APPENDIX C

WEST CONSULTANTS INC. – HYDRAULIC SUMMARY REPORT

Yellowstone River Hydraulic Modeling and Floodplain Mapping

SUMMARY REPORT

February 2013

Prepared for:

US Army Corps of Engineers
Omaha District

Yellowstone River Hydraulic Modeling and Floodplain Mapping

Summary Report

February 2013

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Prepared for:

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1 INTRODUCTION

1.1 BACKGROUND

The U.S. Army Corps of Engineers, Omaha District (the District), in conjunction with the Yellowstone River Conservation District Council (YRCDC), is conducting a cumulative impacts assessment for the Yellowstone River corridor to develop a comprehensive plan that provides for sustainable use of the river and its floodplain for both economic and environmental needs. The Yellowstone River Cumulative Effects Study examines hydrologic, hydraulic, geomorphic, biologic and socioeconomic characteristics of and impacts on the Yellowstone River and adjacent floodplain in a 565-mile reach from Gardiner, Montana, to the confluence with the Missouri River in western North Dakota. The extent of the Yellowstone River corridor is shown in Figure 1-1.

As part of the cumulative impacts assessment, WEST studied the impacts of human development (including man-made structures, encroachments, storage, diversions, and depletions) on the Yellowstone River hydraulic profiles and flood boundaries by comparing current and historic conditions.

Figure 1-1. Yellowstone River Corridor

1.2 STUDY PURPOSE AND SCOPE

The purpose of this study was to perform hydraulic modeling and floodplain mapping for six counties in the Yellowstone River corridor: Treasure, Rosebud, Custer, Prairie, and Richland Counties in Montana and McKenzie County in North Dakota.

Table 1-1 summarizes the Yellowstone River reaches in each county. A separate hydraulic model was constructed for each county, with the exception of Richland and McKenzie Counties which were combined. Floodplains for each county were delineated based on the modeling results.

Table 1-1. Yellowstone River Corridor Counties Studied

Location	YRCDC River Miles
Treasure County	259 to 298
Rosebud County	204 to 259
Custer County	158 to 204
Prairie County	120 to 158
Richland/McKenzie County	0 to 64

Two geometric conditions were modeled and mapped for each county: Developed and Undeveloped. The Developed geometry represents the current conditions of the river and floodplain including bridges, dams, embankments, roads, levees, and other man-made structures. The Undeveloped geometry represents the historic conditions of the river and floodplain with all man-made structures removed.

Two sets of flow conditions were provided by the District: Regulated and Unregulated. The Regulated flows represent current flow conditions resulting from human-controlled reservoirs, irrigation canals, etc. The Unregulated flows represent historic flow conditions without human impacts.

1.3 PROJECT AUTHORIZATION AND ACKNOWLEDGMENTS

This study was performed for the U.S. Army Corps of Engineers, Omaha District, by WEST Consultants, Inc. under Contract No. W9128F-09-D-0002, Task Order No. 16.

Laurel Hamilton, P.E., and Roger Kay, P.E., served as the technical points of contact (POC) for the USACE Omaha District.

Christine Parente, P.E., was the WEST Consultants project manager and technical lead and provided overall modeling and mapping guidance and review. Cameron Jenkins, P.E., and Pedro Miguel Parames, P.E., served as project hydraulic engineers. Kurt Baron, GISP, and Sam Powvall processed terrain data and performed floodplain mapping. Dragoslav Stefanovic, P.E., performed technical review of the hydraulic models and Jake Gusman, P.E., performed report review. Martin Teal, P.E., P.H., provided overall study review and oversight.

2 HYDRAULIC MODEL DEVELOPMENT

Separate HEC-RAS hydraulic models were developed for the five counties listed in Table 1-1. This chapter summarizes the hydraulic model data and parameters used and describes the model development.

2.1 MODEL DATA

2.1.1 TOPOGRAPHY

LiDAR topographic data collected in 2007 was provided by the District for all six counties included in the study. The LiDAR data was downloaded in DEM format (cell size 2.5 meters) from the Yellowstone River Corridor Resource Clearinghouse (Montana State Library website). Each county had locations where the LiDAR data did not extend to high ground and additional topographic data was necessary to fully represent the floodplains. The USGS 1/3-Arc Second National Elevation Dataset was used as the topographic data when this occurred. The DEM tiles for each county (and the immediately adjacent tiles for neighboring counties) along with any supplemental USGS data, were then merged to create a single continuous DEM for each county.

The vertical datum for all of the DEMs is NAVD88 (meters) and the horizontal datum is Montana State Plane, NAD83 (meters). All elevations referenced in this report are NAVD88 (meters). Aerial imagery collected in 2007 was also downloaded from the Yellowstone River Corridor Resource Clearinghouse.

2.1.2 HYDROLOGY

Flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002* (USGS, 2011, draft). Two flow conditions (Regulated and Unregulated) were provided in the report and included in the Yellowstone River hydraulic models. The Regulated flows represent current flow conditions resulting from human-controlled reservoirs, irrigation canals, etc. The Unregulated flows represent natural flow conditions without man-made regulation or diversions. Ten flow events were modeled for each county, including the 5 percent duration flow, and the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year percent probability flows. Flows in the USGS study correspond to the reaches defined by the YRCDC and were reported in cubic feet per second (cfs) and WEST converted to cubic meters per second (cms) for this study. Table 2-1 provides a summary of the discharges used along with corresponding YRCDC reaches and HEC-RAS cross sections.

Table 2-1. Peak Flows for Yellowstone River

HEC-RAS Cross Section	Flow Condition	Computed Peak Discharges (cubic meters per second, cms)										YRCDC Reach or Gage Number
		5% Duration	1.5-yr	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr	200-yr	500-yr	
Treasure County												
XS 61918	Unregulated	1,285.6	1,565.9	1,750.0	2,200.2	2,491.9	2,752.4	3,129.0	3,400.9	3,681.2	4,049.3	C11
	Regulated	965.6	1,166.7	1,336.6	1,744.3	2,007.7	2,234.2	2,568.3	2,803.4	3,029.9	3,341.4	
Rosebud County												
XS 87898	Unregulated	1,285.6	1,565.9	1,752.8	2,203.1	2,494.7	2,755.2	3,129.0	3,398.0	3,681.2	4,049.3	C12
	Regulated	965.6	1,166.7	1,339.4	1,747.1	2,007.7	2,234.2	2,565.5	2,800.5	3,029.9	3,341.4	
XS 33275	Unregulated	1,285.6	1,565.9	1,752.8	2,203.1	2,494.7	2,752.4	3,126.2	3,395.2	3,681.2	4,021.0	C13
	Regulated	965.6	1,166.7	1,339.4	1,747.1	2,007.7	2,231.4	2,565.5	2,797.7	3,029.9	3,341.4	
Custer County												
XS 73418	Unregulated	4,021.0	1,568.8	1,752.8	2,203.1	2,494.7	2,752.4	3,126.2	3,392.4	3,652.9	4,021.0	C14
	Regulated	3,341.4	1,169.5	1,339.4	1,747.1	2,007.7	2,231.4	2,562.7	2,792.0	3,029.9	3,341.4	
XS 59615	Unregulated	4,021.0	1,568.8	1,755.6	2,203.1	2,494.7	2,752.4	3,123.3	3,392.4	3,652.9	4,021.0	C15
	Regulated	3,313.1	1,169.5	1,339.4	1,747.1	2,007.7	2,228.5	2,559.8	2,792.0	3,029.9	3,313.1	
XS 53935	Unregulated	4,021.0	1,568.8	1,755.6	2,205.9	2,494.7	2,752.4	3,123.3	3,392.4	3,652.9	4,021.0	C16
	Regulated	3,313.1	1,169.5	1,339.4	1,747.1	2,007.7	2,228.5	2,559.8	2,789.2	3,029.9	3,313.1	
XS 43424	Unregulated	3,851.1	1,605.6	1,795.0	2,234.8	2,509.2	2,735.4	3,080.9	3,315.9	3,539.6	3,851.1	06309000 (Miles City, MT)
	Regulated	3,058.2	1,180.8	1,363.7	1,774.3	2,017.9	2,194.6	2,491.9	2,673.1	2,860.0	3,058.2	
XS 35607	Unregulated	3,851.1	1,605.6	1,795.3	2,234.2	2,508.9	2,735.4	3,080.9	3,315.9	3,539.6	3,851.1	C18
	Regulated	3,058.2	1,180.8	1,364.9	1,775.5	2,019.0	2,194.6	2,491.9	2,673.1	2,860.0	3,058.2	
XS 30211	Unregulated	3,907.7	1,614.1	1,803.8	2,251.2	2,531.5	2,763.7	3,117.7	3,361.2	3,596.2	3,907.7	C19
	Regulated	3,114.9	1,186.5	1,373.4	1,792.5	2,041.6	2,225.7	2,531.5	2,721.2	2,888.3	3,114.9	
XS 11806	Unregulated	3,936.0	1,614.1	1,806.6	2,254.0	2,534.4	2,769.4	3,126.2	3,369.7	3,596.2	3,936.0	C20
	Regulated	3,143.2	1,189.3	1,376.2	1,795.3	2,047.3	2,231.4	2,540.0	2,729.7	2,916.6	3,143.2	

HEC-RAS Cross Section	Flow Condition	Computed Peak Discharges (cubic meters per second, cms)										YRCDC Reach or Gage Number
		5% Duration	1.5-yr	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr	200-yr	500-yr	
Prairie County												
XS 61391	Unregulated	1,328.1	1,616.9	1,809.4	2,256.9	2,540.0	2,775.1	3,131.8	3,378.2	3,624.6	3,936.0	C21
	Regulated	993.9	1,189.3	1,376.2	1,798.1	2,053.0	2,237.0	2,548.5	2,741.1	2,916.6	3,143.2	
XS 48400	Unregulated	1,393.2	1,710.3	1,928.4	2,469.2	2,826.0	3,154.5	3,616.1	3,958.7	4,304.2	4,785.5	N/A
	Regulated	1,039.2	1,277.1	1,498.0	2,030.3	2,367.3	2,647.6	3,075.2	3,366.9	3,652.9	4,021.0	
XS 45608	Unregulated	1,393.2	1,710.3	1,931.2	2,472.1	2,828.9	3,157.3	3,618.9	3,964.4	4,304.2	4,785.5	D1
	Regulated	1,039.2	1,277.1	1,500.8	2,030.3	2,367.3	2,650.5	3,078.0	3,369.7	3,652.9	4,021.0	
XS 26606	Unregulated	1,396.0	1,713.2	1,934.0	2,477.7	2,837.3	3,168.7	3,635.9	3,981.3	4,332.5	4,813.9	D2
	Regulated	1,042.1	1,279.9	1,503.6	2,038.8	2,378.6	2,664.6	3,095.0	3,392.4	3,681.2	4,049.3	
XS 14724	Unregulated	1,404.5	1,724.5	1,951.0	2,506.0	2,874.2	3,216.8	3,698.2	4,057.8	4,417.4	4,927.1	D3
	Regulated	1,047.7	1,291.2	1,520.6	2,067.1	2,418.3	2,715.6	3,163.0	3,471.6	3,766.1	4,162.6	
Richland/McKenzie County												
XS 103500	Unregulated	1,410.2	1,738.7	1,973.7	2,548.5	2,922.3	3,256.4	3,737.8	4,086.1	4,445.7	4,898.8	D10
	Regulated	1,047.7	1,302.6	1,534.8	2,115.3	2,494.7	2,837.3	3,327.2	3,681.2	4,049.3	4,502.4	
XS 90682	Unregulated	1,410.2	1,738.7	1,976.5	2,551.3	2,925.1	3,253.6	3,735.0	4,077.6	4,417.4	4,870.5	D11
	Regulated	1,047.7	1,302.6	1,534.8	2,118.1	2,503.2	2,851.5	3,349.9	3,712.3	4,077.6	4,559.0	
XS 80182	Unregulated	1,407.4	1,738.7	1,976.5	2,557.0	2,928.0	3,253.6	3,729.3	4,069.1	4,417.4	4,870.5	D12
	Regulated	1,047.7	1,302.6	1,537.6	2,120.9	2,508.9	2,865.7	3,369.7	3,740.7	4,105.9	4,615.6	
XS 58263	Unregulated	1,407.4	1,738.7	1,980.8	2,561.5	2,932.8	3,250.8	3,723.7	4,055.0	4,389.1	4,813.9	06329500 (Sydney, MT)
	Regulated	1,044.9	1,302.6	1,536.8	2,127.4	2,522.7	2,891.2	3,403.7	3,786.0	4,162.6	4,700.6	

2.2 MODEL DEVELOPMENT

The Yellowstone River was modeled using HEC-RAS *River Analysis System*, Version 4.1 (USACE, 2010). Stream centerline, cross sections, flow paths, and bank lines were created for each county using ArcGIS (Version 9.3) with the HEC-GeoRAS extension (Version 4.2). Cross sections were placed at a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. Cross sections were also placed along upstream and downstream bridge faces. Table 2-2 provides a summary of the total length and cross section spacing for each model. Cross sections were labeled using River Miles based on the YRCDC River Miles provided.

Table 2-2. HEC-RAS Model Cross Section Summary

County	Model Length (km)	No. of Cross Sections (Developed/Undeveloped)	Average Cross Section Spacing (meters)
Treasure County	61.9	178/176	351
Rosebud County	87.7	279/276	318
Custer County	73.2	246/242	302
Prairie County	61.6	193/188	328
Richland/McKenzie County	98.7	326/323	306

A geometry file was created for Developed and Undeveloped conditions for each model. The Developed conditions geometry represents the current conditions of the river and floodplain including bridges, dams, embankments, roads, levees, and other man-made structures. The Undeveloped conditions geometry represents the historic conditions of the river and floodplain with all man-made structures removed. For each condition (Developed and Undeveloped), two geometry files were created. Separate geometries were created for low-flows and high-flows to provide a better representation of the ineffective areas at different river stages. The classification of low and high flows was determined based on where a significant change in the flows occurred and is shown in Table 2-3.

Table 2-3. Low and High Flow Designations

County	Low-flows (Regulated)	High Flows (Regulated)	Low-flows (Unregulated)	High Flows (Unregulated)
Treasure County **Rosebud County** **Custer County** **Prairie County**	5%, 1.5-, 2-, 5-, 10-, 20-, 50-, and 100-yr	200- and 500-yr	5%, 1.5-, 2-, 5-, 10-, and 20-yr	50-, 100-, 200-, and 500-yr
Richland/McKenzie County	5%, 1.5-, 2-, 5-, 10-, 20-, and 50-yr	100-, 200-, and 500-yr	5%, 1.5-, 2-, 5-, 10-, and 20-yr	50-, 100-, 200-, and 500-yr

Each geometry file was used with both the Regulated and Unregulated flows (shown in Table 2-1) for the following four scenarios: Developed Conditions with Regulated Flows, Developed Conditions with Unregulated Flows, Undeveloped Conditions with Regulated Flows, and Undeveloped Conditions with Unregulated Flows. This resulted in a total of forty profiles for each model. The following sections describe the model parameters. Appendix A provides individual model summaries for each of the five counties and Appendix B provides specific modeling notes that were included in the final submittal for each of the county models.

2.2.1 Roughness Values

A Manning's roughness shapefile was provided by the District for the five counties being modeled. Roughness values ranged from 0.028 in the channel to 0.10 for developed areas with artificial cover (pavement or other impervious areas). Table 2-4 summarizes the roughness values applied to the Yellowstone River and the overbanks. Roughness values were extracted using the GeoRAS extension and imported into the HEC-RAS models. A number of cross sections had more than the allowable 20 horizontal roughness values. The roughness values were merged and consolidated down to 20 values at these cross sections.

Table 2-4. Manning's Roughness Values

Class Code	Description	Manning's Roughness Value
w	Water	0.028
c	Crop cover	0.035
h1, h2, h3	Herbaceous/Graminoid complex	0.040
p1	Open canopy, short woody	0.050
r1	Open canopy, tall woody	0.055
s	Closed canopy, short woody	0.060
t	Closed canopy, tall woody	0.070
a	Artificial cover	0.100
XX	N/A (outside vegetative study limits)	0.051

The roughness value shapefile provided by the District did not cover the downstream portion of McKenzie County. However, riparian vegetation mapping was available from the Yellowstone River Riparian Vegetation Mapping report (DTM Consulting, 2008), which provided a shapefile with delineated vegetation classes for the Yellowstone River and overbanks in McKenzie County down to the confluence with the Missouri River. The vegetation classes identified for this portion of McKenzie County were cross referenced with the vegetation classes identified in the District's roughness shapefile and appropriate Manning's *n* values were assigned.

Bank stations were generally placed near the 1.5-year water surface elevation to denote bankfull flow. Some cross sections included multiple roughness values within the channel which was a result of large islands in the channel with higher roughness values.

2.2.2 DOWNSTREAM BOUNDARY CONDITIONS

Downstream boundary conditions for Treasure, Rosebud, and Custer Counties were based on the known water surface elevations from the calibrated adjacent downstream county hydraulic model. Dawson County is located downstream of Prairie County and known water surface elevations were not available at the time of the Prairie County hydraulic modeling. Therefore, the downstream boundary condition for Prairie County was based on normal depth calculations using a friction slope estimated from the main channel profile (0.00047).

The downstream end of the Richland/McKenzie hydraulic model is located at the Missouri River confluence. Both rivers have large drainage areas at the confluence (Missouri River approximately 95,000 mi^2, Yellowstone River approximately 68,000 mi^2); however, it was assumed that the two peaks would not be coincident based on the difference in drainage areas and the regulation that occurs along the Missouri River. Therefore, the downstream boundary condition for was based on normal depth calculations using a friction slope estimated from the main channel profile (0.00025). A sensitivity analysis was performed on the friction slope value and the results confirmed this value was appropriate.

2.2.3 LOW-FLOW CHANNEL MODIFICATION

The LiDAR elevation data provided by the District did not include bathymetry below the water surface. However, the LiDAR data does represent the water surface elevation of the river at the time the data was obtained. A low-flow channel was inserted in the models and the computed water surface elevation was calibrated to the LiDAR elevation data by adjusting channel depths. The calibration goal was to achieve a computed water surface elevation within +/- 0.3 meters of the observed LiDAR elevation.

Low-flow channel calibration flows were determined for each county based on the dates the aerial photography and LiDAR data were obtained (dates provided by the District). Four USGS gages with daily flow data available are located within the five counties, as shown in Figure 2-1. Low-flow channel calibration values were calculated at the upstream end of each County, as well as at any major flow change location (large tributaries or diversions). The low-flow channel calibration flows are summarized in Table 2-5.

