a faux culvert using a spreadsheet that assumes the piers are uniformly spaced where the distance between the piers represents the culvert span and the distance from the low chord elevation to the invert elevation is the culvert heights. The pier width is used to calculate the distance between multiple barrels if required.

Table 18 shows the calculations required to convert LDS_ElmR_02 from a bridge with 9 piers to a series of culverts with 10 boxes of equivalent dimension of the surveyed bridge.

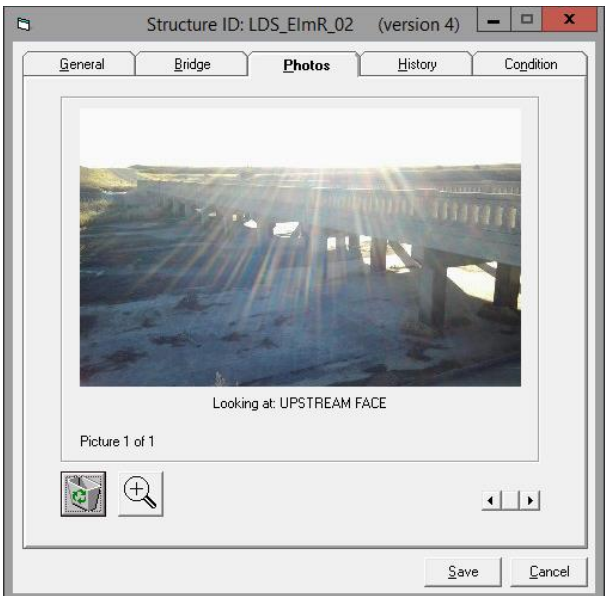

Figure 32: Surveyed Bridge

Table 18: Example of Bridge to Culvert Conversion

Bridge to Culvert Conversion (LDS_ElmR_02)		
Field	**Value (ft)**	**Note**
Sta Lt.	384.63	**<--Enter**
Sta Rt.	554.63	**<--Enter**
CL Sta	**469.63**	**<--Calc'd**
Width	**25**	**<--From LDS Survey**
TOR Elev	**1468.5**	**<--From LDS Survey**
Rail Height	**3.2**	**<--From LDS Survey**

Bridge to Culvert Conversion (LDS_ElmR_02)		
Field	**Value (ft)**	**Note**
Rail Elev	**1471.7**	**<--Calc'd**
Deck Thick	**2**	**<--From LDS Survey**
LC Elev	**1466.5**	**<--Calc'd**
Top Width	**170**	**<--From LDS Survey**
Toe Width	**148**	**<--From LDS Survey**
Channel Top Width	**1350**	**<--From LDS Survey**
Channel Bottom Width	**1349**	**<--From LDS Survey**
No. Piers	**9**	**<--From LDS Survey**
Pier Width	**1.3**	**<--From LDS Survey**
Invert Elev	**1459**	**<--From LDS Survey**
Sta_0	**384.63**	**<--Calc'd**
Faux Culvert Span	**15.83**	**<--Calc'd**
Faux Culvert Rise	**7.5**	**<--Calc'd**
Faux Culvert No.	**10**	**<--Calc'd**
Culvert CL Sta No. 1	**392.545**	**<--Calc'd**
Culvert CL Sta No. 2	**409.675**	**<--Calc'd**
Culvert CL Sta No. 3	**426.805**	**<--Calc'd**
Culvert CL Sta No. 4	**443.935**	**<--Calc'd**
Culvert CL Sta No. 5	**461.065**	**<--Calc'd**
Culvert CL Sta No. 6	**478.195**	**<--Calc'd**
Culvert CL Sta No. 7	**495.325**	**<--Calc'd**
Culvert CL Sta No. 8	**512.455**	**<--Calc'd**
Culvert CL Sta No. 9	**529.585**	**<--Calc'd**
Culvert CL Sta No. 10	**546.715**	**<--Calc'd**

3.6.4 Embedded Structure

Typically when LiDAR is collected, the elevation within waterbodies such as rivers and lakes will be the elevation of the water at the time the LiDAR was flown. Topographic LiDAR does not normally yield reasonable results in these areas due to the presence of floating sediments (see Figure 33). Therefore, when adding field survey into the 2D mesh, there is a high probability that the structure will have a surveyed invert lower than that of DEM.

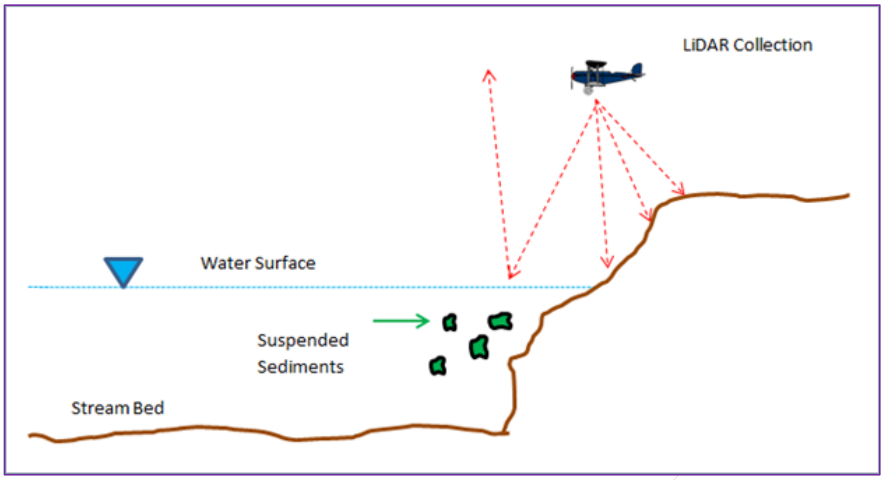

Figure 33: DEM Derived from LiDAR Survey Limitations

The current model configuration within HEC-RAS does not allow the invert elevation of a culvert for example, to be lower than adjacent 2D cells. In lieu of modifying the underlying terrain the submerged portion of the structure can be blocked such that the blocked elevation is equal to or just above the elevation of the adjacent 2D cell (Figure 34).

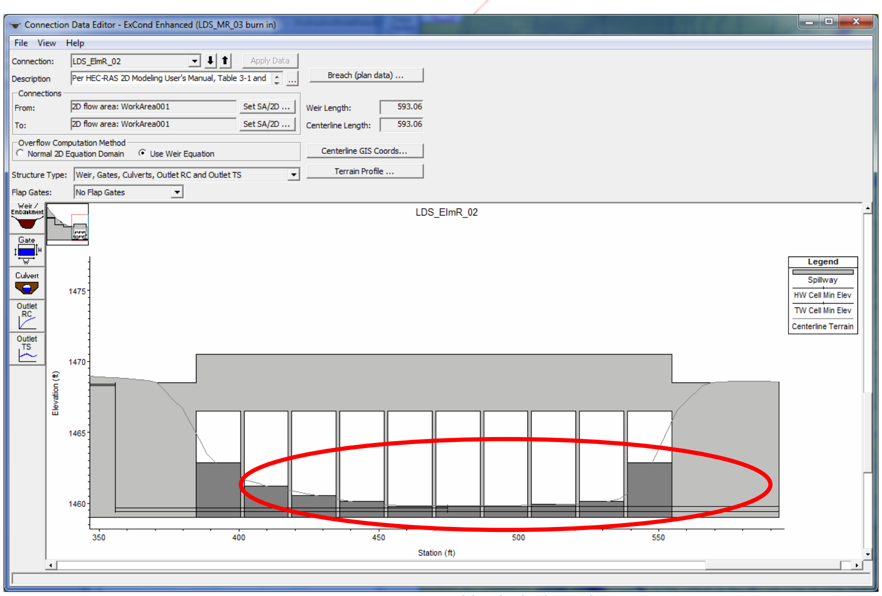

Figure 34: Variable Blocked Depths

3.6.5 Equivalent 1D Model Comparisons

Table 19 provides a general summary of the selected 1D models used to compare against the results of the 2D models. The purpose of these comparisons is to help validate the 2D models, especially where bridges have been simulated as culverts within the 2D domain.

Table 19: Reaches with Equivalent 1D Models

Flooding Source	Downstream Limit of Comparison	Upstream Limit of Comparison	Length (mi)	No. of Structures	Results of Comparison
Unnamed Stream/Ditch in Y1	Starting southwest of 436 Ave. & 306 St	Extending past 437th St.	2.12	2	One structure removed in both 1D and 2D models due to surveyed invert falling below the DEM elevation. Results were favorable between the 1D and 2D models. The 2D model produced slightly higher elevations on the upstream for bridges modeled as culverts
Marne Creek North in Y4	Highway 50	W 23rd St	2.45	2	Results were favorable between the 1D and 2D models with 2D WSEs consistently higher than 1D WSEs. The 2D terrain shows structure locations more clearly.
Marne Creek in Y3	About 325 ft north of W 15th St	Burleigh St	1.75	4	Results were favorable between the 1D and 2D models. The 2D terrain shows structure locations more clearly.

3.7 Computational Parameters

The cell sizes within a 2D model must be adequate to describe the water surface slope and changes in the water surface slope. If the slope of the water does not change rapidly, large cell sizes can be used to accurately compute the water surface elevation. On the other hand, if the water surface slope changes rapidly, then smaller cell sizes are needed. Grid cells were modified within the enhancement reaches to a minimum of 25 feet and a maximum of 200 feet.