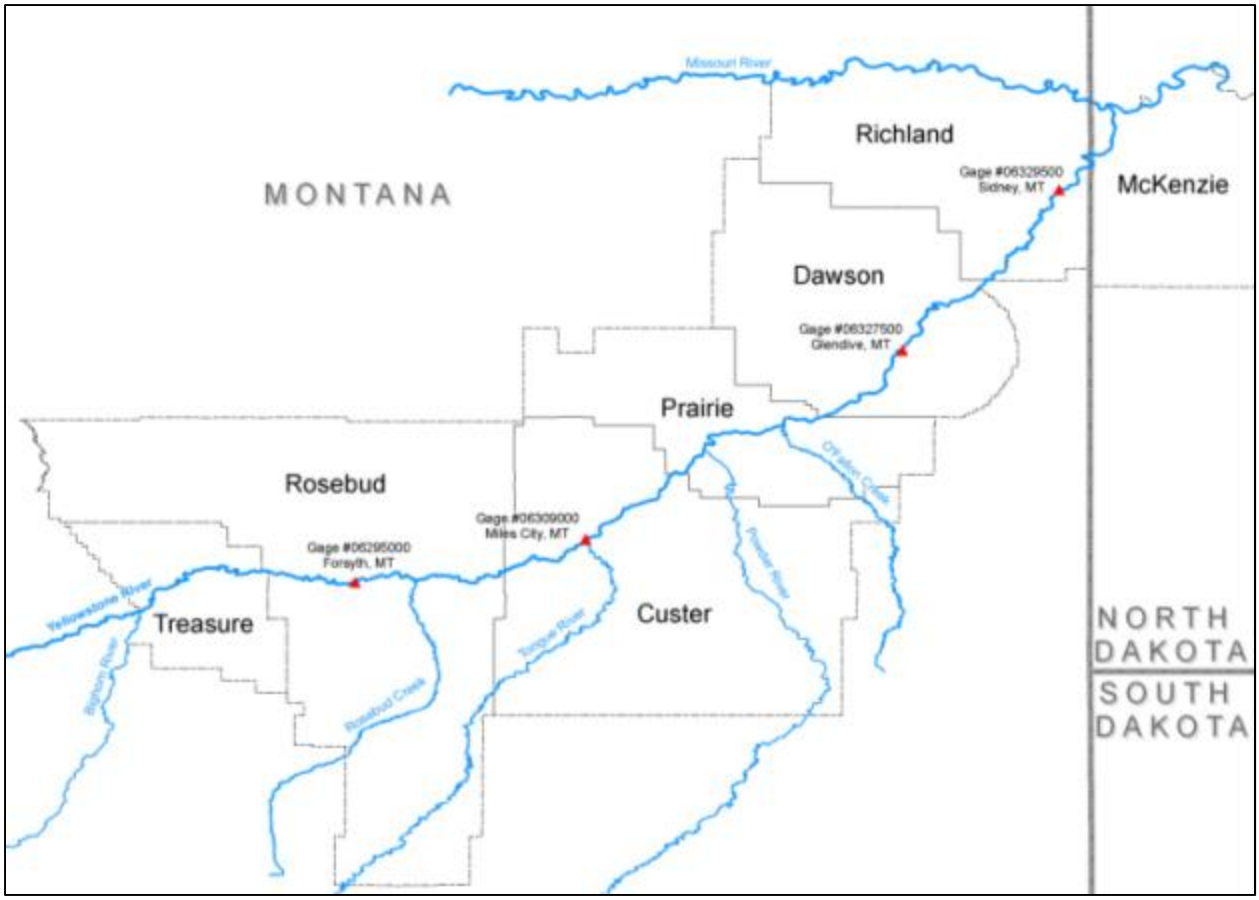

Figure 2-1. USGS Gage Locations

Table 2-5. Low-flow Channel Calibration Flows

County and Flow Location	Date Data Obtained (all in 2007)	Flow (cms)
Treasure County		
Entire reach	10/23 and 10/24	169.3
Rosebud County		
U/S Rosebud Creek	10/23 and 10/24	173.9
D/S Rosebud Creek (XS 33275)		180.7
Custer County		
Entire reach	10/24	184.3
Prairie County		
U/S Powder River	10/24	187.2
D/S Powder River (XS 45914)		217.1
D/S Main Irrigation Canal (XS 6375)		176.8
Richland/McKenzie County		
Entire reach	10/15	159.4

After the flows were determined, the following channel modification steps were completed for each of the five models to calibrate the low-flow channel.

1. A new geometry file was created to perform the low-flow channel calibration using the low-flow calibration flows shown in Table 2-5.
2. Bank stations in the cross sections were placed at the water surface edge using aerial imagery and the LiDAR data as an aid. The bank stations marked the portion of the cross section that would be modified during the low-flow channel calibration.
3. Beginning at the downstream end of each model, the Channel Modification tool in HEC-RAS was used to adjust the depth of the low-flow channel (side slopes were assumed to be vertical walls). In an attempt to preserve the original slope reflected in the LiDAR data, low-flow channel depths were initially adjusted on a reach basis (rather than at individual cross sections) to avoid radical changes to the slope. Low-flow channel depths at individual cross sections were then fine-tuned to reach the calibration goal.

With few exceptions, the calibration goal of +/- 0.3 meters accuracy was achieved for all of the models. At the request of the District, conservative (higher) water surface elevations were obtained during calibration efforts by adjusting the channel depths so that the computed water surface was greater than the LiDAR elevation, where feasible. Table 2-6 summarizes the results of the low-flow calibration for each model. Profile comparisons for each of the five models are provided in Appendix C.

Table 2-6. Low-flow Channel Calibration Summary

County	Low-flow Channel Depth		Difference Between Computed WS and LiDAR Elevation	
	Average (m)	Maximum (m)	Average (m)	Maximum (m)
Treasure County	1.24	1.57	0.12	0.63
Rosebud County	1.25	1.75	0.11	0.30
Custer County	1.10	1.80	0.10	0.66
Prairie County	1.31	1.80	0.09	0.30
Richland/McKenzie County	1.28	1.65	0.11	0.75

2.2.4 Bridges and Levees

Seventeen bridges were included in the Developed conditions geometry and are listed in Table 2-7. The District provided survey data and photographs for each bridge. The survey data included bridge deck data, pier data, and one surveyed underwater cross section at the bridge. Contraction and expansion coefficients were increased at the bridges to 0.3 and 0.5, respectively.

The HEC-RAS levee feature was used in the Developed conditions geometry to define high ground where flow is unable to reach the landward side. This included two major levees constructed for flood protection at Forsythe, MT (Rosebud County) and Miles City, MT (Custer County), agricultural levees, and major roads.

Table 2-7. Bridge Locations

Bridge/Road Name	HEC-RAS Location	YRCDC River Mile
Treasure County		
Old Myers (Hysham) Bridge (piers only)	XS 43660	286.72
Myers (Hysham) Bridge	XS 43230	286.45
Rosebud County		
Forsythe Bridge – Highway 12	XS 56353	239.85
Old Forsythe Bridge (piers only)	XS 55879	239.55
Rosebud Bridge – Highway 446	XS 32620	225.05
Custer County		
Paragon Bridge	XS 49425	189.65
Fort Keough Bridge	XS 44545	186.62
Highway 22 Bridge	XS 40500	184.10
Kingsley Bridge	XS 21310	172.12
Prairie County		
Calypso (Milwauke) Bridge	XS 38642	144.55
Highway 235 Bridge	XS 26616	137.03
Old Highway 235 Bridge (piers only)	XS 26471	136.70
Interstate 94 Bridge	XS 9598	126.40
Frontage Road Bridge	XS 9523	126.37
Richland/McKenzie County		
Highway 23 (Sydney) Bridge	XS 49844	31.10
Fairview Pedestrian Bridge	XS 14952	9.23
Highway 68 (Fairview) Bridge	XS 14629	9.03

2.2.5 INEFFECTIVE FLOW LIMITS

Ineffective flow areas were incorporated into the models based on evaluating the cross sections and water surface profiles for the range of flows modeled (see Table 2-3). Throughout all six counties, the Yellowstone River has significant meandering of the main channel, with a number of oxbows and side channels. Ineffective areas were placed where appropriate based on the portions of each cross section that realistically convey flow for the range of flows modeled. Ineffective flow areas were placed upstream and downstream of bridges to reflect the contraction and expansion of flow at the bridge openings. Ineffective flow areas were also placed at levees when the flow overtopped a levee. This prevented the area behind the levee being included in the total effective flow area.

2.2.6 UNDEVELOPED CONDITIONS

Once the Developed conditions geometry was completed, the Undeveloped conditions geometry was created to represent the natural state of the Yellowstone River. All man-made structures were removed from the Developed conditions geometry cross sections in HEC-RAS, including bridges, bridge embankments, roads, railroads, levees, irrigation canals and ditches. These structures were identified using aerial imagery, elevation data, and a physical feature inventory provided by the District.

Manning's roughness values were adjusted in the Undeveloped conditions geometry to reflect presumed natural conditions. Areas of cross sections with roughness values representing man-made land use (0.035 – crop cover, 0.10 – impervious cover) were changed to equal the roughness value of adjacent land use. Contraction and expansion coefficients that had been increased around bridges were decreased back to values of 0.1 and 0.3, respectively. At bridge locations, the downstream bounding cross section was removed for the Undeveloped conditions geometry and the upstream bounding cross section was modified by removing the embankments from the geometry.

2.2.7 DIFFICULTIES AND ASSUMPTIONS

During the pre-processing setup of Treasure County, a large gap in LiDAR elevation data was discovered at the downstream end of the County along the border of Rosebud County that spanned the entire left side of the main channel. While the missing data was requested from the District, cross sections were placed on either side of the gap (XS 634 and XS 1863) with the potential to add more cross sections once the elevation data was obtained. The missing elevation data was not obtained prior to completion of the Treasure County hydraulic model, so a 1,200 meter gap is present in the cross sections at that location. The energy slope has a low gradient through this reach so the water surface profiles were minimally affected.

3 MODEL CALIBRATION

Each Developed conditions hydraulic model was calibrated to available data that included high water marks (HWM) provided by the District and USGS gage data (USGS, website). The calibration goal was to achieve a computed water surface elevation within +/- 0.5 meters of the observed water surface elevation. Roughness values, ineffective flow areas, and the modified low-flow channel were the parameters that were adjusted during calibration.

With few exceptions, the calibration goal of +/- 0.5 meters accuracy was achieved for each of the five models (see Table 3-1). High water mark MR11-WT1-MT-1014-006 in Treasure County is located on the Bighorn River near the confluence of the Yellowstone River, and not actually on the Yellowstone River. The HWM was included in the available data because the backwater from the Yellowstone River can cause flooding on the Bighorn River at the Interstate 94 Bridge. However, for the observed flow, the backwater did not reach upstream to the I-94 Bridge and this HWM was most likely caused by flooding on the Bighorn River and not from the Yellowstone River.

Calibration attempts were made for the four HWM's in Prairie County; however, after discussion with the District, it was determined that the HWM elevations and observed flows were questionable and that no further calibration was necessary for the Prairie County hydraulic model.

High water marks MR11-WT3-MT-1017-104 and 105 in Richland/McKenzie County and USGS Gage #06329500 are located at the Highway 23 Bridge. Computed water surface elevations are 0.3 meters below the recorded stage at the USGS gage for the observed flow, but approximately 2 meters higher than the District HWM's at the bridge. Since there are known discrepancies in the District HWM's, the recorded stage at the gage is considered more accurate and no further calibration was necessary for the hydraulic model.

All of the HEC-RAS models were thoroughly reviewed by a WEST technical reviewer as documented in Appendix E (Quality Control Report and Certification).

Table 3-1. HEC-RAS Model Calibration Summary

District HWM Mark Number or USGS Gage Number	Location	Flow (cms)	Approximate Flow Event	Observed Water Surface Elevation (m)	Computed Water Surface Elevation (m)	Difference (m)
Treasure County						
MR11-WT1-MT-1014-006	I-94 Bridge (D/S) – Bighorn River*	2,095	< 5-yr	824.9	823.7	-1.2
MR11-WT1-MT-1016-001	Myers Bridge (U/S)			810.9	810.6	-0.3
MR11-WT1-MT-1016-002	Myers Bridge (D/S)			810.5	810.5	0.0
Rosebud County						
MR11-WT1-MT-1016-003	Forsythe (Hwy 12) Bridge (U/S)	2,095	< 5-yr	768.4	768.7	0.3
MR11-WT1-MT-1016-004	Forsythe (Hwy 12) Bridge (D/S)			768.4	768.6	0.2
USGS Gage #06295000	Old Forsythe Bridge			767.7	768.1	0.4
MR11-WT1-MT-1016-005	Rosebud (Hwy 446) Bridge (U/S)	2,155	< 5-yr	755.2	754.8	-0.4
MR11-WT1-MT-1016-006	Rosebud (Hwy 446) Bridge (D/S)			755.0	754.7	-0.3
Custer County						
USGS Gage #06309000	Highway 22 Bridge (U/S)	2,330	> 5-yr	716.2	716.4	0.2
MR11-WT1-MT-1016-007	Highway 22 Bridge (U/S)			716.2	716.4	0.2
MR11-WT1-MT-1016-008	Highway 22 Bridge (D/S)			715.9	716.4	0.5
Prairie County						
MR11-WT1-MT-1016-0010	Highway 235 Bridge (U/S)	3,500	< 50-yr	662.8	663.9	1.1
MR11-WT1-MT-1016-009	Highway 235 Bridge (D/S)			663.0	663.8	0.8
MR11-WT1-MT-1017-002	Interstate 94 Bridge (U/S)			655.9	655.2	-0.7
MR11-WT1-MT-1017-001	Frontage Road Bridge (D/S)			655.7	655.1	-0.6
Richland/McKenzie County						
MR11-WT3-MT-1017-104	Sydney (Hwy 23) Bridge (U/S)	3,170	~ 15-yr	578.8	580.9	2.1
MR11-WT3-MT-1017-105	Sydney (Hwy 23) Bridge (D/S)			578.7	580.5	1.8
USGS Gage #06329500	Sydney (Hwy 23) Bridge (D/S)			580.6	580.3	-0.3

*HWM located on a tributary near the confluence of the Yellowstone River and not on the Yellowstone River

4 FLOODPLAIN MAPPING APPROACH

Floodplains for the Yellowstone River hydraulic models were generated using ArcGIS 9.3 and the HEC-GeoRAS 4.2 extension for the four scenarios: Developed Conditions with Regulated Flows, Developed Conditions with Unregulated Flows, Undeveloped Conditions with Regulated Flows, and Undeveloped Conditions with Unregulated Flows. With ten flow events modeled for each scenario, there were a total of 40 floodplains for each of the models.

Output files from the final HEC-RAS models were imported into ArcGIS and the original floodplains were generated. The floodplains had to be extended to reach the county lines, therefore the mapping was extended into adjacent counties at the upstream and downstream ends. This was accomplished by copying cross sections from the adjacent counties (if available) into the HEC-GeoRAS model and extending the bounding polygons to include these cross sections. Cross sections were not available for Dawson or Yellowstone Counties at the time of mapping, which affected Prairie County (downstream), Richland/McKenzie County (upstream), and Treasure County (upstream). To extend the mapping at these locations, a cross section was created just outside the county being mapped based on the water surface elevations of the most upstream/downstream cross section in that county.

The bounding polygons created in the HEC-GeoRAS process were placed at the end of each cross section or at the location of a levee feature (if used) and were joined by straight lines between cross sections. At locations where the actual levee was not a straight line between cross sections, inundated areas outside of the bounding polygon that should have been included in the floodplain were cut off, as shown in Figure 4-1. The bounding polygons were extended to follow the path of the levee to ensure that the floodplains and depth grids include the entire inundated area.

At some locations (typically the outside of bends), the HEC-RAS cross sections did not extend far enough to include the entire inundated area in between cross sections and floodplains were cut off by the bounding polygon, as shown in Figure 4-2. The cross sections and bounding polygons were extended to ensure that the floodplains and depth grids included the entire inundated area (to the extent of the LiDAR elevation data).

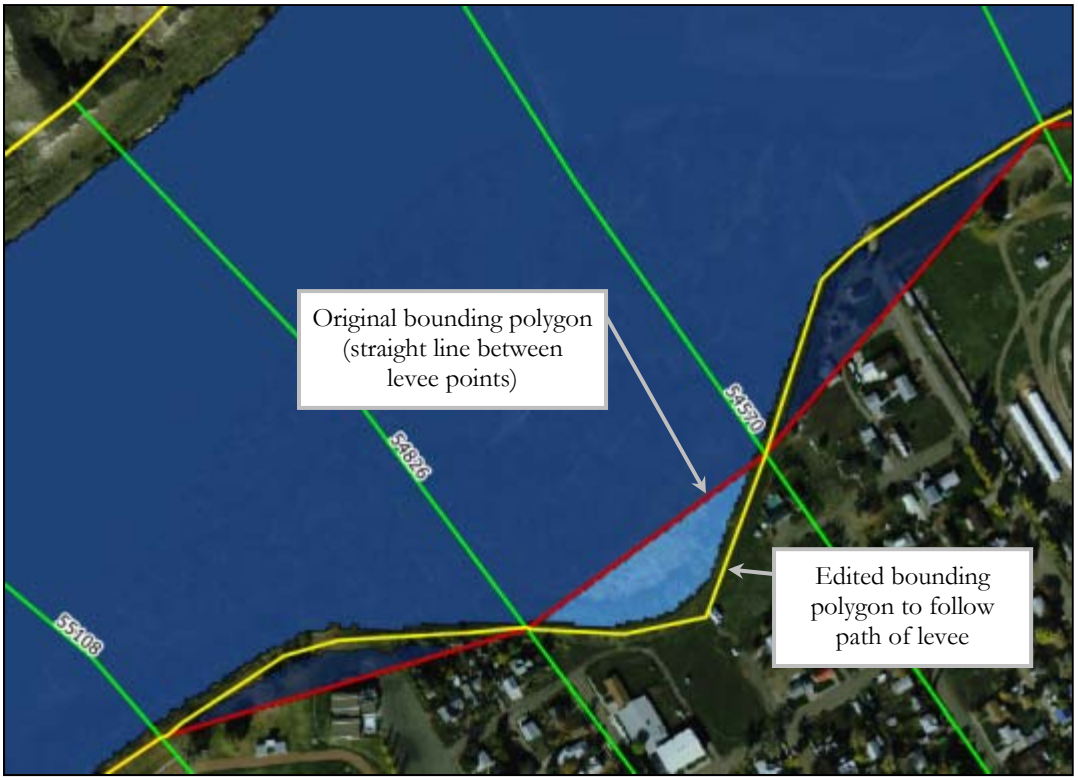

Figure 4-1. Bounding Polygon Extensions at Levee Features

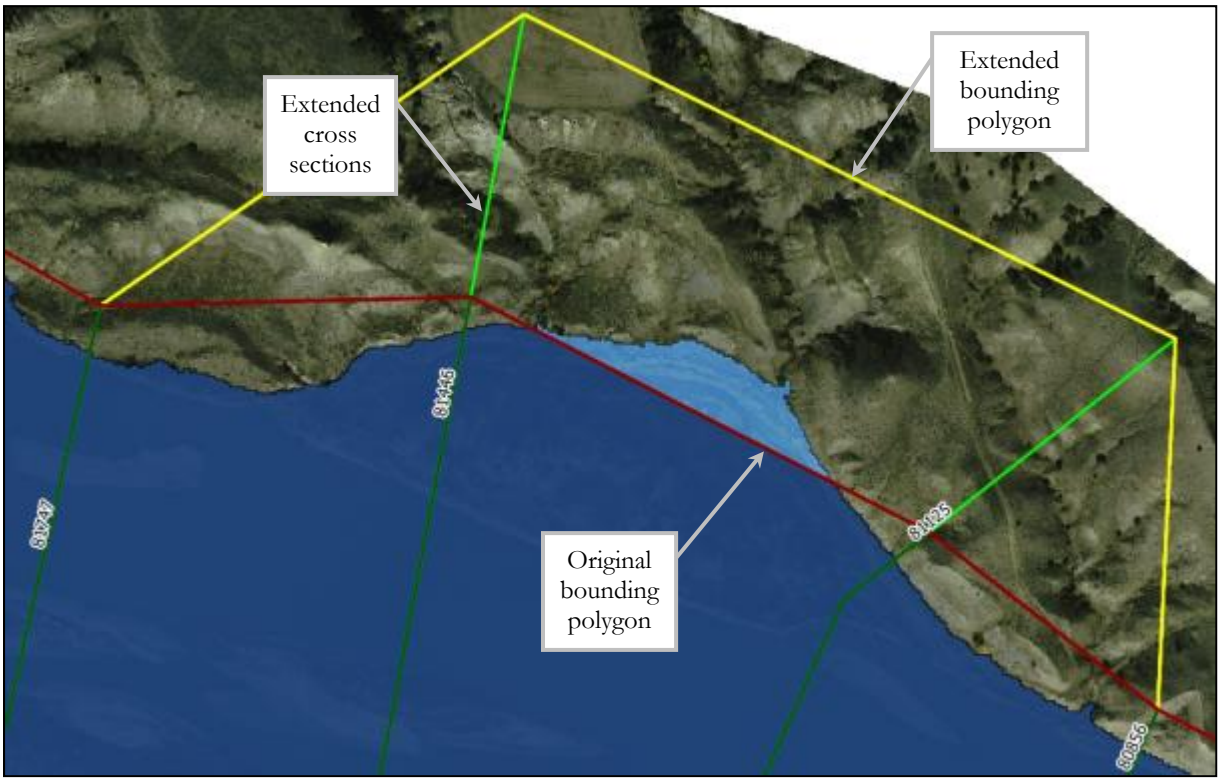

Figure 4-2. Bounding Polygon Extensions at Cross Section Limits

4.1 BACKWATER AREAS

Backwater areas are defined as floodplain areas that connect to the main channel floodplain at their downstream end, but with no connectivity on the upstream end of the ponded area. The backwater areas should be mapped based on water surface elevations where the flow exits the main channel at the downstream end, rather than the main channel water surface elevations.

Major backwater areas were identified based on the original floodplains. Small backwater areas or backwater areas that only affected a single profile were ignored and mapped based on main channel elevations. The following method was used to map the identified backwater areas. Figure 4-3 demonstrates an example of the backwater mapping process described below.

1. A cross section shapefile was created for each flow event using the water surface elevations for that event.
2. For flow events that produced backwater areas, the cross sections were cutoff at the high ground separating the main channel and the backwater area.
3. A 3-D polyline was created along the ends of the cross sections (at the high ground). The 3-D polyline elevations were based on the main channel water surface elevations for the flow event.
4. A backwater line was drawn parallel to the 3-D polyline and was assigned an elevation based on the backwater elevation (water surface elevation where the flow exits the main channel). The backwater line was snapped to the original cross sections ends to encompass the entire backwater area.
5. Once all the backwater areas were addressed for the affected flow event, a water surface TIN was created using the cut cross sections, the 3-D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations) as input.
6. The new water surface TIN's (along with the extended bounding polygons) were used to generate the draft floodplains and depth grids for each flow event.

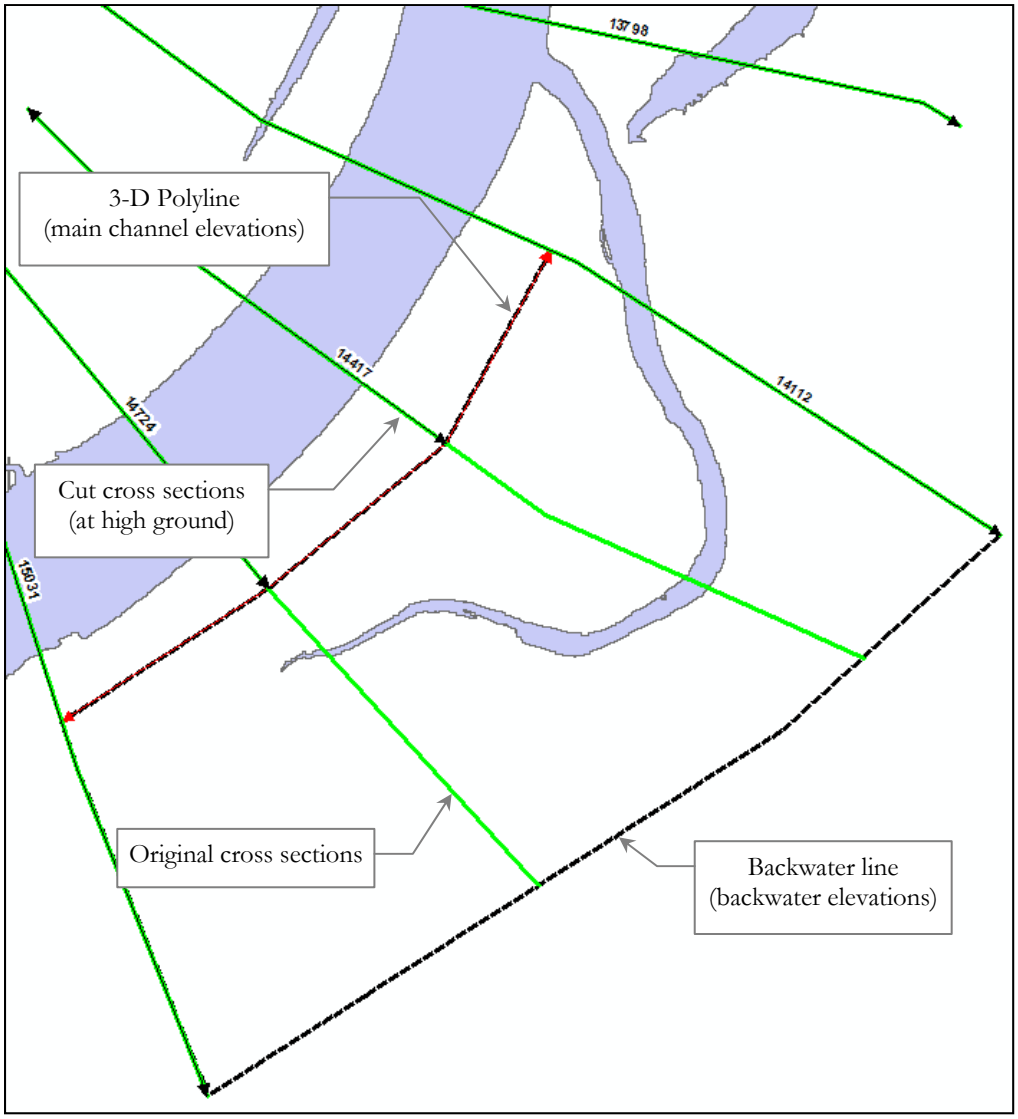

Figure 4-3. Backwater Area Mapping Methodology

4.2 DEVELOPED CONDITIONS

The Developed conditions floodplains reflect man-made structures such as bridges, levees, roads, and irrigation ditches. After the draft floodplains were prepared (including the bounding polygon extensions and backwater area mapping), the Developed conditions floodplains were edited. All wet areas not connected to the main channel floodplain were initially deleted. However, certain disconnected areas should actually be mapped as inundated, such as areas that are connected to the main channel floodplain through culverts or bridges. These areas were identified using aerial imagery and engineering judgment and were included in the Developed conditions floodplain mapping.

4.3 UNDEVELOPED CONDITIONS

The Undeveloped conditions floodplains reflect the natural state of the floodplain without man-made features (bridges, levees, roads, ditches, etc.). Man-made features were identified and removed from each of the floodplains using aerial imagery, elevation data, and a physical feature inventory provided by the District. The HEC-RAS model was also used as a guideline for removing man-made structures from the floodplains by comparing the Developed and Undeveloped geometry conditions to determine where features had been removed.

Irrigation ditches and canals were removed from the floodplain geometry . Based on the LiDAR elevation data, levees, roads, railroads, and other man-made structures with a high elevation were shown as dry areas in the original Developed floodplains but should be inundated for Undeveloped conditions. To address this, polygons were drawn to cover the man-made structures and these polygons were merged into the main channel floodplain to show the area as wet.

The Developed and Undeveloped conditions floodplains were clipped to the county line for each of the models. Depth grids were then clipped to the extents of the final floodplains. Specific mapping notes that were included in the final submittal for each county are included in Appendix D.

4.4 DIFFICULTIES AND ASSUMPTIONS

Two versions of ArcGIS were used during the floodplain mapping process for the Yellowstone River models. All of the original floodplains were processed using ArcGIS Version 9.3. Midway through the mapping process, ArcGIS 10 became the tool of choice and ArcGIS 9.3 was no longer available. For all versions of ArcGIS, the rasterization cell size is set to default to the input raster cell size and cannot be changed when a raster is used. After upgrading to ArcGIS 10, it was discovered that ArcGIS 9.3 had used a rasterization cell size of 2 meters, rather than the correct rasterization cell size of 2.5 meters (based on the input raster cell size) used by ArcGIS 10. This caused minor discrepancies at the border of the floodplains that are discussed below.

For the Treasure and Custer County models, the original processing was completed using ArcGIS 9.3. The floodplains were edited prior to the switch to ArcGIS 10; therefore, the final floodplains are based on the rasterization cell size of 2 meters. The final depth grids were processed after the switch to ArcGIS 10 and are based on the rasterization cell size of 2.5 meters. For these two models, the original and final floodplains are aligned at the borders. However, there may be slight differences (less than 0.5 meters) at the borders between the final floodplains and clipped depth grids.

For the Rosebud, Prairie, and Richland/McKenzie County models, the original processing was also completed using ArcGIS 9.3 with a rasterization cell size of 2 meters. However, draft floodplains were processed after the switch to ArcGIS 10 and are based on the rasterization cell size of 2.5 meters. For these three models, the final floodplains and clipped depth grids are aligned at the borders. However, if the original and final floodplains are compared, there may be slight differences at the borders (less than 0.5 meters).

There were a few locations where the LiDAR elevation data provided by the District had large gaps in data within the main channel. These locations were in Prairie County between XS 57790 and XS 59862, at the county border between Prairie and Custer Counties, and in Treasure County between XS 634 and XS 1863. The locations in Prairie and Custer Counties were patched with USGS topographic data; however, the resulting floodplains are somewhat irregular in these locations. The location in Treasure County was patched with additional data provided by the District prior to the mapping process.

In Rosebud County, a levee runs along the right bank and provides flood protection for the City of Forsythe, MT. Based on LiDAR elevation data, the levee is breached at XS 55398 and the result is flooding of the entire city of Forsythe for the 100-year (Regulated) and 100-, 200-, and 500-year (Unregulated) flows. The width of the breach could potentially limit the volume of water passing through the levee and limit the extent and depth of flooding behind the levee. Therefore, separate floodplains and depth grids were created for flows behind the levee so they could be shown as areas with potential for flooding, rather than part of the main channel floodplain.

5 REFERENCES

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APPENDIX A

HEC-RAS MODEL SUMMARIES

Model Summary and Notes

The Treasure County Yellowstone River steady flow model extends the entire length of Treasure County in Montana. Developed and Undeveloped conditions were included in the model. A low flow channel was added to the model to represent the underwater portion of the channel not included in the elevation data.

The steady flow model summary is provided in Table 1. Peak discharges used for the steady flow model were obtained from the USGS and are summarized in Table 4.

Two bridges were included in the Developed conditions geometry and are listed in Table 2. Bridge survey data and photographs were provided by the District. Bridges were not included in the Undeveloped conditions geometry.

A Manning's *n* value of 0.028 was used in the channel and ranged from 0.035 to 0.10 in the overbanks. The model was calibrated to two high water marks on the Yellowstone River (not including a high water mark on the Bighorn River) and results of the calibration are summarized in Table 3. The largest difference in computed versus observed water surface elevation is 0.3 meters.

Table 1. Steady Flow Model Overview

Model Length	61.9 kilometers
No. of Cross Sections	178 (developed) 176 (undeveloped)
Avg. Cross Section Spacing	351 meters
Vertical Datum	NAVD88 (meters)
Horizontal Projection	Montana State Plane, NAD 83
Downstream Boundary Condition	Known elevations, Rosebud County model

Table 2. Treasure County Bridges

Old Myers (Hysham) Bridge	XS 43660	RM 286.72
Myers (Hysham) Bridge	XS 43230	RM 286.45

Table 3. Steady Flow Model Calibration Results

Location	*Observed Elevation (m)*	*Computed Elevation (m)*	*Difference (m)*
MR11-WT1-MT-1016-001	*810.9*	*810.6*	*-0.3*
MR11-WT1-MT-1016-002	*810.5*	*810.5*	*0.0*

Table 4. Peak Flows for Yellowstone River

XS	*Flow Condition*	*Computed Peak Discharges (cubic meters per second, cms)*									
		5% Dur	*1.5-yr*	*2-yr*	*5-yr*	*10-yr*	*20-yr*	*50-yr*	*100-yr*	*200-yr*	*500-yr*
61918	*Unregulated*	*1,285.6*	*1,565.9*	*1,750.0*	*2,200.2*	*2,491.9*	*2,752.4*	*3,129.0*	*3,400.9*	*3,681.2*	*4,049.3*
	Regulated	*965.6*	*1,166.7*	*1,336.6*	*1,744.3*	*2,007.7*	*2,234.2*	*2,568.3*	*2,803.4*	*3,029.9*	*3,341.4*

Model Summary and Notes

The Rosebud County Yellowstone River steady flow model extends the entire length of Rosebud County in Montana. Developed and Undeveloped conditions were included in the model. A low flow channel was added to the model to represent the underwater portion of the channel not included in the elevation data.

The steady flow model summary is provided in Table 1. Peak discharges used for the steady flow model were obtained from the USGS and are summarized in Table 4.

Three bridges were included in the Developed conditions geometry and are listed in Table 2. Bridge survey data and photographs were provided by the District. Bridges were not included in the Undeveloped conditions geometry.

A Manning's *n* value of 0.028 was used in the channel and ranged from 0.035 to 0.10 in the overbanks. The model was calibrated to four high water marks and one USGS gage on the Yellowstone River and results of the calibration are summarized in Table 3. The largest difference in computed versus observed water surface elevation is 0.4 meters.

Table 1. Steady Flow Model Overview

Model Length	87.7 kilometers
No. of Cross Sections	279 (developed) 276 (undeveloped)
Avg. Cross Section Spacing	318 meters
Vertical Datum	NAVD88 (meters)
Horizontal Projection	Montana State Plane, NAD 83
Downstream Boundary Condition	Known elevations, Custer County model

Table 2. Rosebud County Bridges

Forsythe (Hwy 12) Bridge	XS 56353	RM 239.85
Old Forsythe Bridge	XS 55879	RM 239.55
Rosebud (Hwy 446) Bridge	XS 32620	RM 225.05

Table 3. Steady Flow Model Calibration Results

Location	*Observed Elevation (m)*	*Computed Elevation (m)*	*Difference (m)*
MR11-WT1-MT-1016-001	768.4	768.7	0.3
MR11-WT1-MT-1016-002	768.4	768.6	0.2
MR11-WT1-MT-1016-001	755.2	754.8	-0.4
MR11-WT1-MT-1016-002	755.0	754.7	-0.3
USGS Gage #06295000	767.7	768.1	0.4

Table 4. Peak Flows for Yellowstone River

XS	*Flow Condition*	*Computed Peak Discharges (cubic meters per second, cms)*									
		5% Dur	*1.5-yr*	*2-yr*	*5-yr*	*10-yr*	*20-yr*	*50-yr*	*100-yr*	*200-yr*	*500-yr*
87898	*Unregulated*	1,285.6	1,565.9	1,752.8	2,203.1	2,494.7	2,755.2	3,129.0	3,398.0	3,681.2	4,049.3
	Regulated	965.6	1,166.7	1,339.4	1,747.1	2,007.7	2,234.2	2,565.5	2,800.5	3,029.9	3,341.4
33275	*Unregulated*	1,285.6	1,565.9	1,752.8	2,203.1	2,494.7	2,752.4	3,126.2	3,395.2	3,681.2	4,021.0
	Regulated	965.6	1,166.7	1,339.4	1,747.1	2,007.7	2,231.4	2,565.5	2,797.7	3,029.9	3,341.4

Model Summary and Notes

The Custer County Yellowstone River steady flow model extends the entire length of Custer County in Montana. Developed and Undeveloped conditions were included in the model. A low flow channel was added to the model to represent the underwater portion of the channel not included in the elevation data.

The steady flow model summary is provided in Table 1. Peak discharges used for the steady flow model were obtained from the USGS and are summarized in Table 4.

Four bridges were included in the Developed conditions geometry and are listed in Table 2. Bridge survey data and photographs were provided by the District. Bridges were not included in the Undeveloped conditions geometry.

A Manning's *n* value of 0.028 was used in the channel and ranged from 0.035 to 0.10 in the overbanks. The model was calibrated to two high water marks and one USGS gage on the Yellowstone River and results of the calibration are summarized in Table 3. The largest difference in computed versus observed water surface elevation is 0.5 meters.

Table 1. Steady Flow Model Overview

Model Length	73.2 kilometers
No. of Cross Sections	246 (developed) 242 (undeveloped)
Avg. Cross Section Spacing	302 meters
Vertical Datum	NAVD88 (meters)
Horizontal Projection	Montana State Plane, NAD 83
Downstream Boundary Condition	Known elevations, Prairie County model

Table 2. Custer County Bridges

Paragon Bridge	XS 49425	RM 189.65
Fort Keough Bridge	XS 44545	RM 186.62
Highway 22 Bridge	XS 40500	RM 184.10
Kingsley Bridge	XS 21310	RM 172.12

Table 3. Steady Flow Model Calibration Results

Location	*Observed Elevation (m)*	*Computed Elevation (m)*	*Difference (m)*
MR11-WT1-MT-1016-007	716.2	716.4	0.2
MR11-WT1-MT-1016-008	715.9	716.4	0.5
USGS Gage #06309000	716.2	716.4	0.2

Table 4. Peak Flows for Yellowstone River

XS	*Flow Condition*	*Computed Peak Discharges (cubic meters per second, cms)*									
		5% Dur	*1.5-yr*	*2-yr*	*5-yr*	*10-yr*	*20-yr*	*50-yr*	*100-yr*	*200-yr*	*500-yr*
73418	*Unregulated*	4,021.0	1,568.8	1,752.8	2,203.1	2,494.7	2,752.4	3,126.2	3,392.4	3,652.9	4,021.0
	Regulated	3,341.4	1,169.5	1,339.4	1,747.1	2,007.7	2,231.4	2,562.7	2,792.0	3,029.9	3,341.4
59615	*Unregulated*	4,021.0	1,568.8	1,755.6	2,203.1	2,494.7	2,752.4	3,123.3	3,392.4	3,652.9	4,021.0
	Regulated	3,313.1	1,169.5	1,339.4	1,747.1	2,007.7	2,228.5	2,559.8	2,792.0	3,029.9	3,313.1
53935	*Unregulated*	4,021.0	1,568.8	1,755.6	2,205.9	2,494.7	2,752.4	3,123.3	3,392.4	3,652.9	4,021.0
	Regulated	3,313.1	1,169.5	1,339.4	1,747.1	2,007.7	2,228.5	2,559.8	2,789.2	3,029.9	3,313.1
43424	*Unregulated*	3,851.1	1,605.6	1,795.0	2,234.8	2,509.2	2,735.4	3,080.9	3,315.9	3,539.6	3,851.1
	Regulated	3,058.2	1,180.8	1,363.7	1,774.3	2,017.9	2,194.6	2,491.9	2,673.1	2,860.0	3,058.2
35607	*Unregulated*	3,851.1	1,605.6	1,795.3	2,234.2	2,508.9	2,735.4	3,080.9	3,315.9	3,539.6	3,851.1
	Regulated	3,058.2	1,180.8	1,364.9	1,775.5	2,019.0	2,194.6	2,491.9	2,673.1	2,860.0	3,058.2
30211	*Unregulated*	3,907.7	1,614.1	1,803.8	2,251.2	2,531.5	2,763.7	3,117.7	3,361.2	3,596.2	3,907.7
	Regulated	3,114.9	1,186.5	1,373.4	1,792.5	2,041.6	2,225.7	2,531.5	2,721.2	2,888.3	3,114.9
11806	*Unregulated*	3,936.0	1,614.1	1,806.6	2,254.0	2,534.4	2,769.4	3,126.2	3,369.7	3,596.2	3,936.0
	Regulated	3,143.2	1,189.3	1,376.2	1,795.3	2,047.3	2,231.4	2,540.0	2,729.7	2,916.6	3,143.2

Model Summary and Notes

The Prairie County Yellowstone River steady flow model extends the entire length of Prairie County in Montana. Developed and Undeveloped conditions were included in the model. A low flow channel was added to the model to represent the underwater portion of the channel not included in the elevation data.