HEC-RAS has the ability to perform two-dimensional unsteady flow routing with either the Full Saint Venant (Full Momentum) equations which include added terms for turbulence modeling and Coriolis effects or the Diffusion Wave Equations. In general, the Diffusion Wave equations are more forgiving than the Full Momentum, allowing for larger time steps while still producing a numerically stable and accurate solution. Certain situations, however, call for the Full Momentum equations to be applied to the model. These situations can be areas with rapidly changing velocities over time, abrupt contractions and expansions, or if detailed velocities and water surface elevations are desired at structures. A full comprehensive list of where the Full Momentum equation is generally applied can be found in Chapter 4 of the HEC-RAS 2D User's Manual [4-2].

The following are suggested guidelines from the HEC for picking a computation interval for either 2D Equation.

Saint Venant Equations (Full Momentum):

$$C = \frac{V\Delta T}{\Delta X} \leq 1.0 \; (with\ a \max C = 3.0)$$

Or

$$\Delta T \leq \frac{2\Delta X}{V} \; (with\ C = 1.0)$$

The Diffusion Wave equations:

$$C = \frac{V\Delta T}{\Delta X} \leq 2.0 \; (with\ a \max C = 5.0)$$

Or

$$\Delta T \leq \frac{2\Delta X}{V} \; (with\ C = 2.0)$$

Where: C = Courant Number

V = Flood wave velocity (wave celerity) (ft/sec)

ΔT = Computational time step (sec)

ΔX = Average cell size (ft)

Table 20 provides a summary of the selected 2D equations for each flood source in this study as well as the selected computational parameters. To verify these assumptions, results were reviewed to ensure maximum velocities and Courant numbers were within reasonable limits per the guidelines shown above.

Table 20: 2D Modeling Parameters for this Study

Flooding Source	2D Equation	Base Δt (sec)	Variable Time Step Used (Y/N?)	Max Courant	Min Courant	Max Δt (sec)	Min Δt (sec)
WA10	Full Momentum	5	Y	1	0.4	10	1.25

3.8 Volume Accounting

At the conclusion of 2D simulation a computational log file is written to the disk. This file contains the volume accounting check for the entire simulation. The volume accounting is an important step to gage the overall "health" of a model and is expressed terms of % Error for an entire 2D model.

$$Error = (Ending\ Volume\ - Starting\ Volume) - (Cum\ Inflow - Cum\ Outflow)$$

$$Percent\ Error = \left(\frac{Error}{Cum\ Inflow}\right) * 100$$

2D best practices suggest that the % Error should be less than 1%, but 2-3% can be acceptable depending on the objectives. Values greater than 3% indicate significant problems with the model (TUFLOW User Manual Table 14-1 & Environment Agency of UK, Fluvial Design Guide – Chapter 7).

Volume conservation results were checked for all recurrence intervals for each 2D enhanced flooding source in this study. The results are presented in Table 21.

Table 21: 2D Volume Accounting % Error

Modeled Event	Flooding Source	% Error
10% AC	WA10	0.005266
4% AC	WA10	0.004829
2% AC	WA10	0.02009
1% AC	WA10	0.001698
0.2% AC	WA10	0.003475
1% Minus	WA10	0.01461
1% Plus	WA10	0.005638

3.9 Results Verification

Results from the enhanced 2D model have been verified against the locations and sources listed in Table 22. Figure 35- Figure 43 provide a graphical illustration comparing the enhanced 2D model results for the flood sources listed in Table 22.

Table 22: 2D Verification Locations

Flooding Sources	Verification Type	Identifier	Note
Unnamed Stream/Ditch	Profile line	StreamStats	No FIS/gage available at this location; located in enhancement reach 1
Hillcrest Golf Course Stream	Profile line	StreamStats	No FIS/gage available at this location; located in enhancement reach 2
Marne Creek at Confluence w/ Missouri River	Profile line	FIS study 46135CV000A July 6, 2010 StreamStats	No gage in this location; located in enhancement reach 3
Marne Creek North Above Confluence with Marne Creek Tributary	Profile line	FIS study 46135CV000A July 6, 2010 StreamStats	No gage in this location; located in enhancement reach 3
Marne Creek Tributary Above Confluence with Marne Creek and Marne Creek North	Profile line	FIS study 46135CV000A July 6, 2010 StreamStats	No gage in this location; located in enhancement reach 3
Marne Creek at 23rd Street	Profile line	StreamStats	No FIS/gage available at this location; located in enhancement reach 4
Unnamed Stream/Ditch at 25th Street	Profile line	StreamStats	No FIS/gage available at this location; located in enhancement reach 5
Unnamed Stream at Nichols Avenue	Profile line	FIS study 46135CV000A July 6, 2010 StreamStats	No gage in this location; located in enhancement reach 6

Flooding Sources	Verification Type	Identifier	Note
Unnamed Creek in Irene, SD	Profile line	StreamStats	No FIS/gage in this location; located in Irene reach (T1)