The steady flow model summary is provided in Table 1. Peak discharges used for the steady flow model were obtained from the USGS and are summarized in Table 4.

Five bridges were included in the Developed conditions geometry and are listed in Table 2. Bridge survey data and photographs were provided by the District. Bridges were not included in the Undeveloped conditions geometry.

A Manning's *n* value of 0.028 was used in the channel and ranged from 0.035 to 0.10 in the overbanks. The model was calibrated to four high water marks on the Yellowstone River and results of the calibration are summarized in Table 3. The largest difference in computed versus observed water surface elevation is 1.1 meters. (Note: High water marks and observed flows were questionable for this reach of the Yellowstone River.)

Table 1. Steady Flow Model Overview

Model Length	61.6 kilometers
No. of Cross Sections	193 (developed) 188 (undeveloped)
Avg. Cross Section Spacing	328 meters
Vertical Datum	NAVD88 (meters)
Horizontal Projection	Montana State Plane, NAD 83
Downstream Boundary Condition	Normal depth, Slope = 0.00047

Table 2. Prairie County Bridges

Calypso (Milwauke) Bridge	XS 38642	RM 144.55
Highway 235 Bridge	XS 26616	RM 137.03
Old Highway 235 Bridge	XS 26471	RM 136.70
Interstate 94 Bridge	XS 9598	RM 126.40
Frontage Road Bridge	XS 9523	RM 126.37

Table 3. Steady Flow Model Calibration Results

Location	*Observed Elevation (m)*	*Computed Elevation (m)*	*Difference (m)*
MR11-WT1-MT-1016-009	663.0	663.8	0.8
MR11-WT1-MT-1016-010	662.8	663.9	1.1
MR11-WT1-MT-1017-001	655.7	655.1	-0.6
MR11-WT1-MT-1017-002	655.9	655.2	-0.7

Table 4. Peak Flows for Yellowstone River

XS	*Flow Condition*	*Computed Peak Discharges (cubic meters per second, cms)*									
		5% Dur	*1.5-yr*	*2-yr*	*5-yr*	*10-yr*	*20-yr*	*50-yr*	*100-yr*	*200-yr*	*500-yr*
61391	*Unregulated*	1,328.1	1,616.9	1,809.4	2,256.9	2,540.0	2,775.1	3,131.8	3,378.2	3,624.6	3,936.0
	Regulated	993.9	1,189.3	1,376.2	1,798.1	2,053.0	2,237.0	2,548.5	2,741.1	2,916.6	3,143.2
48400	*Unregulated*	1,393.2	1,710.3	1,928.4	2,469.2	2,826.0	3,154.5	3,616.1	3,958.7	4,304.2	4,785.5
	Regulated	1,039.2	1,277.1	1,498.0	2,030.3	2,367.3	2,647.6	3,075.2	3,366.9	3,652.9	4,021.0
45608	*Unregulated*	1,393.2	1,710.3	1,931.2	2,472.1	2,828.9	3,157.3	3,618.9	3,964.4	4,304.2	4,785.5
	Regulated	1,039.2	1,277.1	1,500.8	2,030.3	2,367.3	2,650.5	3,078.0	3,369.7	3,652.9	4,021.0
26606	*Unregulated*	1,396.0	1,713.2	1,934.0	2,477.7	2,837.3	3,168.7	3,635.9	3,981.3	4,332.5	4,813.9
	Regulated	1,042.1	1,279.9	1,503.6	2,038.8	2,378.6	2,664.6	3,095.0	3,392.4	3,681.2	4,049.3
14724	*Unregulated*	1,404.5	1,724.5	1,951.0	2,506.0	2,874.2	3,216.8	3,698.2	4,057.8	4,417.4	4,927.1
	Regulated	1,047.7	1,291.2	1,520.6	2,067.1	2,418.3	2,715.6	3,163.0	3,471.6	3,766.1	4,162.6

Model Summary and Notes

The Richland/McKenzie County Yellowstone River steady flow model extends the entire length of Richland County in Montana and McKenzie County in North Dakota. Developed and Undeveloped conditions were included in the model. A low flow channel was added to the model to represent the underwater portion of the channel not included in the elevation data.

The steady flow model summary is provided in Table 1. Peak discharges used for the steady flow model were obtained from the USGS and are summarized in Table 4.

Three bridges were included in the Developed conditions geometry and are listed in Table 2. Bridge survey data and photographs were provided by the District. Bridges were not included in the Undeveloped conditions geometry.

A Manning's *n* value of 0.028 was used in the channel and ranged from 0.035 to 0.10 in the overbanks. The model was calibrated to two high water marks and one USGS gage on the Yellowstone River and results of the calibration are summarized in Table 3. The largest difference in computed versus observed water surface elevation is 2.1 meters. High water marks were questionable for this reach of the Yellowstone River. The difference in computed versus observed water surface at the USGS gage is 0.3 meters.

Table 1. Steady Flow Model Overview

Model Length	98.7.6 kilometers
No. of Cross Sections	326 (developed) 323 (undeveloped)
Avg. Cross Section Spacing	306 meters
Vertical Datum	NAVD88 (meters)
Horizontal Projection	Montana State Plane, NAD 83
Downstream Boundary Condition	Normal depth, Slope = 0.00025

Table 2. Richland/McKenzie County Bridges

Highway 23 (Sydney) Bridge	XS 49844	RM 31.10
Fairview Pedestrian Bridge	XS 14952	RM 9.23
Highway 68 (Fairview) Bridge	XS 14629	RM 9.03

Table 3. Steady Flow Model Calibration Results

Location	*Observed Elevation (m)*	*Computed Elevation (m)*	*Difference (m)*
MR11-WT1-MT-1017-004	578.8	580.9	2.1
MR11-WT1-MT-1017-005	578.7	580.5	1.8
USGS Gage #06329500	580.6	580.3	-0.3

Table 4. Peak Flows for Yellowstone River

XS	*Flow Condition*	*Computed Peak Discharges (cubic meters per second, cms)*									
		5% Dur	*1.5-yr*	*2-yr*	*5-yr*	*10-yr*	*20-yr*	*50-yr*	*100-yr*	*200-yr*	*500-yr*
103500	*Unregulated*	1,410.2	1,738.7	1,973.7	2,548.5	2,922.3	3,256.4	3,737.8	4,086.1	4,445.7	4,898.8
	Regulated	1,047.7	1,302.6	1,534.8	2,115.3	2,494.7	2,837.3	3,327.2	3,681.2	4,049.3	4,502.4
90682	*Unregulated*	1,410.2	1,738.7	1,976.5	2,551.3	2,925.1	3,253.6	3,735.0	4,077.6	4,417.4	4,870.5
	Regulated	1,047.7	1,302.6	1,534.8	2,118.1	2,503.2	2,851.5	3,349.9	3,712.3	4,077.6	4,559.0
80182	*Unregulated*	1,407.4	1,738.7	1,976.5	2,557.0	2,928.0	3,253.6	3,729.3	4,069.1	4,417.4	4,870.5
	Regulated	1,047.7	1,302.6	1,537.6	2,120.9	2,508.9	2,865.7	3,369.7	3,740.7	4,105.9	4,615.6
58263	*Unregulated*	1,407.4	1,738.7	1,980.8	2,561.5	2,932.8	3,250.8	3,723.7	4,055.0	4,389.1	4,813.9
	Regulated	1,044.9	1,302.6	1,536.8	2,127.4	2,522.7	2,891.2	3,403.7	3,786.0	4,162.6	4,700.6

APPENDIX B

HEC-RAS MODELING NOTES

Treasure County Modeling Notes

Pre-Processing

The Treasure County stream centerline, flow paths, and cross section files were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Treasure County County (DEM's 1 through 6) as well as Rosebud County (DEM 1) at the downstream end. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data in locations where the cross sections extended beyond the Treasure County DEM's.

Cross sections were placed along the centerline based on a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. At the downstream end, there was a large gap in elevation data between Treasure County DEM 6 and Rosebud County DEM 1 and cross sections were placed on each side of the gap, at a distance of 1,200 meters. Cross sections were also placed along the upstream and downstream bridge faces. Manning's *n* values were derived from the vegetation shapefile provided by the District and were extracted during the GeoRAS process.

The horizontal datum for the project is NAD 1983 Montana State Plane and the vertical datum is NAVD88. All models and calculations were completed in the metric system.

Developed Conditions

One bridge, Myers (Hysham) Bridge, was included in the developed conditions geometry. The piers from the Old Myers (Hysham) Bridge were also included in the developed conditions geometry. The bridge features, such as the deck, piers, and embankments, were defined in HEC-RAS based on survey data and photographs provided by the District. Ineffective flow areas were placed at appropriate locations near bridges and other features that resulted in contraction or expansion of flow.

The levee feature was utilized in the developed conditions geometry to define high ground (levees or roads) where flow was unable to reach the landward side of the levee. If a levee was overtopped, the flow behind the levee was designated as ineffective.

The elevation data provided did not include underwater data; therefore, a low flow channel was incorporated into the HEC-RAS geometry using the Channel Modification tool. The low flow channel was calibrated to the water surface elevation that occurred on the date of the aerial photography. Calibration efforts were made to produce a water surface elevation within 0.5 feet of the actual water surface elevations (maximum difference of 1.0 feet), erring on the side of the calibrated water surface being higher than the actual water surface for conservative modeling.

A low flow and a high flow geometry was created for both of the conditions (developed and undeveloped) in the Treasure County hydraulic model. This allowed for a more accurate placement of ineffective flow areas to represent the low or high flows.

Two high water marks for the Yellowstone River were provided by the District at the upstream and downstream sides of the Old Myers (Hysham) Bridge. After calibration, the modeled water surface elevations were within 0.4 meters and 0.0 meters, respectively, of the observed water surface elevations. These differences were considered adequate and no further calibration was performed. A high water mark was also provided at the Highway 94 Bridge on the Bighorn River, just upstream of the

confluence with the Yellowstone River. After calibration, the modeled water surface elevation was 1.2 meters below the observed water surface elevations. For the observed flow, the backwater caused by the Yellowstone River does not reach the Highway 94 Bridge on the Bighorn River. Therefore, the high water mark was more likely caused from flooding on the Bighorn River and not the Yellowstone River and is therefore not appropriate for calibration of the Yellowstone River model.

Undeveloped Conditions

For the undeveloped conditions, all man-made structures were removed manually from the geometry, including bridges, levees, roads, irrigation ditches, etc. Aerial photography and planimetric data provided by the District were used as guidance to determine the locations of the man-made features.

Manning's *n* values were adjusted for the undeveloped conditions to represent roughness values prior to development in the area. The Manning's *n* values of areas that were defined as crop land (n = 0.035) or developed (n = 0.10) were adjusted to be equal to the adjacent land Manning's *n* values.

Flows

Ten flow events were modeled for Treasure County, including the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year and the 5 percent duration flow. The flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002*. Both regulated and unregulated flows were modeled for each of the geometries (developed and undeveloped), resulting in 40 output events in the HEC-RAS model. The flows reported in the USGS study correspond to the reaches defined by the Yellowstone River Conservation Districts Council (YRCDC).

Rosebud County Modeling Notes

Pre-Processing

The Rosebud County stream centerline, flow paths, and cross section files were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Rosebud County County (DEM's 1 through 7) as well as Treasure County (DEM 6) at the upstream end. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data in locations where the cross sections extended beyond the Rosebud County DEM's.

Cross sections were placed along the centerline based on a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. Cross sections were also placed along the upstream and downstream bridge faces. Manning's *n* values were derived from the vegetation shapefile provided by the District and were extracted during the GeoRAS process.

The horizontal datum for the project is NAD 1983 Montana State Plane and the vertical datum is NAVD88. All models and calculations were completed in the metric system.

Developed Conditions

Three bridges were included in the developed conditions geometry including the Rosebud Bridge (Highway 446), Old Forsythe Bridge, and Forsythe Bridge (Highway 12). The bridge features, such as the deck, piers, and embankments, were defined in HEC-RAS based on survey data and photographs provided by the District. Ineffective flow areas were placed at appropriate locations near bridges and other features that resulted in contraction or expansion of flow.

The levee feature was utilized in the developed conditions geometry to define high ground (levees or roads) where flow was unable to reach the landward side of the levee. If a levee was overtopped, the flow behind the levee was designated as ineffective. The levee protecting the City of Forsythe provided flood protection up to the 500-year event (based on HEC-RAS modeling).

The elevation data provided did not include underwater data; therefore, a low flow channel was incorporated into the HEC-RAS geometry using the Channel Modification tool. The low flow channel was calibrated to the water surface elevation that occurred on the date of the aerial photography. Calibration efforts were made to produce a water surface elevation within 0.5 feet of the actual water surface elevations (maximum difference of 1.0 feet), erring on the side of the calibrated water surface being higher than the actual water surface for conservative modeling.

A low flow and a high flow geometry was created for both of the conditions (developed and undeveloped) in the Rosebud County hydraulic model. This allowed for a more accurate placement of ineffective flow areas to represent the low or high flows.

High water marks were provided by the District at the Highway 12 and the Highway 446 Bridges. After calibration, the modeled water surface elevations fell within 0.3 meters of the observed high water marks. The peak stage from the USGS Gage #06295000 located at the Highway 12 Bridge was also included in the calibration effort and the modeled water surface fell within 0.5 meters of the observed peak stage. These differences were considered adequate and no further calibration was performed.

Undeveloped Conditions

For the undeveloped conditions, all man-made structures were removed manually from the geometry, including bridges, levees, roads, irrigation ditches, etc. Aerial photography and planimetric data provided by the District were used as guidance to determine the locations of the man-made features.

Manning's *n* values were adjusted for the undeveloped conditions to represent roughness values prior to development in the area. The Manning's *n* values of areas that were defined as crop land (n = 0.035) or developed (n = 0.10) were adjusted to be equal to the adjacent land Manning's *n* values.

Flows

Ten flow events were modeled for Rosebud County, including the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year and the 5 percent duration flow. The flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002*. Both regulated and unregulated flows were modeled for each of the geometries (developed and undeveloped), resulting in 40 output events in the HEC-RAS model. The flows reported in the USGS study correspond to the reaches defined by the Yellowstone River Conservation Districts Council (YRCDC).

Custer County Modeling Notes

Pre-Processing

The Custer County stream centerline, flow paths, and cross section files were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Custer County County (DEM's 1 through 6) as well as Rosebud County (DEM 7) at the upstream end and Prairie County (DEM 1) at the downstream end. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data in locations where the cross sections extended beyond the Custer County DEM's.

Cross sections were placed along the centerline based on a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. Cross sections were also placed along the upstream and downstream bridge faces. Manning's *n* values were derived from the vegetation shapefile provided by the District and were extracted during the GeoRAS process.

The horizontal datum for the project is NAD 1983 Montana State Plane and the vertical datum is NAVD88. All models and calculations were completed in the metric system.

Developed Conditions

Four bridges were included in the developed conditions geometry including the Kingsley Bridge, Highway 22/59 Bridge, Fort Keough Road Bridge, and Paragon Bridge. The bridge features, such as the deck, piers, and embankments, were defined in HEC-RAS based on survey data and photographs provided by the District. Ineffective flow areas were placed at appropriate locations near bridges and other features that resulted in contraction or expansion of flow.

The levee feature was utilized in the developed conditions geometry to define high ground (levees or roads) where flow was unable to reach the landward side of the levee. If a levee was overtopped, the flow behind the levee was designated as ineffective. The levee protecting Miles City provided flood protection up to the 500-year event.

The elevation data provided did not include underwater data; therefore, a low flow channel was incorporated into the HEC-RAS geometry using the Channel Modification tool. The low flow channel was calibrated to the water surface elevation that occurred on the date of the aerial photography. Calibration efforts were made to produce a water surface elevation within 0.5 feet of the actual water surface elevations (maximum difference of 1.0 feet), erring on the side of the calibrated water surface being higher than the actual water surface for conservative modeling.

A low flow and a high flow geometry was created for both of the conditions (developed and undeveloped) in the Custer County hydraulic model. This allowed for a more accurate placement of ineffective flow areas to represent the low or high flows.

High water marks were provided by the District at the Highway 22/59 Bridge. After calibration, the modeled water surface elevations fell within 0.5 meters of the observed high water marks. This difference was considered adequate and no further calibration was performed.

Undeveloped Conditions

For the undeveloped conditions, all man-made structures were removed manually from the geometry, including bridges, levees, roads, irrigation ditches, etc. Aerial photography and planimetric data provided by the District were used as guidance to determine the locations of the man-made features.

Manning's *n* values were adjusted for the undeveloped conditions to represent roughness values prior to development in the area. The Manning's *n* values of areas that were defined as crop land (n = 0.035) or developed (n = 0.10) were adjusted to be equal to the adjacent land Manning's *n* values.

Flows

Ten flow events were modeled for Custer County, including the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year and the 5 percent duration flow. The flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002*. Both regulated and unregulated flows were modeled for each of the geometries (developed and undeveloped), resulting in 40 output events in the HEC-RAS model. The flows reported in the USGS study correspond to the reaches defined by the Yellowstone River Conservation Districts Council (YRCDC).

Prairie County Modeling Notes

Pre-Processing

The Prairie County stream centerline, flow paths, and cross section files were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Prairie County (DEM's 1 through 4) as well as Custer County (DEM 6) at the upstream end. USGS 1/3-Arc Second National Elevatoin Dataset was used to supplement topographic data in locations where the cross sections extended beyond the Prairie County DEM's.

Cross sections were placed along the centerline based on a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. Cross sections were also placed along the upstream and downstream bridge faces. Manning's *n* values were derived from the vegetation shapefile provided by the District and were extracted during the GeoRAS process.

The horizontal datum for the project is NAD 1983 Montana State Plane and the vertical datum is NAVD88. All models and calculations were completed in the metric system.

Developed Conditions

Four bridges were included in the developed conditions geometry including the Interstate 94 Bridges, Fallon Frontage Bridge, Highway 235 Bridge, and Milwauke Road (Calypso) Bridge. The bridge features, such as the deck, piers, and embankments, were defined in HEC-RAS based on survey data and photographs provided by the District. Ineffective flow areas were placed at appropriate locations near bridges and other features that resulted in contraction or expansion of flow.

The levee feature was utilized in the developed conditions geometry to define high ground (levees or roads) where flow was unable to reach the landward side of the levee. If a levee was overtopped, the flow behind the levee was designated as ineffective.

The elevation data provided did not include underwater data; therefore, a low flow channel was incorporated into the HEC-RAS geometry using the Channel Modification tool. The low flow channel was calibrated to the water surface elevation that occurred on the date of the aerial photography. Calibration efforts were made to produce a water surface elevation within 0.5 feet of the actual water surface elevations (maximum difference of 1.0 feet), erring on the side of the calibrated water surface being higher than the actual water surface for conservative modeling.

A low flow and a high flow geometry was created for both of the conditions (developed and undeveloped) in the Prairie County hydraulic model. This allowed for a more accurate placement of ineffective flow areas to represent the low or high flows.

High water marks were provided by the District at the Highway 235 Bridge and the Interstate 94 Bridge. After several attempts to calibrate the model to these elevations, the District reviewed the high water marks further and found that the Interstate 94 high water mark and the estimated calibration flow could have questionable accuracy. Therefore, the District determined that no further calibration attempts were necessary and that the model was adequate and realistic.

Undeveloped Conditions

For the undeveloped conditions, all man-made structures were removed manually from the geometry, including bridges, levees, roads, irrigation ditches, etc. Aerial photography and planimetric data provided by the District were used as guidance to determine the locations of the man-made features.

Manning's *n* values were adjusted for the undeveloped conditions to represent roughness values prior to development in the area. The Manning's *n* values of areas that were defined as crop land (n = 0.035) or developed (n = 0.10) were adjusted to be equal to the adjacent land Manning's *n* values.

Flows

Ten flow events were modeled for Prairie County, including the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year and the 5 percent duration flow. The flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002*. Both regulated and unregulated flows were modeled for each of the geometries (developed and undeveloped), resulting in 40 output events in the HEC-RAS model.

The flows reported in the USGS study correspond to the reaches defined by the Yellowstone River Conservation Districts Council (YRCDC). However, in Prairie County, the flow change location specified for Reach D3 in the USGS study was located approximately 3 miles upstream of the edge of the YRCDC Reach D3 at the confluence of O'Fallon Creek at XS 14724. After discussion with the District, it was determined that this flow change location better represents the flow through that reach and the flow change location was left at XS 14724.

Richland/McKenzie County Modeling Notes

Pre-Processing

The Richland/McKenzie County stream centerline, flow paths, and cross section files were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Richland County (DEM's 1 through 7) and McKenzie County (DEM's 1 through 4) as well as Dawson County (DEM 46) at the upstream end. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data in locations where the cross sections extended beyond the Richland/McKenzie County DEM's.

Cross sections were placed along the centerline based on a maximum spacing of 350 meters, except at sharp bends where cross sections were placed further apart to avoid overlap in the overbanks. Cross sections were also placed along the upstream and downstream bridge faces. Manning's *n* values were derived from the vegetation shapefile provided by the District and were extracted during the GeoRAS process. The downstream limit of the hydraulic model was set at the confluence with the Missouri River floodplain.

The horizontal datum for the project is NAD 1983 Montana State Plane and the vertical datum is NAVD88. All models and calculations were completed in the metric system.

Developed Conditions

Three bridges were included in the developed conditions geometry including the Sydney (Highway 23) Bridge, Fairview Pedestrian Bridge, and Fairview (Highway 68) Bridge. The bridge features, such as the deck, piers, and embankments, were defined in HEC-RAS based on survey data and photographs provided by the District. Ineffective flow areas were placed at appropriate locations near bridges and other features that resulted in contraction or expansion of flow.

The levee feature was utilized in the developed conditions geometry to define high ground (levees or roads) where flow was unable to reach the landward side of the levee. If a levee was overtopped, the flow behind the levee was designated as ineffective.

The elevation data provided did not include underwater data; therefore, a low flow channel was incorporated into the HEC-RAS geometry using the Channel Modification tool. The low flow channel was calibrated to the water surface elevation that occurred on the date of the aerial photography. Calibration efforts were made to produce a water surface elevation within 0.5 feet of the actual water surface elevations (maximum difference of 1.0 feet), erring on the side of the calibrated water surface being higher than the actual water surface for conservative modeling.

A low flow and a high flow geometry was created for both of the conditions (developed and undeveloped) in the Richland/McKenzie County hydraulic model. This allowed for a more accurate placement of ineffective flow areas to represent the low or high flows.

High water marks were provided by the District at the Highway 23 Bridge and observed stages were available from USGS Gage #063295000, also located at Highway 23. After calibration, the modeled water surface elevations fell within 0.3 meters of the observed stage at the USGS gage. However, the computed water surface elevation was approximately 2 meters higher than the high water marks

provided by the District. Since there are known discrepancies in the District high water marks, the observed stage at the USGS gage is considered more accurate and no further calibration was performed.

Undeveloped Conditions

For the undeveloped conditions, all man-made structures were removed manually from the geometry, including bridges, levees, roads, irrigation ditches, etc. Aerial photography and planimetric data provided by the District were used as guidance to determine the locations of the man-made features.

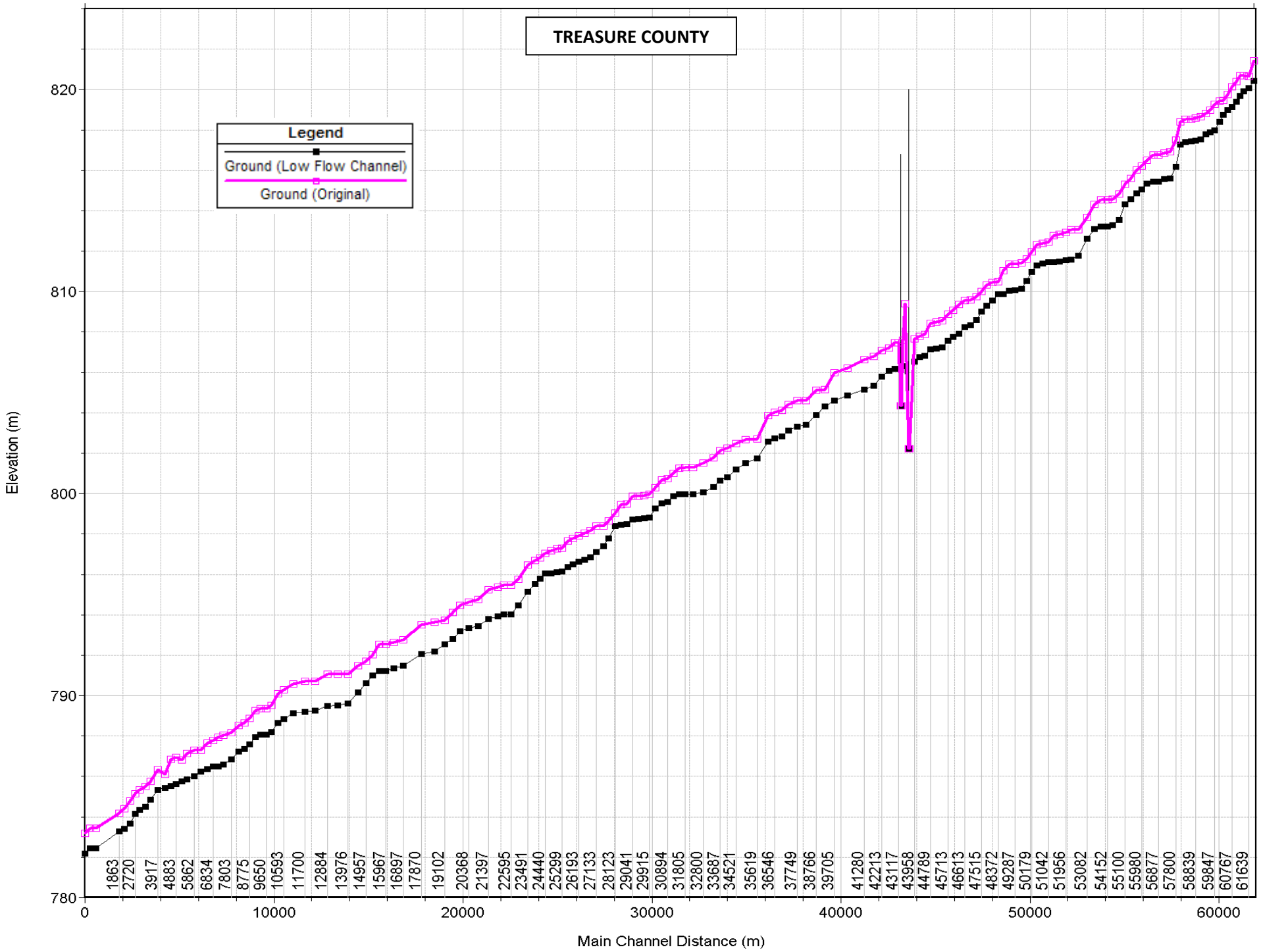
Manning's *n* values were adjusted for the undeveloped conditions to represent roughness values prior to development in the area. The Manning's *n* values of areas that were defined as crop land (n = 0.035) or developed (n = 0.10) were adjusted to be equal to the adjacent land Manning's *n* values.

Flows

Ten flow events were modeled for Richland/McKenzie County, including the 1.5-, 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year and the 5 percent duration flow. The flows were provided by the District and were based on the draft USGS report *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928–2002*. Both regulated and unregulated flows were modeled for each of the geometries (developed and undeveloped), resulting in 40 output events in the HEC-RAS model. The flows reported in the USGS study correspond to the reaches defined by the Yellowstone River Conservation Districts Council (YRCDC).

APPENDIX C

LOW-FLOW CHANNEL INVERT COMPARISON


TREASURE COUNTY
Legend
Ground (Low Flow Channel)
Ground (Original)
Elevation (m)
820
810
800
790
780
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)
1863
2720
3917
4883
5862
6834
7803
8775
9650
10593
11700
12884
13976
14957
15967
16897
17870
19102
20368
21397
22595
23491
24440
25299
26193
27133
28123
29041
29915
30894
31805
32800
33687
34521
35619
36546
37749
38766
39705
41280
42213
43117
43958
44789
45713
46613
47515
48372
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50179
51042
51956
53082
54152
55100
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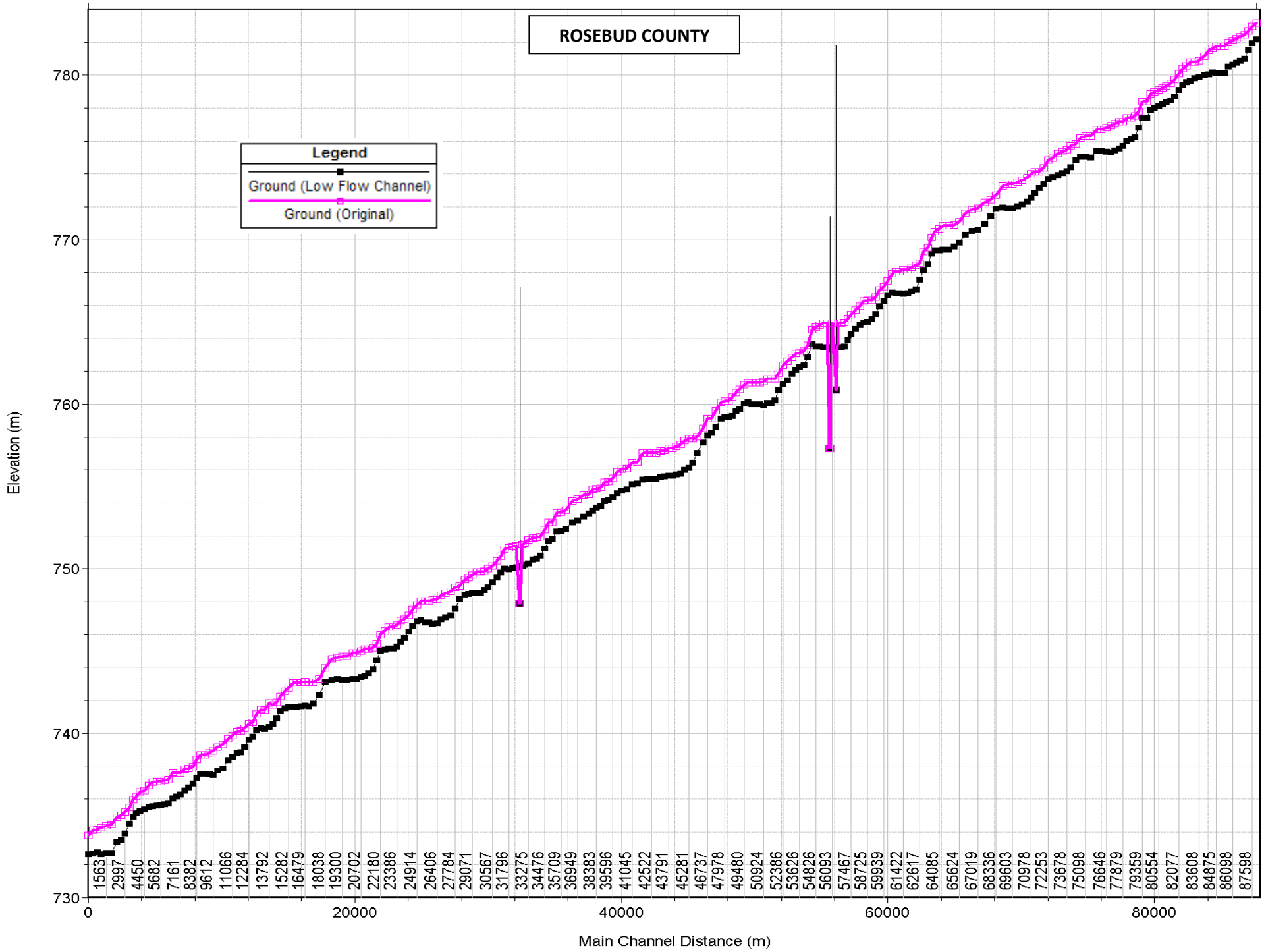
56877
57800
58839
59847
60767
61639


ROSEBUD COUNTY
Legend
Ground (Low Flow Channel)
Ground (Original)
Elevation (m)
Main Channel Distance (m)
730
740
750
760
770
780
0
20000
40000
60000
80000
1563
2997
4450
5682
7161
8382
9612
11066
12284
13792
15282
16479
18038
19300
20702
22180
23386
24914
26406
27784
29071
30567
31796
33275
34476
35709
36949
38383
39596
41045
42522
43791
45281
46737
47978
49480
50924
52386
53626
54826
56093
57467
58725
59939
61422
62617
64085
65624
67019
68336
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75098
76646
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79359
80554
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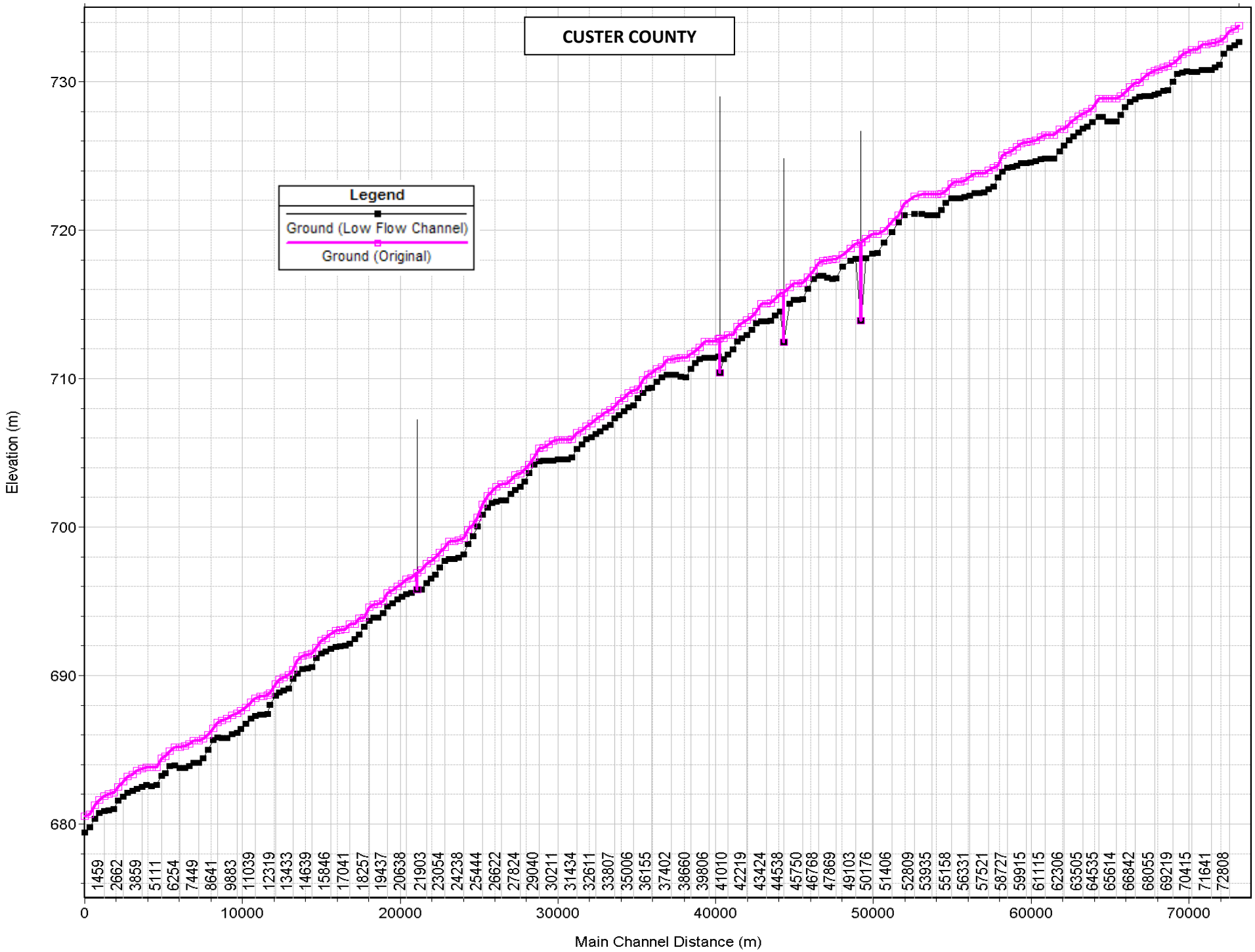
86098
87598


CUSTER COUNTY
Legend
Ground (Low Flow Channel)
Ground (Original)
Elevation (m)
730
720
710
700
690
680
0
10000
20000
30000
40000
50000
60000
70000
Main Channel Distance (m)
1459
2662
3859
5111
6254
7449
8641
9883
11039
12319
13433
14639
15846
17041
18257
19437
20638
21903
23054
24238
25444
26622
27824
29040
30211
31434
32611
33807
35006
36155
37402
38660
39806
41010
42219
43424
44538
45750
46768
47869
49103
50176
51406
52809
53935
55158
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62306
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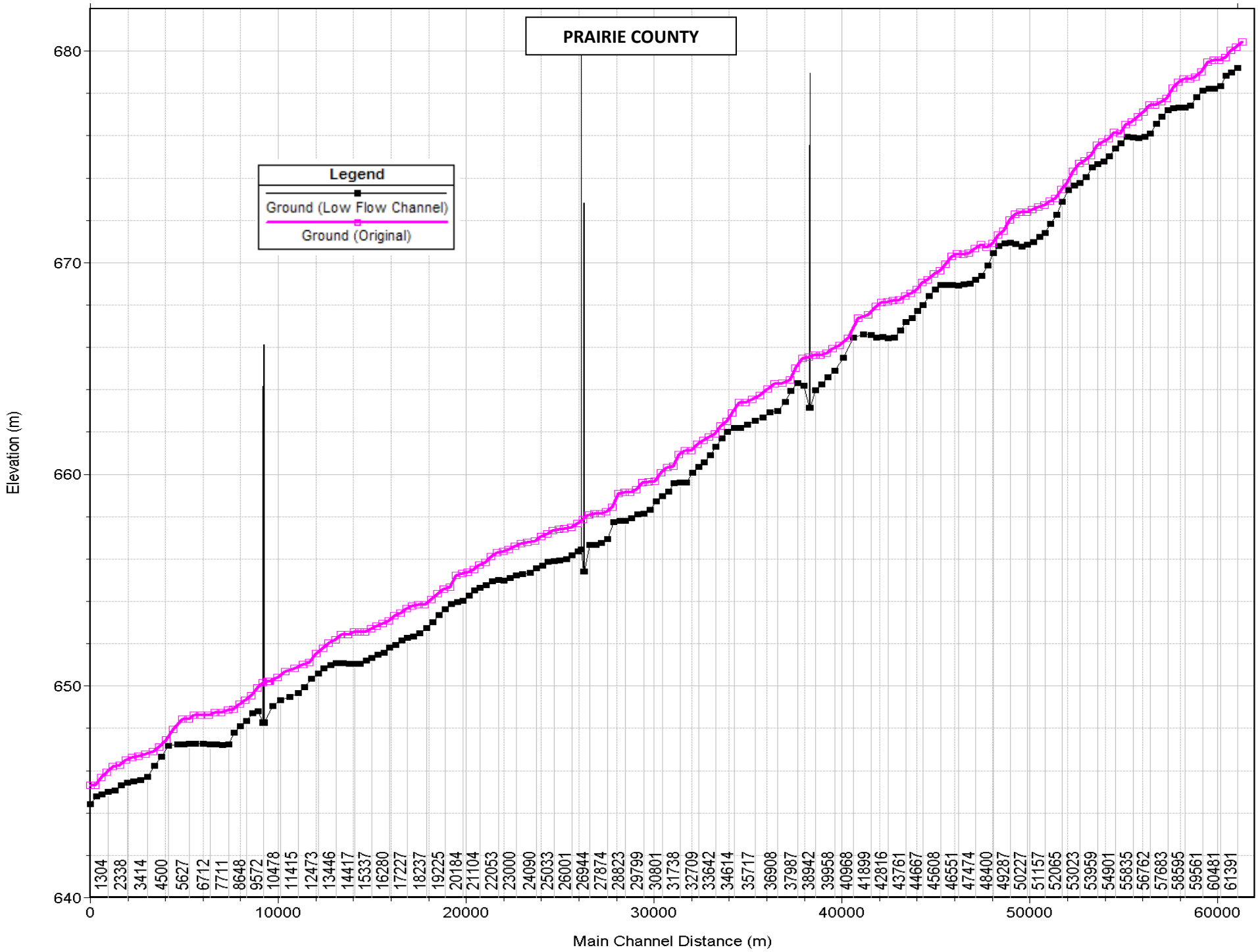
71641
72808