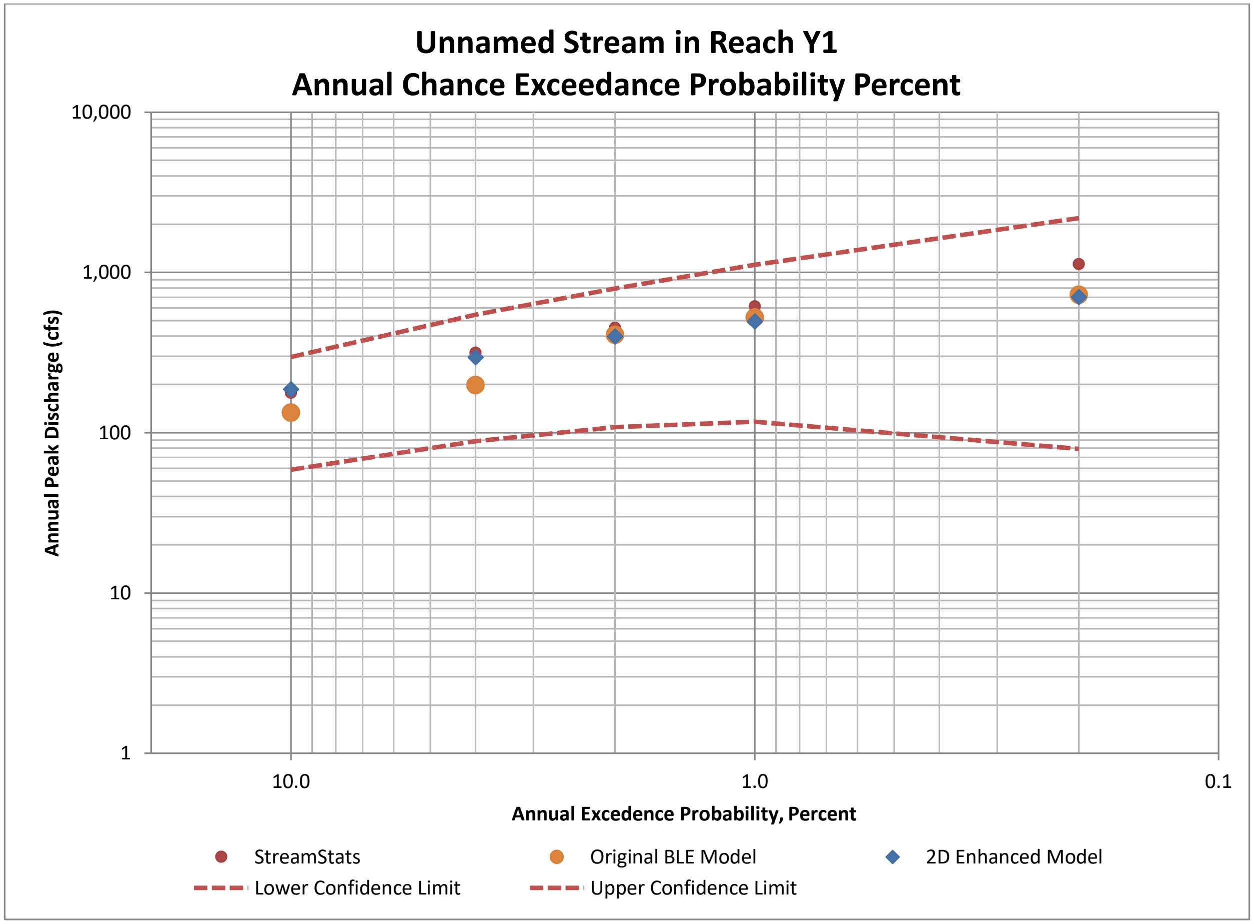

Figure 35: Verification Point No. 1

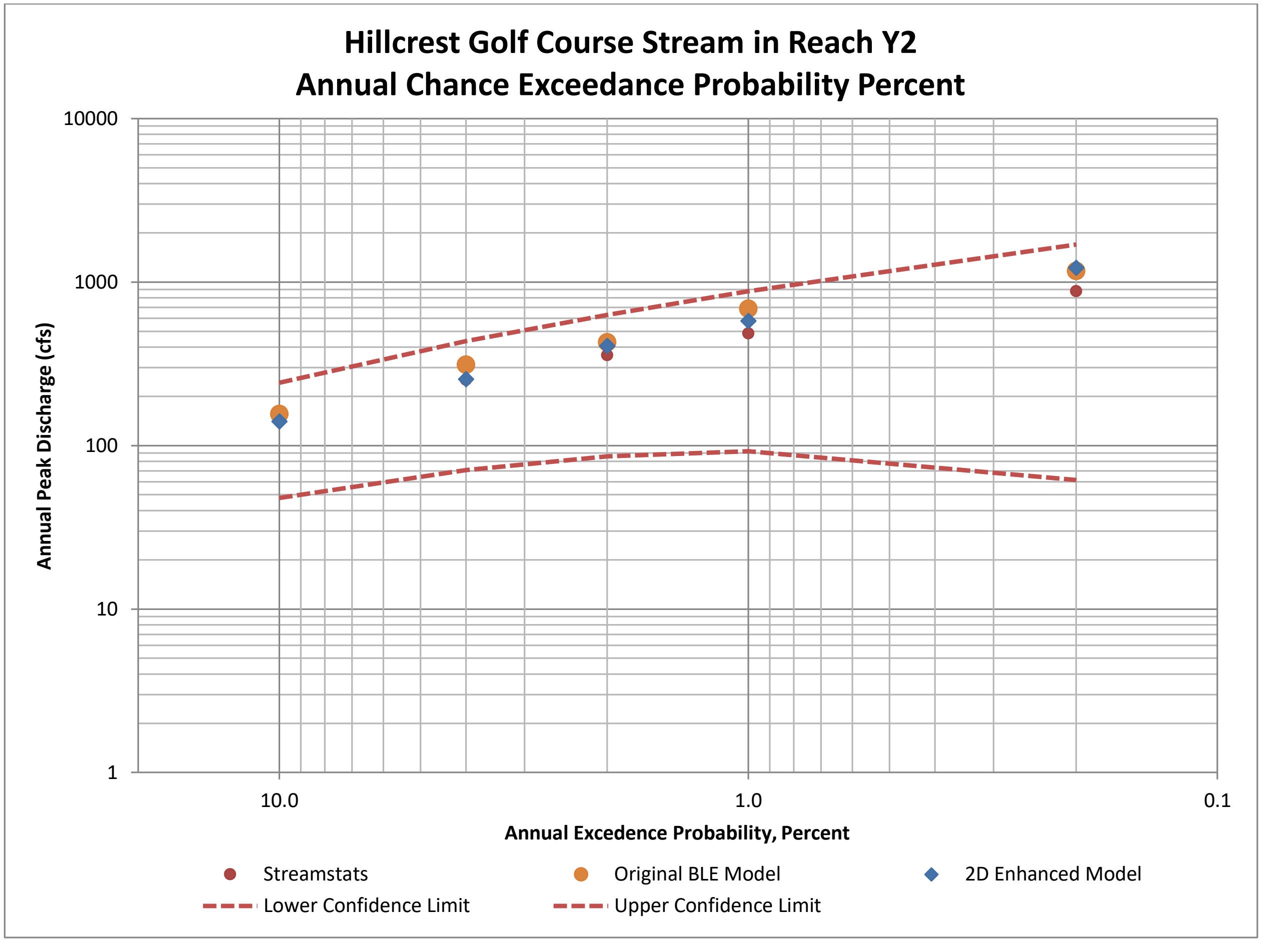

Figure 36: Verification Point No. 2

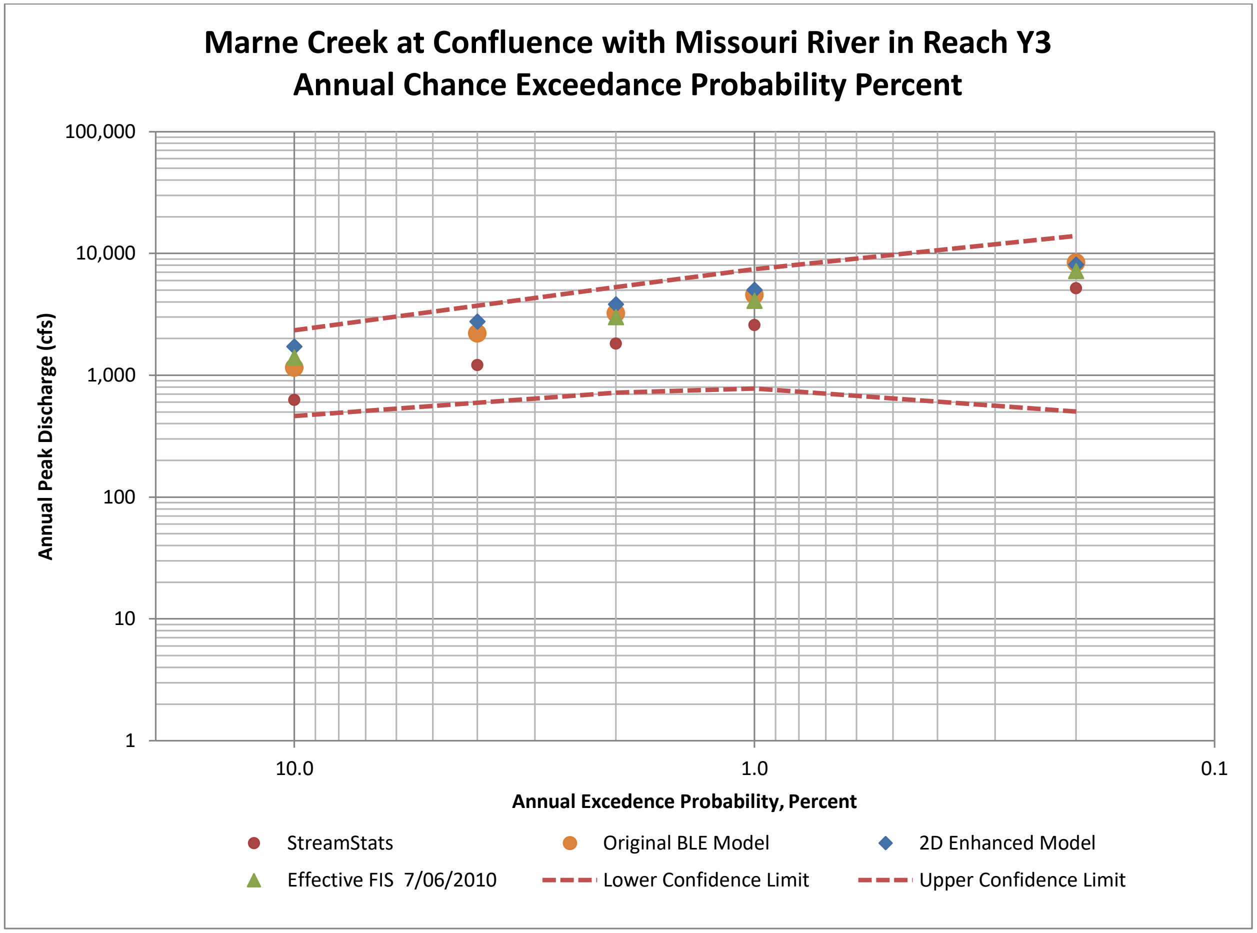

Figure 37: Verification Point No. 3

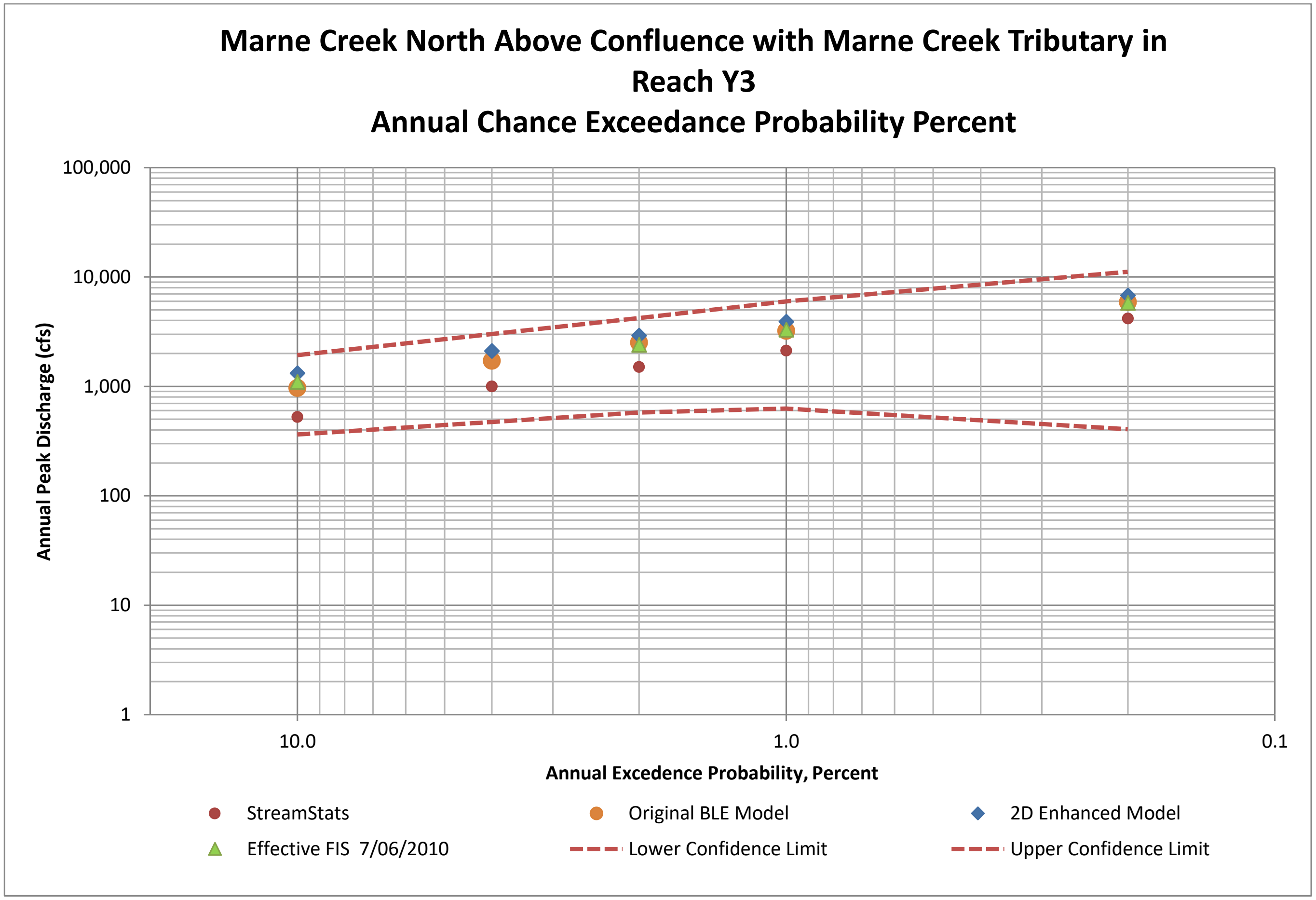

Figure 38: Verification Point No. 4

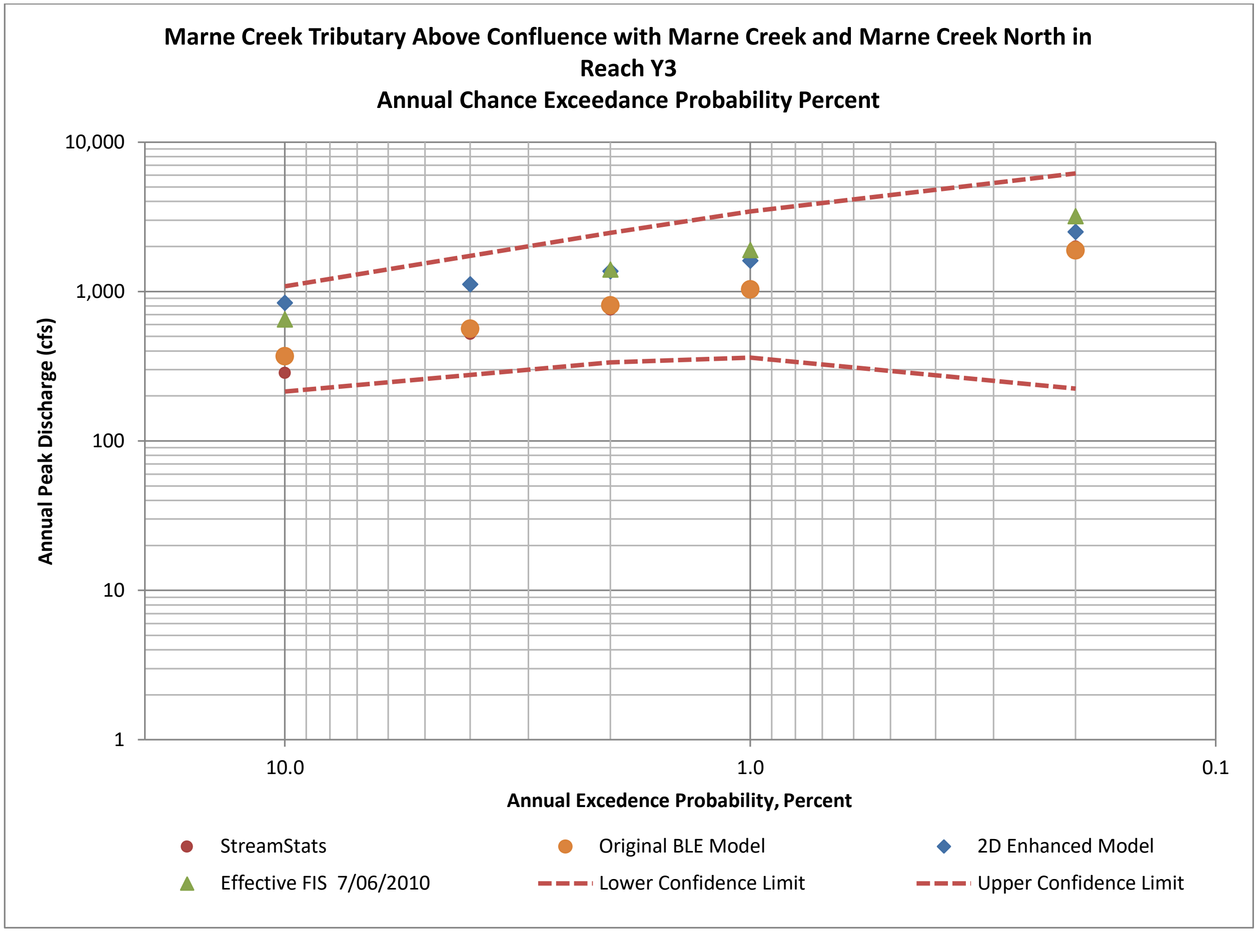

Figure 39: Verification Point No. 5

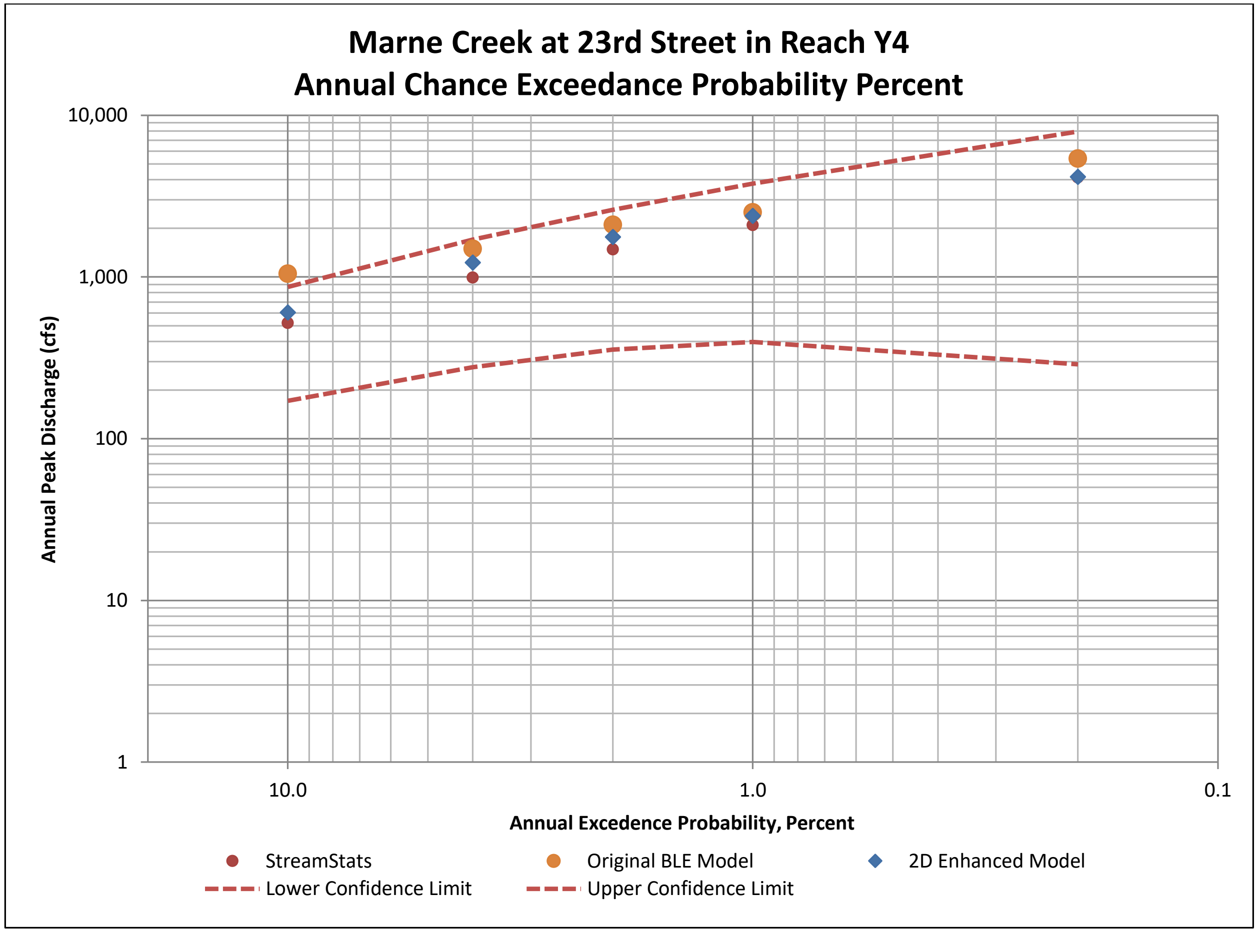

Figure 40: Verification Point No. 6

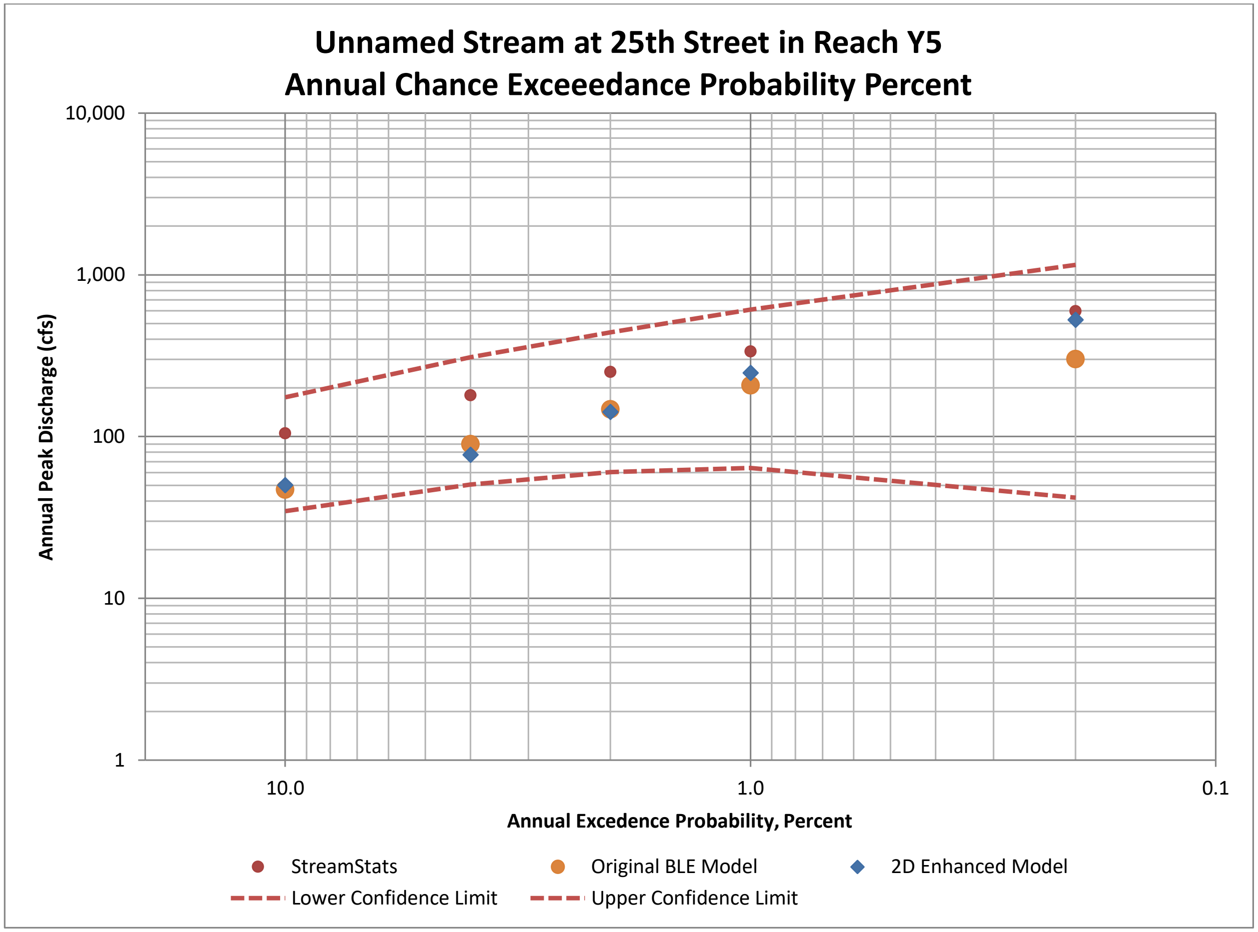

Figure 41: Verification Point No. 7

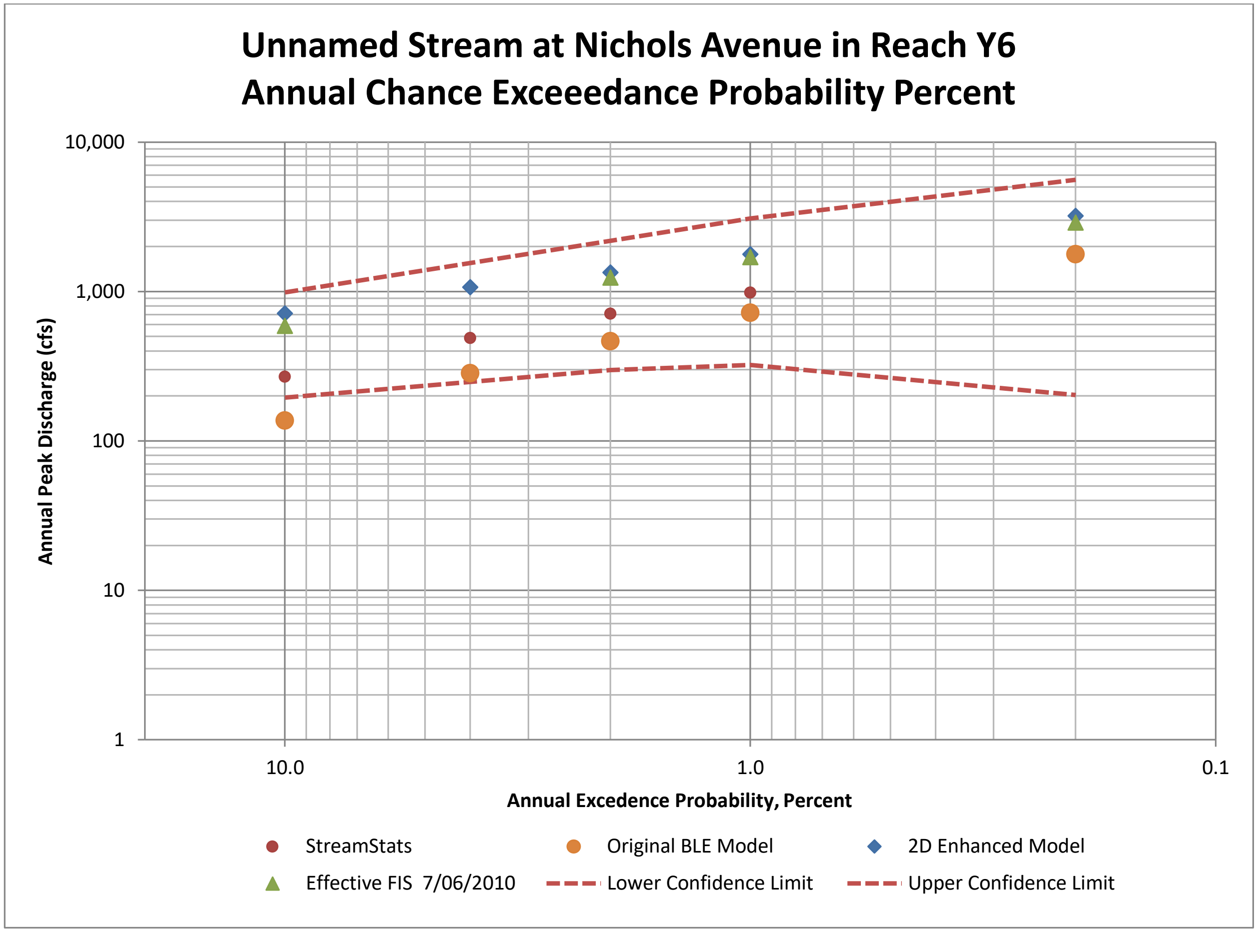

Figure 42: Verification Point No. 8

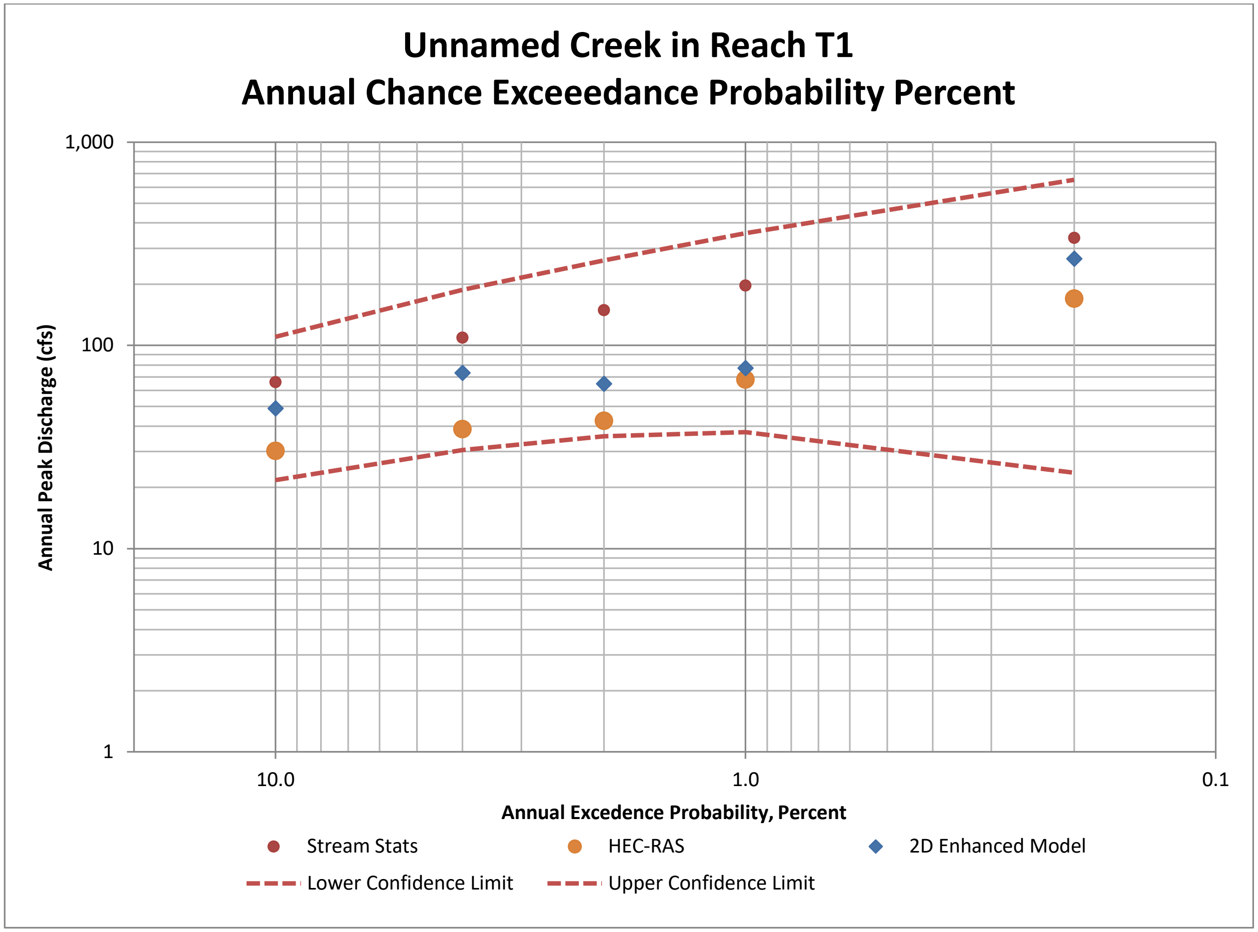

Figure 43: Verification Point No. 9

3.10 Modeling Assumptions

1. The modeling results approximately represent the flood inundation extents for the modeled recurrence interval as if it occurred at every location within the work area simultaneously. Within a large watershed, it is unlikely that an infrequent and extreme rain storm would produce the same rainfall amount across the entire watershed or work area at the same time.
2. Rainfall losses are represented by a single SCS Curve Number (CN) for each computational mesh area, although losses vary within each computational runoff area.
3. Manning's roughness coefficients were selected based on NLCD land cover data and are identical for all modeling scenarios.