PRAIRIE COUNTY
Legend
Ground (Low Flow Channel)
Ground (Original)
Elevation (m)
680
670
660
650
640
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)
1304
2338
3414
4500
5627
6712
7711
8648
9572
10478
11415
12473
13446
14417
15337
16280
17227
18237
19225
20184
21104
22053
23000
24090
25033
26001
26944
27874
28823
29799
30801
31738
32709
33642
34614
35717
36908
37987
38942
39958
40968
41899
42816
43761
44667
45608
46551
47474
48400
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52065
53023
53959
54901
55835
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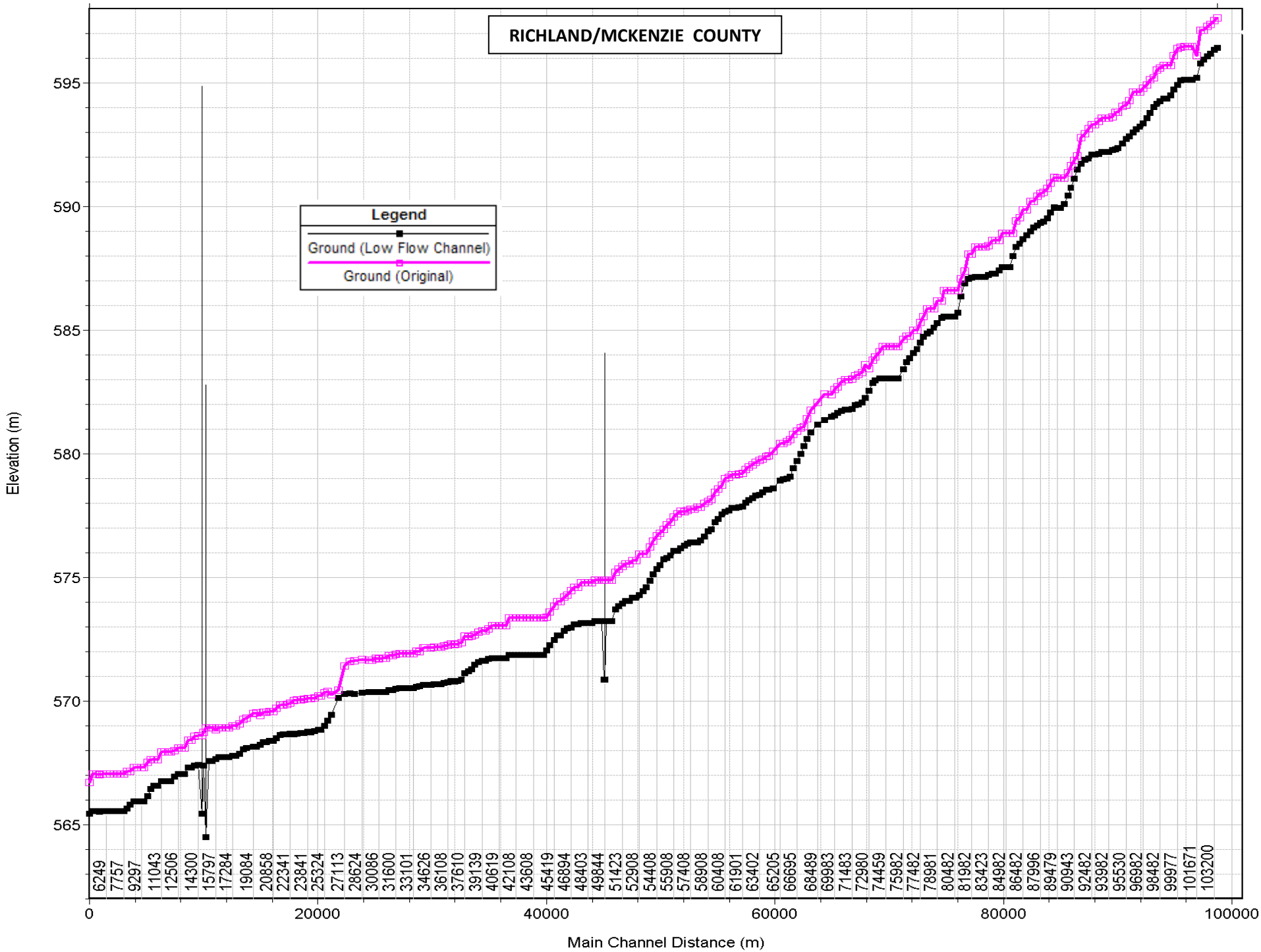
57683
58595
59561
60481
61391


RICHLAND/MCKENZIE COUNTY
Legend
Ground (Low Flow Channel)
Ground (Original)
Elevation (m)
595
590
585
580
575
570
565
0
20000
40000
60000
80000
100000
Main Channel Distance (m)
6249
7757
9297
11043
12506
14300
15797
17284
19084
20858
22341
23841
25324
27113
28624
30086
31600
33101
34626
36108
37610
39139
40619
42108
43608
45419
46894
48403
49844
51423
52908
54408
55908
57408
58908
60408
61901
63402
65205
66695
68489
69983
71483
72980
74459
75982
77482
78981
80482
81982
83423
84982
86482
87996
89479
90943
92482
93982
95530
96982
98482
99977
101671
103200

APPENDIX D

FLOODPLAIN MAPPING NOTES

Treasure County Mapping Notes

Pre-Processing

The Treasure County pre-processing files (stream centerline, flow paths, and cross sections) were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Treasure County (DEM's 1 through 6) as well as Rosebud County (DEM 1) at the downstream end (XS 68 to 634). A number of cross sections were extended beyond the County DEM's in order to reach high ground to contain the computed water surface for the larger flows. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data when this occurred. Cross sections XS 55980 to XS 60985 were partially based on the USGS topographic data. Small gaps were present in the District DEM's along the Treasure County line at both the upstream and downstream ends. The gaps were patched with the USGS topographic data and affected XS 68, XS 347, and XS 60767 to XS 61918.

Floodplain Processing

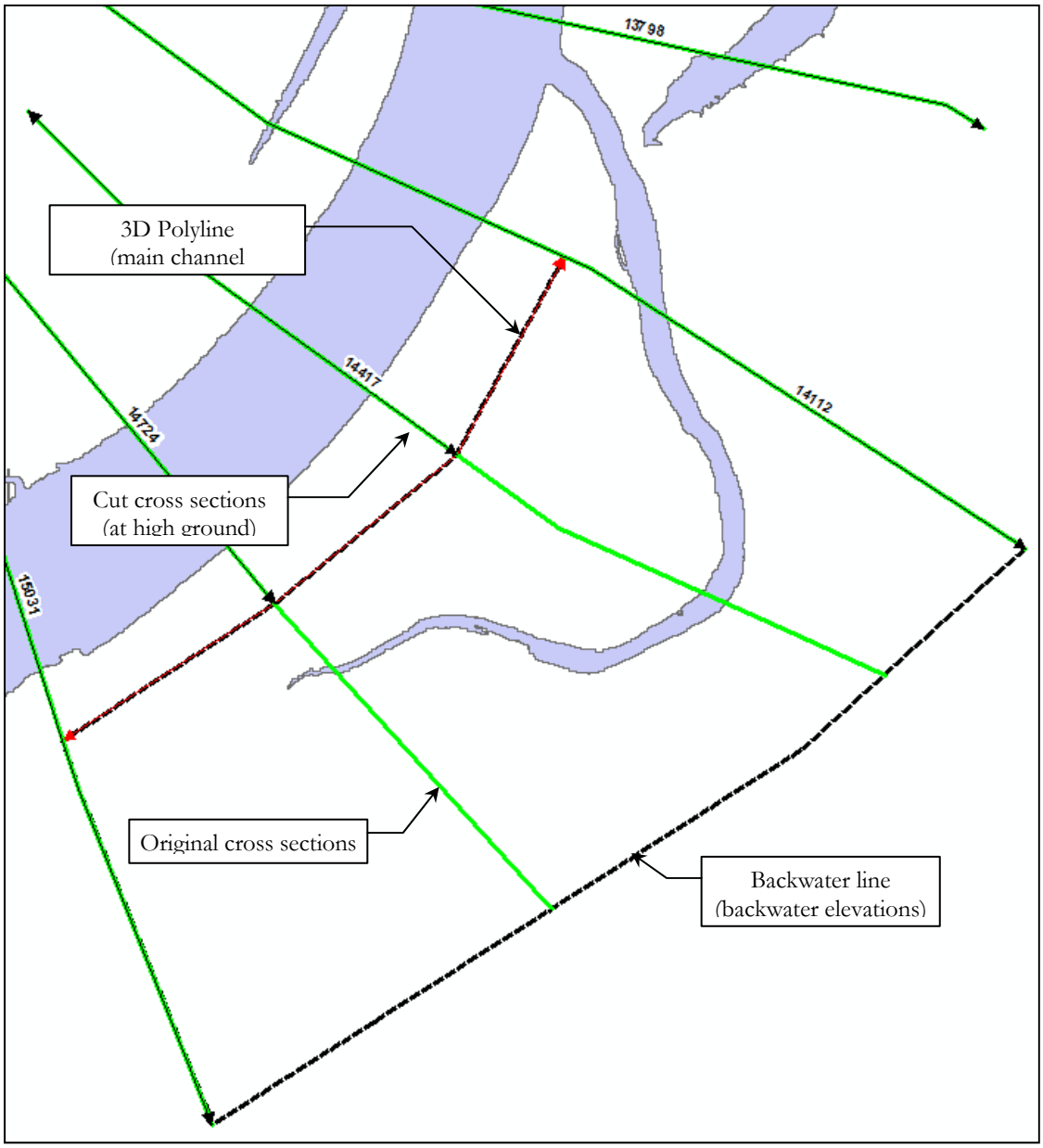
The original floodplains were generated using ArcGIS 9.3 and the Geo-RAS 4.2 extension. The output file from the final Treasure County HEC-RAS model was imported into ArcGIS and the water surface TIN's and the original floodplains were generated. In order to provide floodplains and depth grids to the extent of the entire county, the Treasure County model was extended into the adjacent counties. Since the Yellowstone County models were not available at the time of mapping, at the upstream end a cross section was created just upstream of the County line using the water surface elevations from the most upstream cross section of the Treasure County model (XS 61918). At the downstream end, cross sections from the Rosebud County model were added to the model (XS 87292 to XS 87898). The bounding polygons were extended to the adjacent county cross sections and after the floodplains and depth grids were delineated, they were clipped to the Treasure County limits.

The original floodplains for both developed and undeveloped conditions were reviewed to identify any areas where the length and orientation of the HEC-RAS cross sections cut off the floodplains in between cross sections. At these locations, the cross sections were extended in ArcGIS (along with the bounding polygons) to ensure the floodplains extended to the limits of the DEM's provided by the District.

The original mapping was also reviewed to identify any backwater areas where the floodplain should be mapped based on the water surface elevations where the flow leaves the main channel rather than the actual water surface elevation at the cross section. Only major backwater areas were identified, small backwater areas or areas only affecting a single profile were ignored and mapped based on main channel elevations. The backwater areas adjusted for Treasure County were located at XS 11700, XS 22238, XS 20571, XS35619, XS 48667, XS 59113, and XS 60093. The following steps were followed to map the backwater areas for each flow event. An example of the backwater features is shown in the figure below (from Prairie County).

1) A cross section shapefile was created for each flow event based on the extended cross sections and the water surface elevations for the corresponding event.
2) The cross sections were cutoff at the high ground separating the main channel and the backwater area for flow events that produced backwater areas.
3) A 3D polyline was created at the ends of the cross sections (at the high ground) based on the main channel water surface elevations for flow events that produced backwater areas.

4) A second line (backwater line) was drawn parallel to the 3D polyline and was assigned an elevation based on the backwater water surface elevation. The backwater line was snapped to the ends of the original cross sections to encompass the entire backwater area.
5) After all the backwater areas were addressed, a water surface TIN was created for each flow event based on the cut cross sections, the 3D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations).
6) In the geodatabase, the water surface TIN's from the original mapping were replaced with the new water surface TIN's and the original bounding polygons file was replaced with the extended bounding polygon file.
7) Using ArcGIS 10 and the Geo-RAS 10 extension, the draft floodplains and depth grids were generated for each flow event.



Floodplain Editing – Developed Conditions

Once the draft floodplains were processed in ArcGIS 9.3, all polygons outside of the main channel polygon were deleted in order to eliminate the small "ponds" or disconnected areas that show up in the mapping process that are not actually part of the floodplain wet. However, this process also deleted areas that should be included in the floodplain. For example, some areas that are mapped as disconnected are actually connected to the main polygon through a culvert or bridge. These areas were adjusted based on aerial photography and engineering judgment.

Floodplain Editing – Undeveloped Conditions

Man-made features, including ditches, canals, levees, roads, railroads, etc., were manually removed from each of the undeveloped conditions floodplains. Ditches and canals were removed by cutting and deleting the polygons where applicable and levees, roads, and other high elevation areas were removed by drawing a polygon to cover the dry area that represented the levee and then merging to the main polygon to show the area as wet. The HEC-RAS model was utilized for guidance to determine which features should be removed from the floodplains.

Once the appropriate edits and adjustments were made to the developed and undeveloped draft floodplains, the depth grids were clipped to the extents of the final floodplains.

Difficulties and Assumptions

Two versions of ArcGIS were used during the mapping process for Treasure County. The original floodplains and the draft floodplains were processed using ArcGIS 9.3 and the final depth grids were processed using ArcGIS 10 after addressing the District's comments. In all versions of ArcGIS, when a raster is used as the input elevation data, the rasterization cell size should default to the input raster cell size and cannot be changed in the program. During the project, it was discovered that ArcGIS 9.3 used a rasterization cell size of 2 meters, rather than the correct cell size of 2.5 meters based on the input DEM's. ArcGIS 10 used the correct rasterization cell size of 2.5 meters. Therefore, when the depth grids (Version 10) were clipped based on the final floodplains (Version 9.3), slight gaps were present at the borders (less than 0.5 meters). This was brought to the District's attention and the small gaps were determined to be insignificant.

During the pre-processing setup, it was discovered that there was missing elevation data in Rosebud DEM 1 along the northwest corner of the DEM. The missing elevation data was requested from the District and cross sections were setup to span the gap while the missing data was obtained. Therefore, cross sections were placed on both sides of the gap (XS 634 and XS 1863) with the potential for cross sections to be added once the elevation data was obtained. However, the missing elevation data was not obtained prior to finalizing the HEC-RAS model, so no new cross sections were added in the gap. The elevation data was provided prior to the mapping process and was added to the Treasure County DEM and used for developing floodplains and depth grids.

Rosebud County Mapping Notes

Pre-Processing

The Rosebud County pre-processing files (stream centerline, flow paths, and cross sections) were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Rosebud County (DEM's 1 through 7) as well as Treasure County (DEM 6) at the upstream end (XS 87292 to 87898). A number of cross sections were extended beyond the County DEM's in order to reach high ground to contain the floodplains for the larger flows. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data when this occurred. The following cross sections were partially based on the USGS topographic data: XS 33275 to XS 33884, XS 36062 to XS 36949, XS 56093, and XS 56546 to XS 56741. Although elevation data from Custer County was not necessary for pre-processing, the Custer County DEM 1 was included in the combined Rosebud DEM for the purposes of mapping.

Floodplain Processing

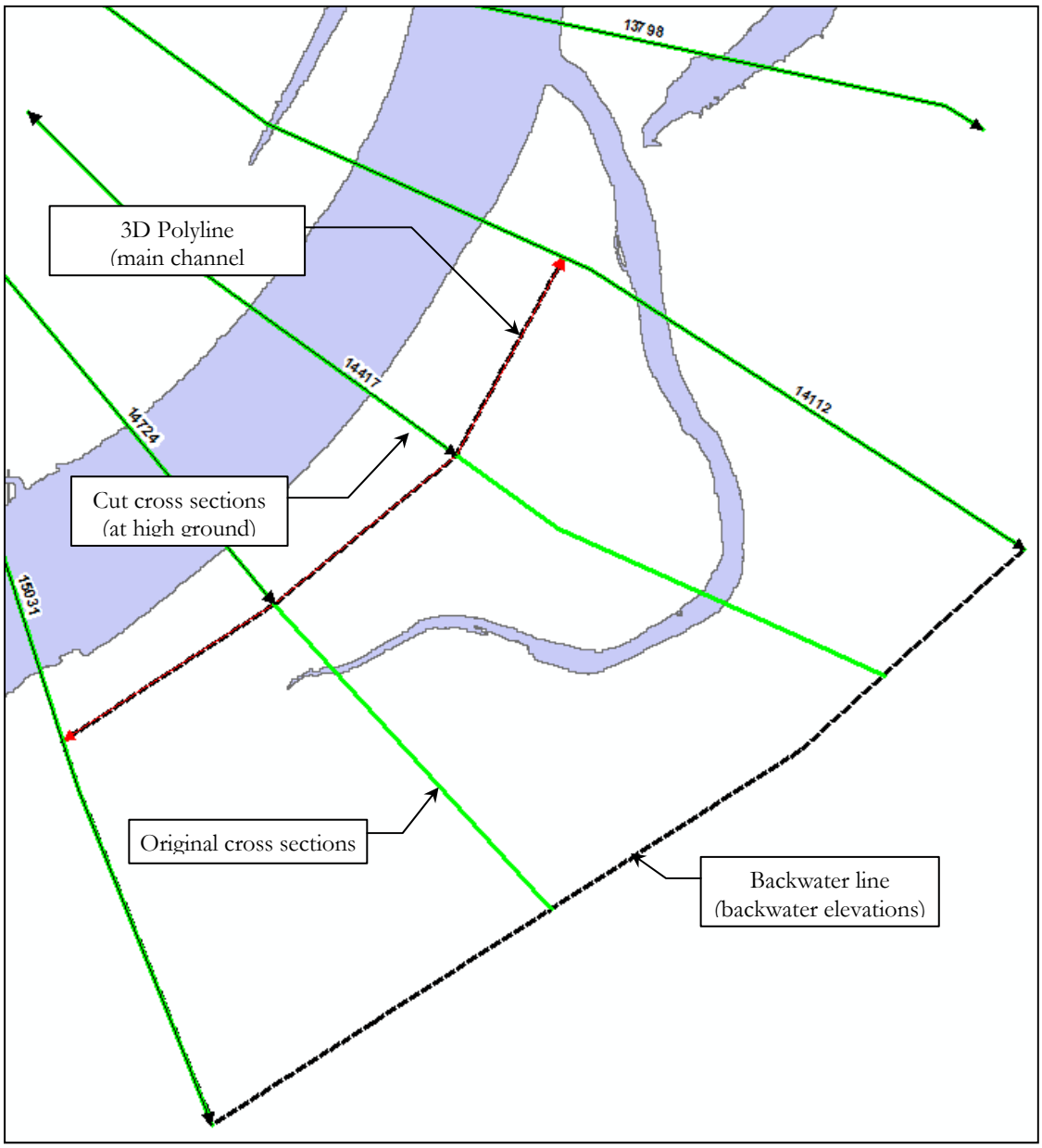
The original floodplains were generated using ArcGIS 9.3 and the Geo-RAS 4.2 extension. The output file from the final Rosebud County HEC-RAS model was imported into ArcGIS and the water surface TIN's and the original floodplains were generated. In order to provide floodplains and depth grids to the extent of the entire county, the Rosebud County model was extended into the adjacent counties. At the upstream end of the model, the most downstream cross section from the Treasure County model (XS 68) was added to the model. At the downstream end, cross sections from the Custer County model were added to the model (XS 71641 to XS 73418). Because a backwater area that overlaps the County line, cross sections down to XS 69483 were added for the profiles affected by the backwater area to ensure correct mapping. The bounding polygons were extended to the adjacent county cross sections and after floodplains and depth grids were delineated, they were clipped to the Rosebud County limits.

The original floodplains for both developed and undeveloped conditions were reviewed to identify any areas where the length and orientation of the HEC-RAS cross sections cut off the floodplains in between cross sections. At these locations, the cross sections were extended in ArcGIS (along with the bounding polygons) to ensure the floodplains extended to the limits of the DEM's provided by the District.

The original mapping was also reviewed to identify any backwater areas where the floodplain should be mapped based on the water surface elevations where the flow leaves the main channel rather than the actual water surface elevation at the cross section. Only major backwater areas were identified, small backwater areas or areas only affecting a single profile were ignored and mapped based on main channel elevations. The backwater areas adjusted for Rosebud County were located at XS 243, XS 1563, XS 6257, XS 6571, XS 7774, XS 8382, XS 9946, XS 14672, XS 17550, XS 21276, XS 27401, XS 29391, XS 32083, XS 40676, XS 49133, XS 55938, XS 58725, XS 70978, XS 83257, XS 82630, and XS 84298. The following steps were followed to map the backwater areas for each flow event. An example of the backwater features is shown in the figure below (from Prairie County).

1) A cross section shapefile was created for each flow event based on the extended cross sections and the water surface elevations for the corresponding event.
2) The cross sections were cutoff at the high ground separating the main channel and the backwater area for flow events that produced backwater areas.
3) A 3D polyline was created at the ends of the cross sections (at the high ground) based on the main channel water surface elevations for flow events that produced backwater areas.

4) A second line (backwater line) was drawn parallel to the 3D polyline and was assigned an elevation based on the backwater water surface elevation. The backwater line was snapped to the ends of the original cross sections to encompass the entire backwater area.
5) After all the backwater areas were addressed, a water surface TIN was created for each flow event based on the cut cross sections, the 3D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations).
6) In the geodatabase, the water surface TIN's from the original mapping were replaced with the new water surface TIN's and the original bounding polygons file was replaced with the extended bounding polygon file.
7) Using ArcGIS 10 and the Geo-RAS 10 extension, the draft floodplains and depth grids were generated for each flow event.



Floodplain Editing – Developed Conditions

Once the draft floodplains were processed in ArcGIS 10, all polygons outside of the main channel polygon were deleted in order to eliminate the small "ponds" or disconnected areas that show up in the mapping process that are not actually part of the floodplain wet. However, this process also deleted areas that should be included in the floodplain. For example, some areas that are mapped as disconnected are actually connected to the main polygon through a culvert or bridge. These areas were adjusted based on aerial photography and engineering judgment.

Floodplain Editing – Undeveloped Conditions

Man-made features, including ditches, canals, levees, roads, railroads, etc., were manually removed from each of the undeveloped conditions floodplains. Ditches and canals were removed by cutting and deleting the polygons where applicable and levees, roads, and other high elevation areas were removed by drawing a polygon to cover the dry area that represented the levee and then merging to the main polygon to show the area as wet. The HEC-RAS model was utilized for guidance to determine which features should be removed from the floodplains.

Once the appropriate edits and adjustments were made to the developed and undeveloped draft floodplains, the depth grids were clipped to the extents of the final floodplains.

Difficulties and Assumptions

Two versions of ArcGIS were used during the mapping process for Rosebud County. The original floodplains were processed using ArcGIS 9.3 and the draft and final floodplains were processed using ArcGIS 10. In all versions of ArcGIS, when a raster is used as the input elevation data, the rasterization cell size should default to the input raster cell size and cannot be changed in the program. During the project, it was discovered that ArcGIS 9.3 used a rasterization cell size of 2 meters, rather than the correct cell size of 2.5 meters based on the input DEM's. ArcGIS 10 used the correct rasterization cell size of 2.5 meters. Therefore, there may be slight differences at the border of the floodplains (less than 0.5 meters) if the original floodplains and final floodplains are compared. Because the draft and final floodplains were both processed in ArcGIS 10, the depth grids created and clipped to the final floodplains are aligned at the borders.

For the developed conditions, a levee runs along the right bank of the Yellowstone River to provide flood protection for Forsythe. During the mapping process, a low spot in the levee was detected at XS 55398, which resulted in flooding of Forsythe for the 100-yr Regulated and 100-, 200-, and 500-yr Unregulated flows. After closer examination of the low spot, it appears it could either be an error based on filtering of the survey data points or an actual low spot where flow will breach the levee. Since it could not be conclusively determined that the low spot was a DEM error, this area was included in the floodplains for Rosebud County. The small breach area of the levee at would potentially limit the volume of water that would overtop and limit the extent and depth of flooding behind the levee. A separate floodplain and depth grid was created for flooding behind the levee in Forsythe for each of the affected flows so it could be shown as an area with potential for flooding, rather than part of the main channel floodplain.

The 500-yr Regulated and 100-yr Unregulated floodplains were delineated using the backwater method upstream of the low spot. The 200- and 500-yr Unregulated floodplains connect at the upstream end of Forsythe (near XS 56334) and were delineated based on main channel elevations rather than backwater elevations. The section of levee overtopped at the upstream end is also small, therefore the Forsythe floodplains for the 200- and 500-yr Unregulated flows were still displayed as a separate floodplain and depth grid because the small breach areas at both locations would still limit the volume of water that would overtop and would limit the extent and depth of flooding behind the levee.

Custer County Mapping Notes

Pre-Processing

The Custer County pre-processing files (stream centerline, flow paths, and cross sections) were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Custer County (DEM's 1 through 6) as well as Rosebud County (DEM 7) at the upstream end (XS 71895 to 73418) and Prairie County (DEM 1) at the downstream end. Only one cross section (XS 23054) was extended beyond the County DEM's in order to reach high ground to contain the floodplains for the larger flows. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data at this location.

Floodplain Processing

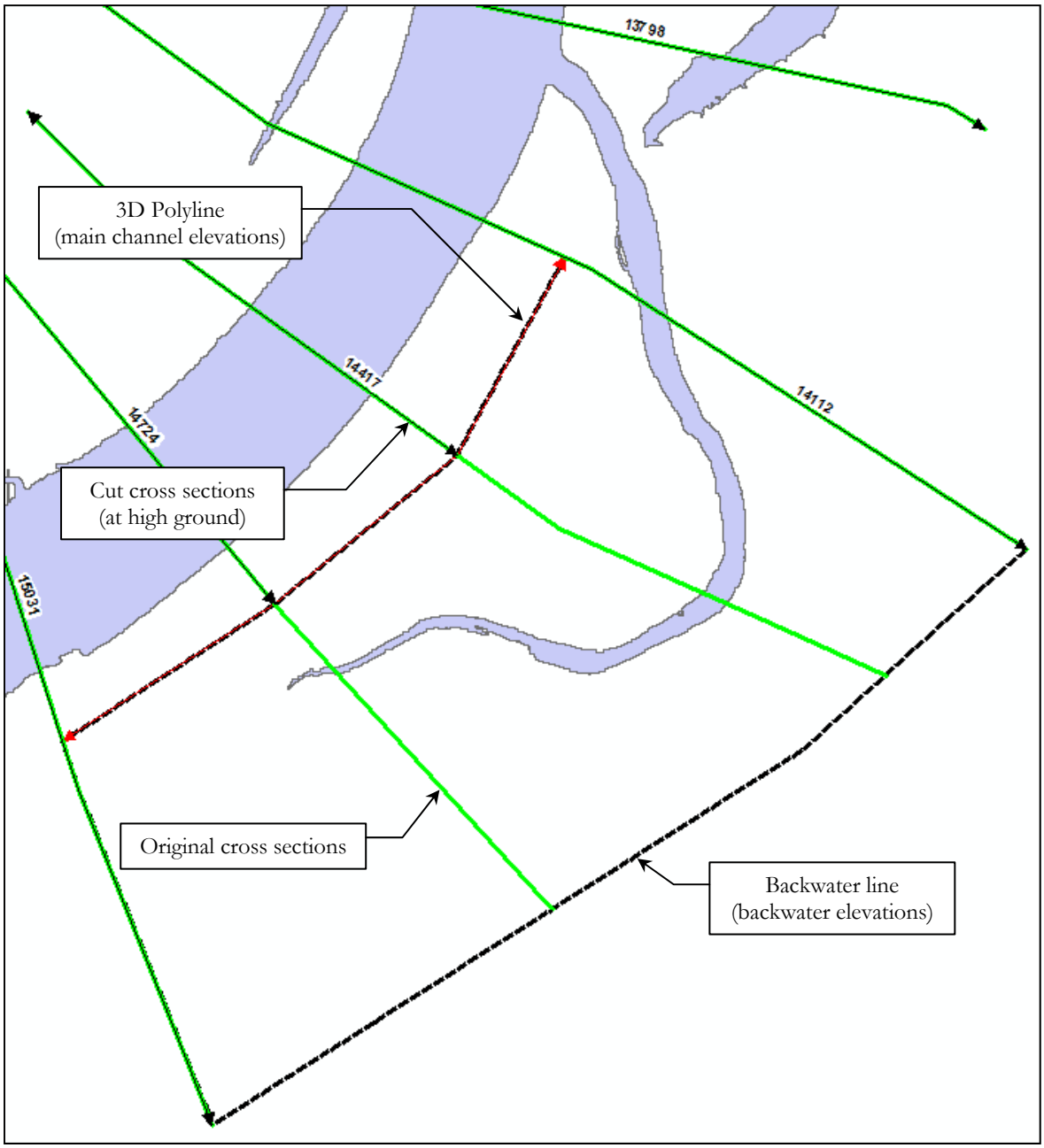
The original floodplains were generated using ArcGIS 9.3 and the Geo-RAS 4.2 extension. The output file from the final Custer County HEC-RAS model was imported into ArcGIS and the water surface TIN's and the original floodplains were generated. In order to provide floodplains and depth grids to the extent of the entire county, the Custer County model was extended into the adjacent counties. At the upstream end of the model, the most downstream cross section from the Rosebud County model (XS 243) was added to the model. At the downstream end, the most upstream cross section from the Prairie County model (XS 61391) was added to the model. The bounding polygons were extended to the adjacent county cross sections and after the floodplains and depth grids were delineated, they were clipped to the Custer County limits.

The original floodplains for both developed and undeveloped conditions were reviewed to identify any areas where the length and orientation of the HEC-RAS cross sections cut off the floodplains in between cross sections. At these locations, the cross sections were extended in ArcGIS (as well as the bounding polygons) to ensure the floodplains extended to the limits of the DEM.

The original mapping was also reviewed to identify any backwater areas where the floodplain should be mapped based on the water surface elevations where the flow leaves the main channel rather than the actual water surface elevation at the cross section. Only major backwater areas were identified, small backwater areas or areas only affecting a single profile were ignored and mapped based on main channel elevations. The backwater areas adjusted for Custer County were located at XS 10440, XS 19437, XS 21585, XS 23054, XS 45421, XS 47024, XS 49416, XS 54525, XS 56024, XS 56643, XS 57824, and XS 69483. The following steps were followed to map the backwater areas for each flow event (an example of the backwater features is shown in the figure below, from Prairie County):

1) A cross section shapefile was created for each flow event based on the extended cross sections and the water surface elevations for the corresponding event.
2) The cross sections were cutoff at the high ground separating the main channel and the backwater area for flow events that produced backwater areas.
3) A 3D polyline was created at the ends of the cross sections (at the high ground) based on the main channel water surface elevations for flow events that produced backwater areas.
4) A second line (backwater line) was drawn parallel to the 3D polyline and was assigned an elevation based on the backwater water surface elevation. The backwater line was snapped to the ends of the original cross sections to encompass the entire backwater area.

5) After all the backwater areas were addressed, a water surface TIN was created for each flow event based on the cut cross sections, the 3D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations).
6) In the geodatabase, the water surface TIN's from the original mapping were replaced with the new water surface TIN's and the original bounding polygons file was replaced with the extended bounding polygon file.
7) Using ArcGIS 9.3 and the Geo-RAS 4.2 extension, the draft floodplains and depth grids were generated for each flow event.



Floodplain Editing – Developed Conditions

Once the draft floodplains were processed in ArcGIS 9.3, all polygons outside of the main channel polygon were deleted in order to eliminate the small "ponds" or disconnected areas that show up in the mapping process that are not actually part of the floodplain wet. However, this process also deleted areas that should be included in the floodplain. For example, some areas that are mapped as disconnected are actually connected to the main polygon through a culvert or bridge. These areas were adjusted based on aerial photography and engineering judgment.

Floodplain Editing – Undeveloped Conditions

Man-made features, including ditches, canals, levees, roads, railroads, etc., were manually removed from each of the undeveloped conditions floodplains. Ditches and canals were removed by cutting and deleting the polygons where applicable and levees, roads, and other high elevation areas were removed by drawing a polygon to cover the dry area that represented the levee and then merging to the main polygon to show the area as wet. The HEC-RAS model was utilized for guidance to determine which features should be removed from the floodplains.

Once the appropriate edits and adjustments were made to the developed and undeveloped draft floodplains and comments by the District were addressed, the depth grids were clipped to the extents of the final floodplains.

Difficulties and Assumptions

Two versions of ArcGIS were used during the mapping process for Custer County. The original floodplains and the draft floodplains were processed using ArcGIS 9.3 and the final depth grids were processed using ArcGIS 10 after addressing the District's comments. In all versions of ArcGIS, when a raster is used as the input elevation data, the rasterization cell size should default to the input raster cell size and cannot be changed in the program. During the project, it was discovered that ArcGIS 9.3 used a rasterization cell size of 2 meters, rather than the correct cell size of 2.5 meters based on the input DEM's. ArcGIS 10 used the correct rasterization cell size of 2.5 meters. Therefore, when the depth grids (Version 10) were clipped based on the final floodplains (Version 9.3), slight gaps were present at the borders (less than 0.5 meters). This was brought to the District's attention and the small gaps were determined to be insignificant.

Prairie County Mapping Notes

Pre-Processing

The Prairie County pre-processing files (stream centerline, flow paths, and cross sections) were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Prairie County (DEM's 1 through 4) as well as Custer County (DEM 6) at the upstream end (XS 57683 to 61391). A number of cross sections were extended beyond the County DEM's in order to reach high ground to contain the floodplains for the larger flows. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data when this occurred. The following cross sections were partially based on the USGS topographic data: XS 350 to XS 1304, XS 22682, XS 45608 to XS 45914, XS 46551, and XS 53023.

Floodplain Processing

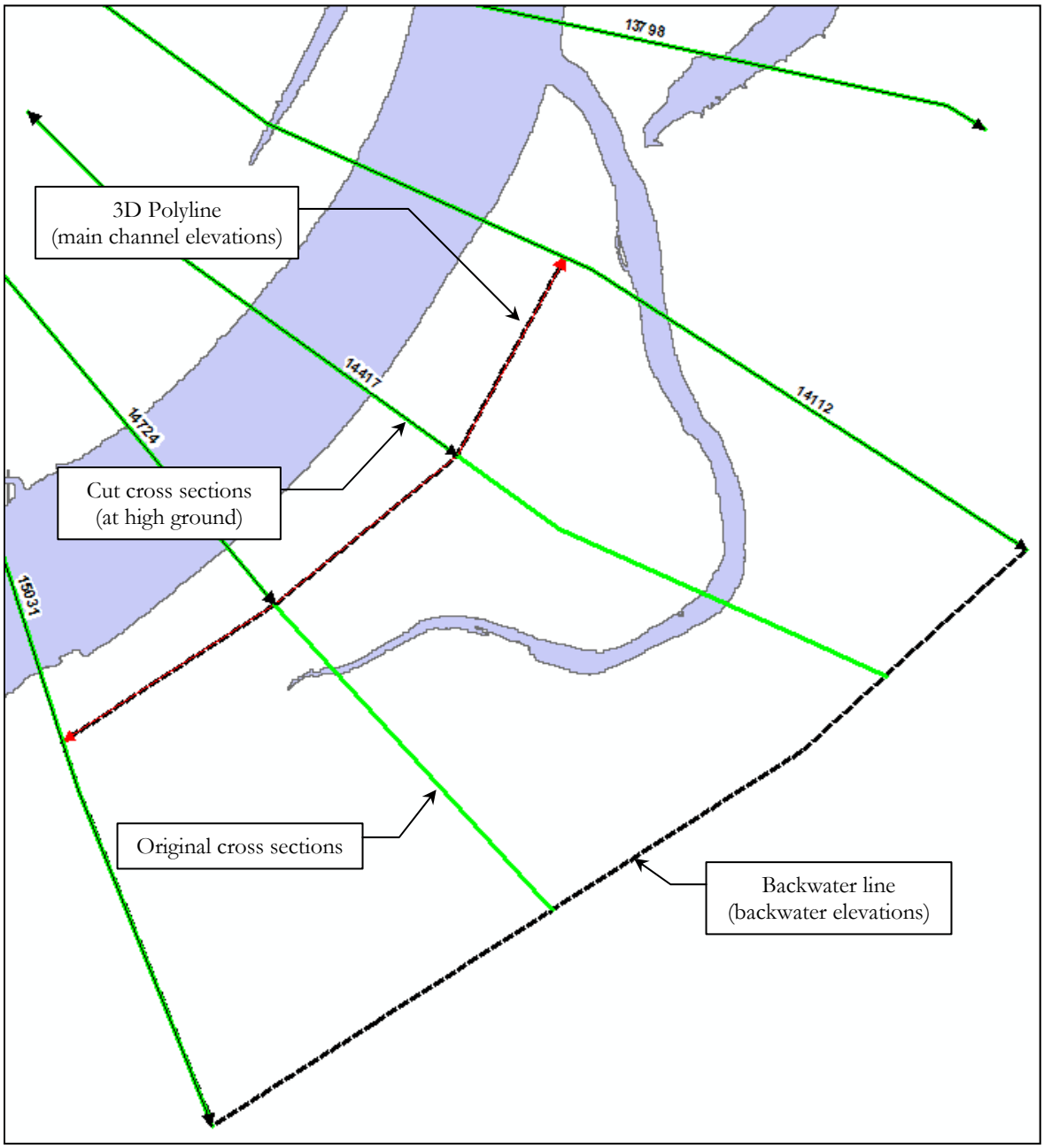
The original floodplains were generated using ArcGIS 9.3 and the Geo-RAS 4.2 extension. The output file from the final Prairie County HEC-RAS model was imported into ArcGIS and the water surface TIN's and the original floodplains were generated. In order to provide floodplains and depth grids to the extent of the entire county, the Prairie County model was extended into the adjacent counties. At the upstream end of the model, the most downstream cross section from the Custer County model (XS 229) was added to the model. Since the Dawson County models were not available at the time of mapping, the most downstream cross section of the Prairie County model (XS 350) was copied and pasted just downstream of the Dawson County line to extend the Prairie County model to the county line at the downstream end. The bounding polygons were extended to the adjacent county cross sections and after the floodplains and depth grids were delineated, they were clipped to the Prairie County limits.