4. The computed discharges were developed to approximately equal expected discharges based on stream gage data, regional frequency-peak discharge regression relationships, or published discharges in the FEMA FIS. The uniform CN applied to a 2D Flow Area was the only parameter that was adjusted to produce the expected 100-year peak discharges at the selected discharge calibration locations. Therefore, the selected CN primarily represents the watershed response to rainfall-runoff during a 100-year flood scenario and may not comply with the suggested CN ranges for different storms and land coverage.
5. The selected CN obtained from the 100-year flood scenario was applied to other frequencies of flood scenarios.
6. The Missouri River flows along the southern border of Yankton County, which presented a variety of unique engineering challenges. The expansiveness of the Missouri River floodplain causes significant backwater into the downstream extents of the tributaries flowing to the south through Yankton County, including the James River. Because of this, large portion of the downstream flood extent on these tributaries were controlled by the backwater from the Missouri River. To ensure uniform downstream conditions, a constant flow rate was utilized for the Missouri River inflow hydrograph. Due to the extensive flow regulation on the Missouri River upstream of the study area, this was determined to be a reasonable assumption.
7. For approximate structures, structure invert was determined from the DEM elevation at the inlet and additional information was determined through imagery and streetview. Approximating inverts may fail to show appropriate blockages in the barrels.