The original floodplains for both developed and undeveloped conditions were reviewed to identify any areas where the length and orientation of the HEC-RAS cross sections cut off the floodplains in between cross sections. At these locations, the cross sections were extended in ArcGIS (as well as the bounding polygons) to ensure the floodplains extended to the limits of the DEM.

The original mapping was also reviewed to identify any backwater areas where the floodplain should be mapped based on the water surface elevations where the flow leaves the main channel rather than the actual water surface elevation at the cross section. Only major backwater areas were identified, small backwater areas or areas only affecting a single profile were ignored and mapped based on main channel elevations. The backwater areas adjusted for Prairie County were located at XS 3012, XS 14112, and XS 52065. The following steps were followed to map the backwater areas for each flow event (an example of the backwater features is shown in the figure below):

1) A cross section shapefile was created for each flow event based on the extended cross sections and the water surface elevations for the corresponding event.
2) The cross sections were cutoff at the high ground separating the main channel and the backwater area for flow events that produced backwater areas.
3) A 3D polyline was created at the ends of the cross sections (at the high ground) based on the main channel water surface elevations for flow events that produced backwater areas.
4) A second line (backwater line) was drawn parallel to the 3D polyline and was assigned an elevation based on the backwater water surface elevation. The backwater line was snapped to the ends of the original cross sections to encompass the entire backwater area.

5) After all the backwater areas were addressed, a water surface TIN was created for each flow event based on the cut cross sections, the 3D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations).
6) In the geodatabase, the water surface TIN's from the original mapping were replaced with the new water surface TIN's and the original bounding polygons file was replaced with the extended bounding polygon file.
7) Using ArcGIS 10 and the Geo-RAS 10 extension, the draft floodplains and depth grids were generated for each flow event.



Floodplain Editing – Developed Conditions

Once the draft floodplains were processed in ArcGIS 10, all polygons outside of the main channel polygon were deleted in order to eliminate the small "ponds" or disconnected areas that show up in the mapping process that are not actually part of the floodplain wet. However, this process also deleted areas that should be included in the floodplain. For example, some areas that are mapped as disconnected are actually connected to the main polygon through a culvert or bridge. These areas were adjusted based on aerial photography and engineering judgment.

Floodplain Editing – Undeveloped Conditions

Man-made features, including ditches, canals, levees, roads, railroads, etc., were manually removed from each of the undeveloped conditions floodplains. Ditches and canals were removed by cutting and deleting the polygons where applicable and levees, roads, and other high elevation areas were removed by drawing a polygon to cover the dry area that represented the levee and then merging to the main polygon to show the area as wet. The HEC-RAS model was utilized for guidance to determine which features should be removed from the floodplains.

Once the appropriate edits and adjustments were made to the developed and undeveloped draft floodplains, the depth grids were clipped to the extents of the final floodplains.

Difficulties and Assumptions

There is a large gap in DEM data between the Prairie DEM 1 and Custer DEM 6 at the upstream end of the model. This area was patched with the USGS topographic data, which caused the floodplains between XS 57790 and XS 59862 and at the county line to be somewhat irregular where the patched data was used. The Prairie County floodplains were merged with the draft Custer County floodplains to create a smooth transition at the county line. The irregular areas located between XS 57790 and XS 59862 were not edited because they are based on the best available data and the floodplain delineation was consistent between the different flood events.

Two versions of ArcGIS were used during the mapping process for Prairie County. The original floodplains were processed using ArcGIS 9.3 and the draft and final floodplains were processed using ArcGIS 10. In all versions of ArcGIS, when a raster is used as the input elevation data, the rasterization cell size should default to the input raster cell size and cannot be changed in the program. During the project, it was discovered that ArcGIS 9.3 used a rasterization cell size of 2 meters, rather than the correct cell size of 2.5 meters based on the input DEM's. ArcGIS 10 used the correct rasterization cell size of 2.5 meters. Therefore, there may be slight differences at the border of the floodplains (less than 0.5 meters) if the original floodplains and final floodplains are compared. Because the draft and final floodplains were both processed in ArcGIS 10, the depth grids created and clipped to the final floodplains will be lined up at the borders.

Richland-McKenzie County Mapping Notes

Pre-Processing

The Richland-McKenzie County pre-processing files (stream centerline, flow paths, and cross sections) were created using ArcGIS 9.3 and the Geo-RAS 4.2 extension. Elevation data was based on DEM's provided by the District for Richland and McKenzie Counties (Richland DEM's 1 through 7 and McKenzie DEM's 1 through 4) as well as Dawson County (DEM 46) at the upstream end (XS 101671 to XS 103500). A number of cross sections were extended beyond the County DEM's in order to reach high ground to contain the floodplains for the larger flows. USGS 1/3-Arc Second National Elevation Dataset was used to supplement topographic data when this occurred. The following cross sections were partially based on the USGS topographic data: XS 6550, XS 17284 to 26537, and XS 33973. Although elevation data from Custer County was not necessary for pre-processing, the Custer County DEM 1 was included in the combined Richland-McKenzie DEM for the purposes of mapping.

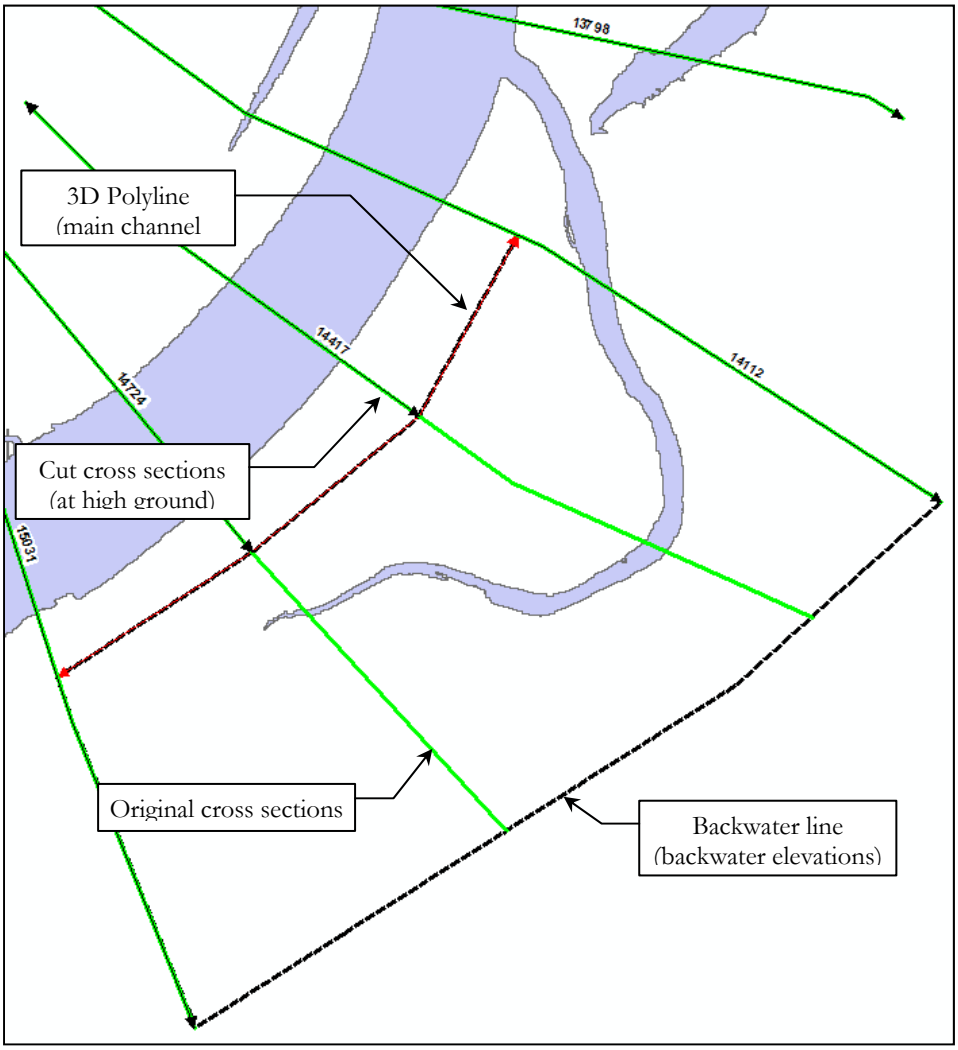
Floodplain Processing

The original floodplains were generated using ArcGIS 9.3 and the Geo-RAS 4.2 extension. The output file from the final Richland-McKenzie County HEC-RAS model was imported into ArcGIS and the water surface TIN's and the original floodplains were generated. In order to provide floodplains and depth grids to the extent of the entire county, the Richland-McKenzie County model was extended into Dawson County at the upstream end of the model. Since the Dawson County models were not available at the time of mapping, a cross section was created just upstream of the County line with the water surface elevations from the most upstream cross section of the Richland-McKenzie County model (XS 103500). The bounding polygons were extended to the new cross section and after the floodplains were delineated, they were clipped to the Richland-McKenzie County limits. The downstream end of the Richland-McKenzie County model is located at the confluence of the Missouri River and the most downstream cross section is located where the Yellowstone River intersects the Missouri River floodplain. After discussion with the District, this was determined to be an appropriate place to end the Richland-McKenzie floodplains, rather than extend to the actual confluence of the Missouri River.

The original floodplains for both developed and undeveloped conditions were reviewed to identify any areas where the length and orientation of the HEC-RAS cross sections cut off the floodplains in between cross sections. At these locations, the cross sections were extended in ArcGIS (along with the bounding polygons) to ensure the floodplains extended to the limits of the DEM's provided by the District.

The original mapping was also reviewed to identify any backwater areas where the floodplain should be mapped based on the water surface elevations where the flow leaves the main channel rather than the actual water surface elevation at the cross section. Only major backwater areas were identified, small backwater areas or areas only affecting a single profile were ignored and mapped based on main channel elevations. The backwater areas adjusted for Richland-McKenzie County were located at XS 8623, XS 8926, XS 13080, XS 19686, XS 28624, XS 35264, XS 40008, XS 44208, XS 51709, XS 56208, XS 66695, XS 70899, XS 87112, XS 89768, and XS 93982. The following steps were followed to map the backwater areas for each flow event. An example of the backwater features is shown in the figure below (from Prairie County).

1) A cross section shapefile was created for each flow event based on the extended cross sections and the water surface elevations for the corresponding event.
2) The cross sections were cutoff at the high ground separating the main channel and the backwater area for flow events that produced backwater areas.
3) A 3D polyline was created at the ends of the cross sections (at the high ground) based on the main channel water surface elevations for flow events that produced backwater areas.
4) A second line (backwater line) was drawn parallel to the 3D polyline and was assigned an elevation based on the backwater water surface elevation. The backwater line was snapped to the ends of the original cross sections to encompass the entire backwater area.
5) After all the backwater areas were addressed, a water surface TIN was created for each flow event based on the cut cross sections, the 3D polylines (based on the main channel elevations), and the backwater lines (based on backwater elevations).
6) In the geodatabase, the water surface TIN's from the original mapping were replaced with the new water surface TIN's and the original bounding polygons file was replaced with the extended bounding polygon file.
7) Using ArcGIS 10 and the Geo-RAS 10 extension, the draft floodplains and depth grids were generated for each flow event.



Floodplain Editing – Developed Conditions

Once the draft floodplains were processed in ArcGIS 10, all polygons outside of the main channel polygon were deleted in order to eliminate the small "ponds" or disconnected areas that show up in the mapping process that are not actually part of the floodplain wet. However, this process also deleted areas that should be included in the floodplain. For example, some areas that are mapped as disconnected are actually connected to the main polygon through a culvert or bridge. These areas were adjusted based on aerial photography and engineering judgment.

Once the appropriate edits and adjustments were made to the developed and undeveloped draft floodplains, the depth grids were clipped to the extents of the final floodplains.

Floodplain Editing – Undeveloped Conditions

Man-made features, including ditches, canals, levees, roads, railroads, etc., were manually removed from each of the undeveloped conditions floodplains. Ditches and canals were removed by cutting and deleting the polygons where applicable and levees, roads, and other high elevation areas were removed by drawing a polygon to cover the dry area that represented the levee and then merging to the main polygon to show the area as wet. The HEC-RAS model was utilized for guidance to determine which features should be removed from the floodplains.

Difficulties and Assumptions

Two versions of ArcGIS were used during the mapping process for Richland-McKenzie County. The original floodplains were processed using ArcGIS 9.3 and the draft and final floodplains were processed using ArcGIS 10. In all versions of ArcGIS, when a raster is used as the input elevation data, the rasterization cell size should default to the input raster cell size and cannot be changed in the program. During the project, it was discovered that ArcGIS 9.3 used a rasterization cell size of 2 meters, rather than the correct cell size of 2.5 meters based on the input DEM's. ArcGIS 10 used the correct rasterization cell size of 2.5 meters. Therefore, there may be slight differences at the border of the floodplains (less than 0.5 meters) if the original floodplains and final floodplains are compared.

There were several locations where the floodplains extended into the USGS topographic area for mapping. At the majority of these locations, a large inconsistency between the elevations of the District DEM's and the USGS topographic data was evident. This is most likely due to the level of vertical accuracy associated with the two datasets. Locations where this occurred are at XS 15797 to XS 16084 (right), XS 19686 to XS 21429 (left), XS 22341 to XS 24144 (right), and XS 24144 to XS 26537 (left). At XS 16084, the floodplains were clipped to the edge of the District DEM because the part that extended into the USGS topographic data was a tributary and not part of the main channel floodplain.

APPENDIX E

QUALITY CONTROL REPORT AND CERTIFICATION

Yellowstone River Hydraulic Modeling and Floodplain Mapping

Quality Control Report and Certification

February 2013

Contract No. W9128F-09-D-0002
Task Order No. 16

Prepared for:

US Army Corps of Engineers
Omaha District
1616 Capitol Ave, Suite 9000
Omaha, NE 68102

Prepared by:

WEST Consultants, Inc.
11440 W. Bernardo Court, Suite 360
San Diego, CA 92127

WEST Project No. USAC001040

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1 INTRODUCTION

1.1 NAME OF PROJECT

Hydraulic modeling and floodplain mapping to support Yellowstone River Cumulative Effects Study.

1.2 CONSULTANT

This project is being performed by WEST Consultants, Inc., San Diego, California (Architect-Engineer or A-E), for the U.S. Army Corps of Engineers, Omaha District.

1.3 MEMBERS OF DEVELOPMENT TEAM AND AREAS OF EXPERTISE

Martin J. Teal, P.E., P.H., D.WRE
Principal-in-Charge
Areas of Expertise: Development and application of hydraulic models, providing training in hydraulic, hydrologic, and sediment transport modeling and analysis, sediment transport modeling, review of technical reports, quality assurance concepts.

Christine Parente, P.E.
Project Manager, Senior Hydraulic Engineer
Areas of Expertise: Development and application of hydrologic, hydraulic, and sedimentation models, GIS technology application, and floodplain management.

Dragoslav Stefanovic, Ph.D., P.E., D.WRE
Project Manager
Areas of Expertise: Development and application of hydrologic, hydraulic and sedimentation models, scheduling, review of technical reports.

Cameron Jenkins, P.E.
Hydraulic Engineer
Areas of Expertise: Development and application of hydrologic and hydraulic models, GIS technology application, sediment transport model analysis, and scour analysis.

Miguel Parames, P.E.
Hydraulic Engineer
Areas of Expertise: Development and application of hydraulic models, GIS technology application, and hydrologic model development.

Daniel Christensen, P.E.
Hydraulic Engineer
Areas of Expertise: Development and application of hydraulic models, GIS technology application, and hydrologic model development.

Kurt Baron, GISP
GIS Specialist
Areas of Expertise: GIS technology application, development of hydrologic and hydraulic models, data processing, and mapping.

Sam Powvall
GIS Technician
Areas of Expertise: GIS technology application and mapping.

Joanne Buck
GIS Technician
Areas of Expertise: GIS technology application and mapping.

1.4 MEMBERS OF INDEPENDENT TECHNICAL REVIEW TEAM AND AREAS OF EXPERTISE

Martin J. Teal, P.E., P.H., D.WRE
Quality Assurance Manager
Areas of Expertise: Development and application of hydraulic models, providing training in hydraulic, hydrologic, and sediment transport modeling and analysis, sediment transport modeling, review of technical reports, quality assurance concepts.

Jake Gusman, P.E., D.WRE
Project Manager
Areas of Expertise: Development and application of hydraulic models, hydrologic model development, sediment and scour analysis, sediment/debris yield, floodplain management, and quality assurance concepts.

Daniela Todesco, P.E.
Hydraulic Engineer
Areas of Expertise: Development and application of hydraulic models, hydrologic model development, and scour analysis.

1.5 SUMMARY OF ENGINEERS AND REVIEWERS BY TASK

Provided in the table below is a summary of the hydraulic engineers and the independent technical reviewer for each of the major study tasks.

Study Task	Hydraulic Engineer(s)	WEST Reviewer(s)
Construct Hydraulic Models		
Treasure County	Cameron Jenkins, P.E.	Christine Parente, P.E. Dragoslav Stefanovic, P.E.
Rosebud County	Cameron Jenkins, P.E. Miguel Parames, P.E.	Christine Parente, P.E. Dragoslav Stefanovic, P.E.
Custer County	Cameron Jenkins, P.E. Miguel Parames, P.E.	Christine Parente, P.E. Dragoslav Stefanovic, P.E.
Prairie County	Daniel Christensen, P.E.	Miguel Parames, P.E. Christine Parente, P.E.
Richland/McKenzie County	Miguel Parames, P.E.	Christine Parente, P.E.
Delineate Floodplain Mapping		
Treasure County	Sam Powvall Joanne Buck	Christine Parente, P.E.
Rosebud County	Sam Powvall	Christine Parente, P.E.
Custer County	Sam Powvall	Christine Parente, P.E.
Prairie County	Sam Powvall	Christine Parente, P.E.
Richland/McKenzie County	Sam Powvall	Christine Parente, P.E.
Final Report	Christine Parente, P.E.	Jake Gusman, P.E. Martin Teal, P.E., P.H.

* Includes major review dates; supervisory and other in-progress reviews are not listed.

2 QUALITY CONTROL CERTIFICATION

The products included with this deliverable were completed and reviewed in accordance with our Company's Quality Control Plan that is on file with the Omaha District's Project Manager. All applicable design checks, interdisciplinary checks and quality control reviews have been completed by the designated designers and reviewers as stated in the Quality Control Plan. Our company believes this product is in compliance with all applicable criteria and the stated scope of work. Incomplete work will be added to this product at no additional cost to the government.

Martin J. Teal, P.E., P.H. Principal-in-Charge Quality Assurance Manager	Christine Parente, P.E. Project Manager

Certification Date: 15 February 2013