3.11 Modeling Challenges

In order to direct water in the streams correctly, stream centerlines were enforced with a cell spacing of 50. This meant that a low time-step was needed, which increased computation time. The floodway in this enhancement reach was also challenging as there were locations where split flow occurs. In addition, the Marne Creek floodway presented challenges due to its length as well as the presence of backwater from the Missouri River that impacted surcharges within the affected part.

04 Floodway

4.1 Floodway

Table 23 provides a list of flooding sources within Yankton County.

Table 23: Flooding Sources with a Floodway Analysis

Flooding Source	Downstream Limit	Upstream Limit	Length (mi)
Marne Creek	Missouri River	Highway 50	5.06
Unnamed Stream/Ditch	Mission Hill City Limit	Mission Hill City Limit	0.91
Unnamed Creek	Irene City Limit	Irene City Limit	0.67

Per methodology described in the FEMA report titled *Best Practice for Flood Risk Analysis and Mapping 2D Modeling: Zone AE Upgrades and Floodways, March 2017,* the floodway analysis for the flooding sources uses the Hazard (Depth x Velocity Product) approach. The approach outlined in this document is currently being evaluated by FEMA and they will be publishing a best practice on it. The Hazard best practice approach for delineating floodways uses the product of a depth raster multiplied by the velocity raster for the 1% annual exceedance probability event. This depth x velocity raster derivative is also known as a flood severity grid. The flood severity grid represents the combined effect of these two rasters (D x V) and is typically communicated in categories of Low, Medium, High, Very High, and Extreme Hazard and represented in units of (ft^2/sec) per the *FEMA Guidance for Flood Risk Analysis and Mapping, Flood Depth and Analysis Grids, May 2014.*

The flood hazard categories and their respective ranges are described as follows in Table 24. Figure 44 shows an example of the 1% annual exceedance probability event flood severity for the flooding sources.

Table 24: Simplified Flood Severity Categories

Flood Severity Category[1]	Depth * Velocity Range (ft^2/sec)
Low	< 2.2
Medium	2.2 – 5.4
High	5.4 – 16.1
Very High	16.1 – 26.9
Extreme	>26.9

[1] D*V Categories per *FEMA Guidance for Flood Risk Analysis and Mapping, Flood Depth and Analysis Grids, May 2014*

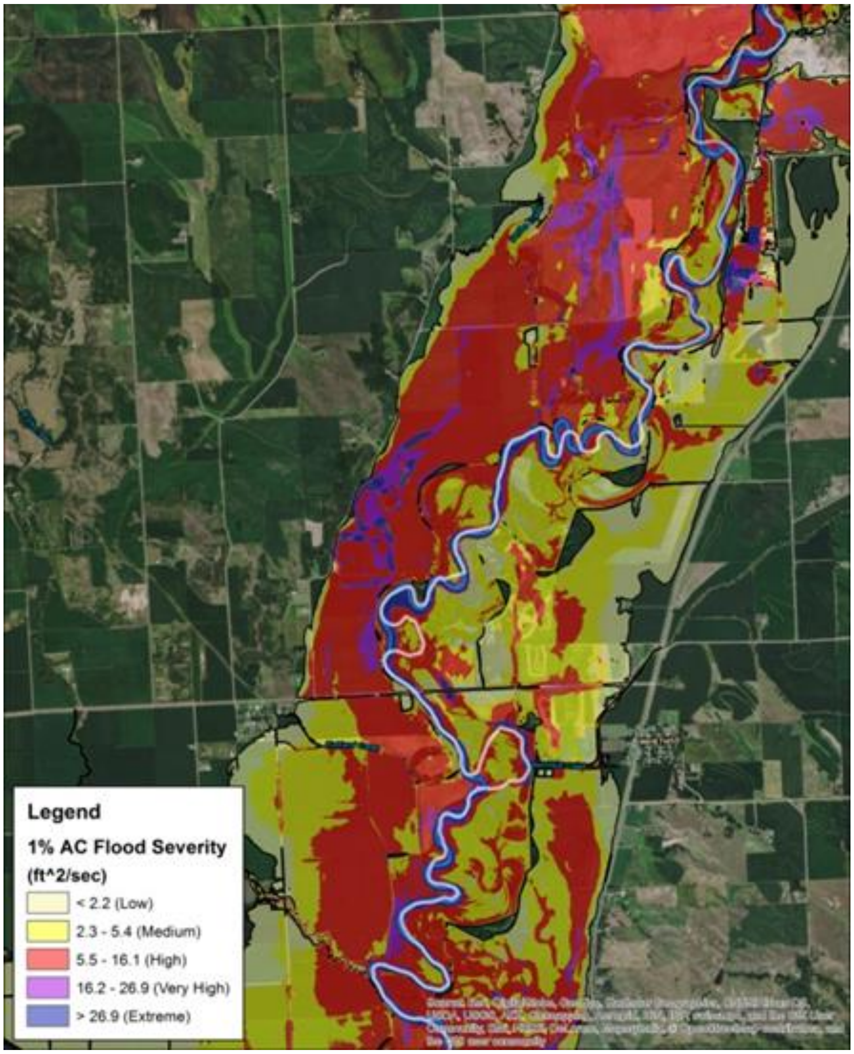

Figure 44: Flood Severity Grid Example

Once the flood severity grid has been defined, the floodway determination can draw from these results by delineating through areas of significant danger of flow velocity and depth in 2D Flow Areas and the 1D stream corridor. Typically, deep swift waters that are greater than 4 ft^2/sec have been used as the starting point for the floodway delineation as they present dangerous conditions for people and structures.

For the floodway analysis within the hydraulic model; a walled raster has been mosaicked into the existing conditions digital elevation model (DEM) of the terrain. The walled raster is used to simulate the encroachment of the base flood within the 2D domain and initially uses the Depth x Velocity data (flood severity) as a guide to assist in the delineation of this boundary.

For a traditional 1D riverine analysis the land adjacent to the floodway delineation must be preserved in order to discharge the base flood without cumulatively increasing the water-surface by more than a designated height. This preserved area is known as the Flood Fringe as shown in Figure 45. In South Dakota the floodway criterion is 1.0 foot. Similarly, for the flood severity floodway approach the land adjacent to the proposed floodway delineation must convey the base flood without increase the water-surface by more than 1.0 feet. Figure 46 shows an example of a proposed floodway delineation using the Depth x Velocity (Flood Severity) raster as a guide.

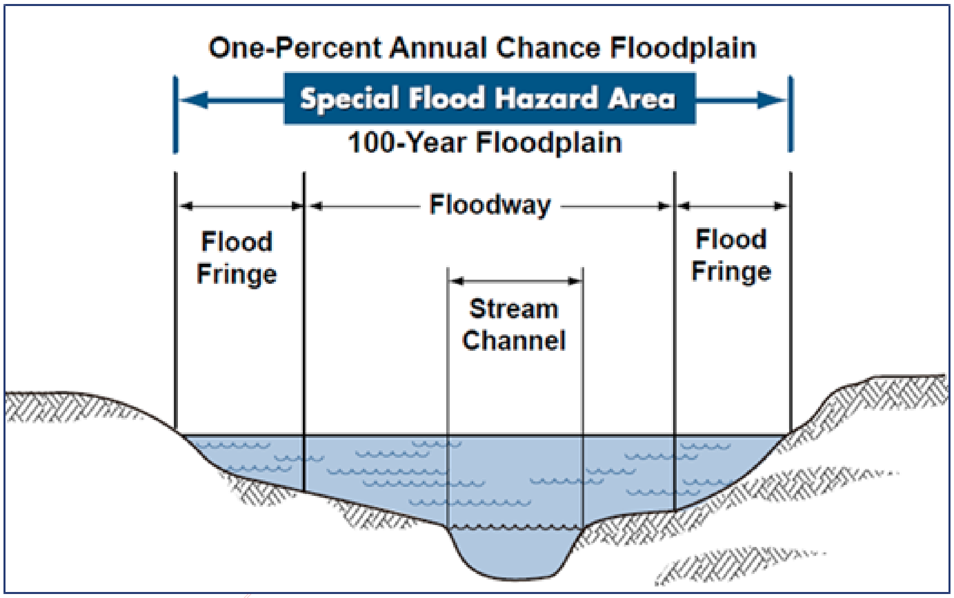

Figure 45: 1% AEP Floodplain

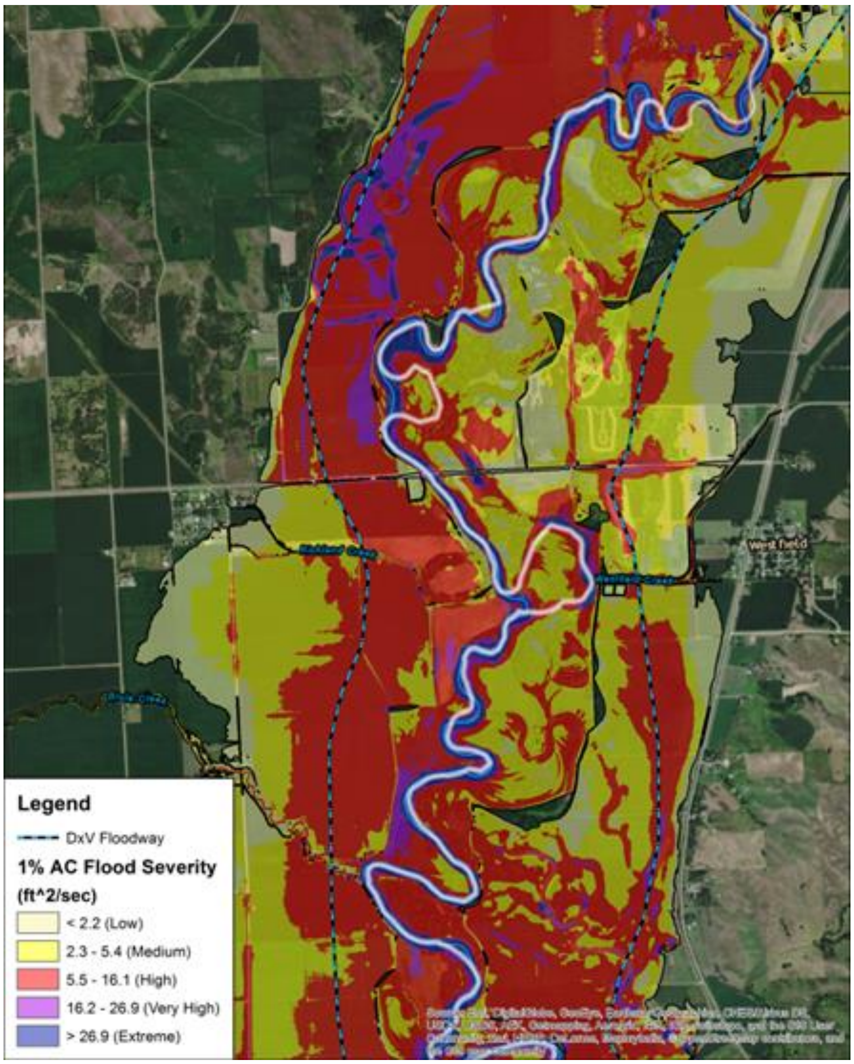

Figure 46: Flood Severity (D*V) Raster with Floodway Delineation

Through an iterative process this walled raster which represents the floodway is adjusted until the desired floodway surcharge is achieved. For South Dakota the floodway surcharge criterion is 0.0 – 1.0 feet.

The surcharge during the iterative process can be determined creating a water-surface change raster. This raster is created by subtracting the 1% annual exceedance probability base flood water-surface elevation against the 1% annual exceedance probability floodway water-surface elevation. This water-surface change raster which depicts the floodway surcharge can then be classified similar to Figure 47 to highlight areas that are out of compliance.

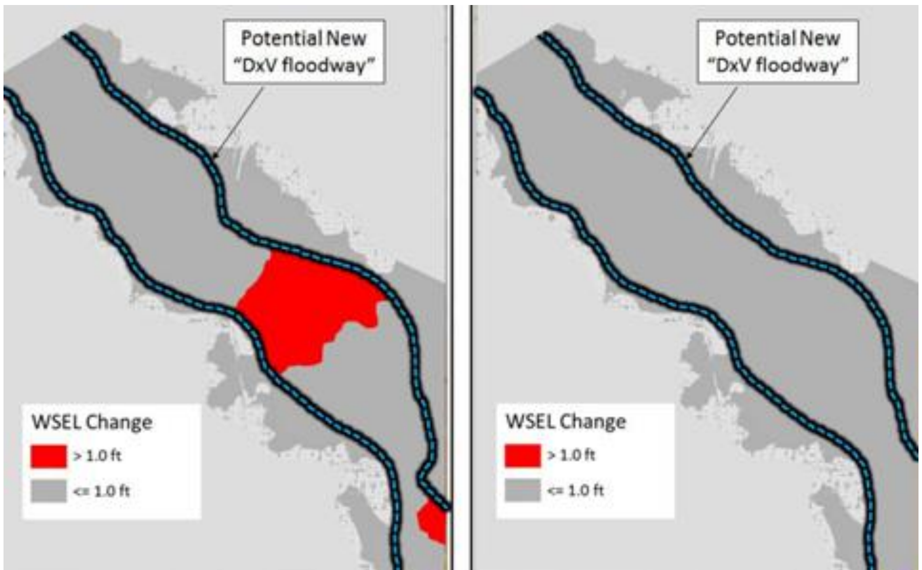

Figure 47: Sample Floodway Derived from Flood Severity (D*V)

05 Floodplain Mapping

The following sections provide a synopsis of how raw modeled depths were translated into Special Flood Hazard Areas (SFHA). Figure 48 illustrates the transition from raw model data to processed flood hazard areas suitable for mapping 1-percent-annual-chance SFHA.

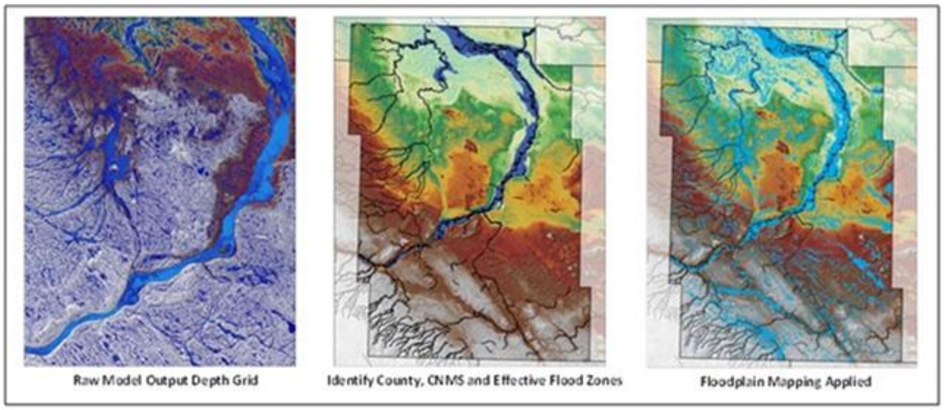

Figure 48: Floodplain Mapping Overview

5.1 Special Flood Hazard Areas

5.1.1 Model Outputs

HEC-RAS acknowledged RAS Mapper may not render model values appropriately for direct export and use in conversion to flood hazard area polygons. As a result, Compass created a workflow using model values for each 2-dimensional cell centroid to create special flood hazard area and non-special flood hazard area mapping features. These point values were used to create high resolution water surface and elevation and depth grids from triangular irregular networks (TINs) that can be converted to FIRM database polygon features. A mapping workflow that considers effective mapping, drainage area, and 2D BLE depth was developed to address where and how previously unmapped areas would receive new special flood hazard area features.

5.1.2 Methodology

Compass exported max water surface elevation, depth, and velocity values for each model's 2-dimensional computational mesh cell centroid. A triangular irregular network (TIN) was created and high resolution water surface elevation, depth, and velocity grids were developed with a 1-meter resolution to match the source terrain DEM. Compass created special flood hazard area and non-special flood hazard area features using the following approach, based on FEMA SID 110:

- 2D BLE 1% annual exceedance probability inundation converted from grid cells to SFHA (Zone A) polygons where:
  - Effective SFHA or CNMS features exist and where

- Flooding source drains greater than 1 square mile and have 2D BLE 1% annual exceedance probability depths greater than 1-foot and where
- Disconnected flooding is greater than 40 acres and has an average depth greater than 0.5-foot (North Dakota request to represented sloughs or other disconnected ponding)

- 2D BLE 0.2% annual exceedance probability inundation results associated with the 2D BLE 1% SFHA extent will be mapped as Shaded Zone X (non-SFHA)

Zone AE areas were derived from enhanced stream reaches and structures along these reaches. Once floodplain mapping made preliminary decisions on the Zone AE polygons, they were sent back to engineering to confirm that the proposed zones fell in line with structures along the reaches and were adjusted as necessary. From there, finalized Zone AE reaches were developed and tied in with Zone A reaches.

BFE lines for Zone AE areas were derived from the 100 year raw WSE grid. The Contour Tool was used in Arc Map to develop contours from the 100 year raw WSE grid at 1 foot intervals. These contours were classified as BFE lines and snapped to the extent of the Zone AE boundaries.

To develop a countywide product, the Union tool in Arc Map was utilized to aggregate overlapping work areas to provide a seamless SFHA and Zone X. Traditional and approved floodplain mapping approaches were used to remove unnecessary points, bends, and angles while preserving the natural shape of the polygon. Furthermore, small voids (or “holes”) inside of the floodplain were aggregated with the larger surrounding polygons to complete the floodplain.

5.1.3 Flood Hazard Area Layer

FIRM database format S_FLD_HAZ_AR were developed and attributed with Zone AE, Zone A and Shaded Zone X features. The S_FLD_HAZ_AR feature class was tested for topological errors described in the FIRM Database Technical Reference and all errors were fixed for data integrity and schema agreement.

06 References

Table 25: Bibliography and References

Citation in this Report	Publisher/ Issuer	*Publication Title,* "Article," Volume, Number, etc.	Author/Editor	Place of Publication	Publication Date/ Date of Issuance	Link
FEMA 2010	Federal Emergency Management Agency	*Flood Insurance Study, Yankton County, South Dakota , and Incorporated Areas*		Washington, D.C.	July 6, 2010	FEMA Flood Map Service Center msc.fema.gov
FEMA 2016	Federal Emergency Management Agency	*FEMA Policy Standards for Flood Risk Analysis and Mapping*		Washington, D.C.	November 1, 2016	https://www.fema.gov/media-library-data/1480449548025-4736d89b89d30fbf102228680c1f8acd/Standards_for_Flood_Risk_Projects_(Nov2016).pdf
FEMA 2017	Federal Emergency Management Agency	*Best Practice for Flood Risk Analysis and Mapping 2D Modeling: Zone AE Upgrades and Floodways*		Washington, D.C.	March 1, 2017	
NLCD 2015	U.S. Department of the Interior, U.S Geological Survey	*Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354*	Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K.	Washington, D.C.	2011	http://bit.ly/1K7WjO3

Citation in this Report	Publisher/ Issuer	*Publication Title,* "Article," Volume, Number, etc.	Author/Editor	Place of Publication	Publication Date/ Date of Issuance	Link
NOAA 2008	U.S. Department of Commerce, NOAA (National Oceanic and Atmospheric Administration)	*Atlas-14, Volume 8, Hydrometeorological Design Studies, Precipitation Frequency Data Server*		Washington D.C.	2013	http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume8.pdf
South Dakota 2012	*The State of South Dakota*	*South Dakota LiDAR Project*		Lompoc, California	January 1, 2012	
USACE 2000	U.S. Army Corps of Engineers, Hydrologic Engineering Center	*Hydrologic Modeling System HEC-HMS, Technical Reference Manual*		U.S. Army Corps of Engineers Center, 609 Second Street, Davis, CA 95616-4687	March 2000	HEC-HMS Technical Reference Manual
USACE 2012	U.S. Army Corps of Engineers, Hydrologic Engineering Center	*HEC-GeoRAS, GIS Tools for Support of HEC-RAS using ArcGIS 10*	Hydrologic Engineering Center	U.S. Army Corps of Engineers Center, 609 Second Street, Davis, CA 95616-4687	May 1, 2012	http://www.hec.usace.army.mil/software/hec-georas/downloads.aspx
USACE 2016	U.S. Army Corps of Engineers, Hydrologic Engineering Center	*HEC-RAS River Analysis System, User's Manual, Version 5.0*	Hydrologic Engineering Center	U.S. Army Corps of Engineers Center, 609 Second Street, Davis, CA 95616-4687	February 1, 2016	http://www.hec.usace.army.mil/

Citation in this Report	Publisher/ Issuer	*Publication Title,* "Article," Volume, Number, etc.	Author/Editor	Place of Publication	Publication Date/ Date of Issuance	Link
USACE 2017	U.S. Army Corps of Engineers, Hydrologic Engineering Center	*HEC-RAS River Analysis System, version 5.0.5*	Hydrologic Engineering Center	U.S. Army Corps of Engineers Center, 609 Second Street, Davis, CA 95616-4687	April 1, 2016	http://www.hec.usace.army.mil/
USGS 1982	U.S Department of the Interior, U.S. Geological Survey	*Guidelines for Determining Flood Flow Frequency, Bulleting #17B of the Hydrology Subcommittee*	Interagency Advisory Committee on Water Data	Washington, D.C.	March 1982	http://water.usgs.gov/osw/bulletin17b/dl_flow.pdf
USGS 1998	U.S Department of the Interior, U.S. Geological Survey	*Techniques for Estimating Peak Flow Magnitude and Frequency Relations for South Dakota Streams* *WRIR 98-4055*	Steven K. Sando	Washington, D.C.	1998	http://pubs.water.usgs.gov/wri984055
USGS 2017	U.S. Department of the Interior, U.S Geological Survey	*USGS WaterWatch Toolkit, Flood Table & Rating Curve Builder*		Washington, D.C.	May 1, 2017	https://waterwatch.usgs.gov/
USGS 2017	U.S. Department of the Interior, U.S Geological Survey	*Peak Streamflow for South Dakota Streams*		Washington, D.C.		https://nwis.waterdata.usgs.gov/nwis/peak?state_cd=SD&format=station_list

Citation in this Report	Publisher/ Issuer	*Publication Title,* "Article," Volume, Number, etc.	Author/Editor	Place of Publication	Publication Date/ Date of Issuance	Link
WISE 2004	Watershed Concepts	*WISE (Watershed Information System)*		Greensboro, North Carolina	2004	

07 Appendix

INSERT PDFs of WISE OPEN SYSTEM COUNTY WIDE SURVEY EXPORTS

Commented [MS1]: N:\Compass_2D\RTO\R8\SD\60550589_YanktonCoFY17\400_PRODUCTION\Engineering\(Watershed-Sub-basin name)\Limited Detail\Survey\Deliverables\Reports
Include all 66 pages? Will fill out this section once exported to PDF