May 2011 Photo - Kestrel Aerial Services, Inc.

Musselshell River Floodplain Study – Phase II

Hydraulic Analysis and Floodplain Mapping

PETROLEUM COUNTY
MONTANA

November 2016

Contract Number: WO-MM-143
Mapping Activity Statement No. 2015-12

MONTANA DNRC

Morrison Maierle
engineers · surveyors · planners · scientists

FEMA

Musselshell River Floodplain Study – Phase II

Hydraulic Analysis and Floodplain Mapping Report

Petroleum County, MT

PREPARED FOR:

Montana Department of Natural Resources and Conservation

Federal Emergency Management Agency

November 18, 2016

PREPARD BY:

Morrison Maierle
engineers · surveyors · planners · scientists

P.O. Box 6147
Helena, MT 59604
Telephone: (406) 442-3050
www.m-m.net

I hereby certify that all work products (maps, reports, etc.) prepared for this project were done so under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Montana.

Mark A. Franchi

Mark A. Franchi, PE, CFM

MONTANA
MARK-ANTHONY E. FRANCHI
8847PE
REGISTERED PROFESSIONAL ENGINEER

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1.0 Introduction and Background

Morrison-Maierle, Inc. has completed a hydraulic analysis of the Musselshell River within Petroleum County, Montana, as part of the Flood Risk Project initiated by the Montana Department of Natural Resources and Conservation (DNRC) in partnership with the Federal Emergency Management Agency (FEMA). The purpose of this report is to document the hydraulic analysis, and to provide results for incorporation into floodplain mapping and a Flood Insurance Study (FIS).

Most severe flooding events in this watershed have been produced from spring snowmelt and runoff from intense rainfall events. In May 2011 and March 2014, significant flooding occurred in the Musselshell River basin, appreciably exceeding previous peak floods of record.

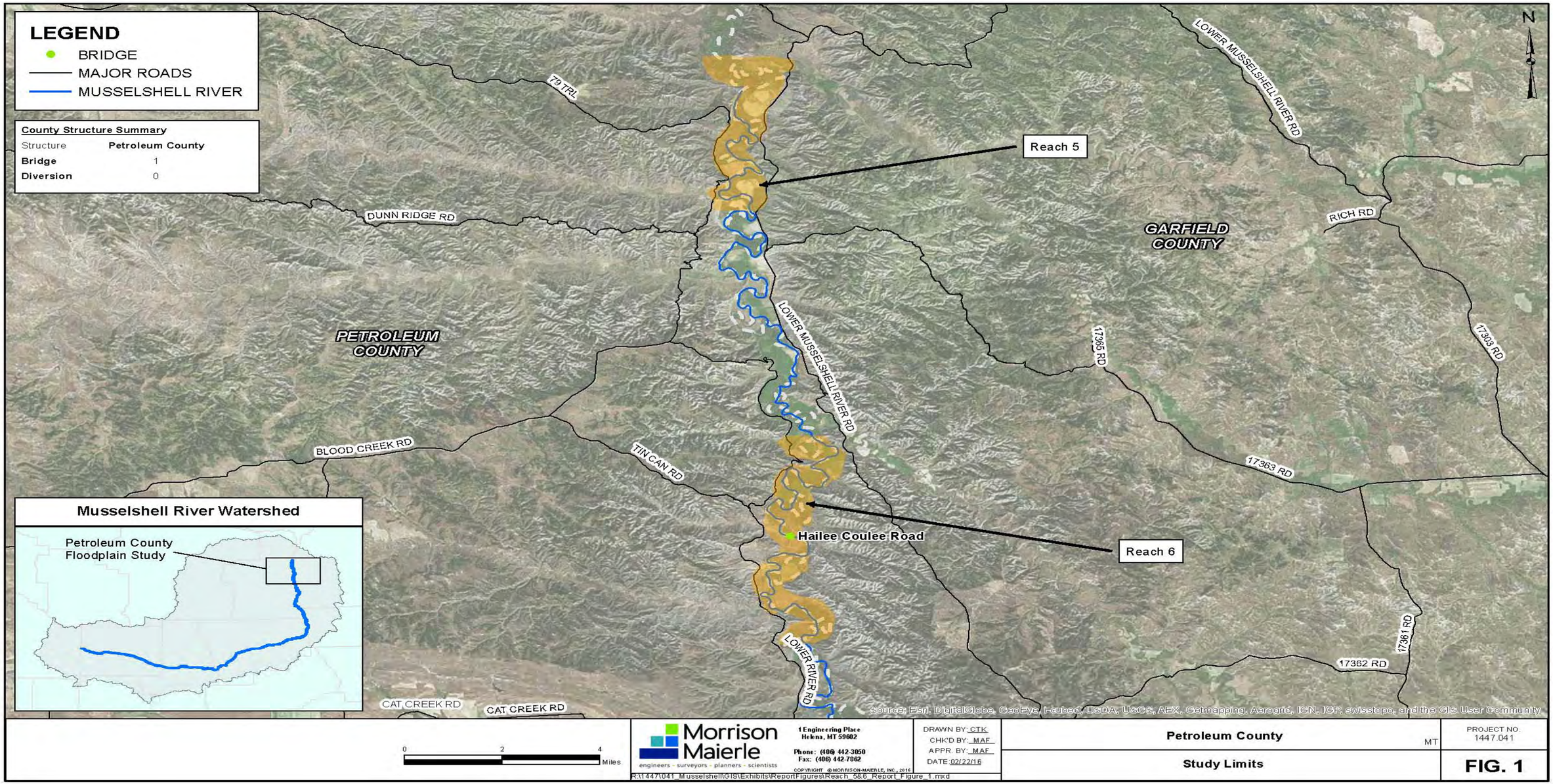
The study limits consists of two segments, Reach 5 and Reach 6. Reach 5, out of 10 reaches in the contract, begins at the UL Bend (Charles M. Russel) National Wildlife Refuge and extends upstream approximately 6 river miles (Figure 1). Reach 6 begins approximately 16.7 river miles upstream of Reach 5 and extends upstream approximately 8.3 river miles. The total length of study within Petroleum County is approximately 14.3 river miles.

This Summary Report details the information and methods used to develop the 1-percent-annual-chance (100-year) and 0.2-percent-annual-chance (500-year) floodplains. This detailed study is based on the best available information including LIDAR, bathometric, structure survey, and a new hydrologic analysis developed specifically for this mapping update. The LIDAR was obtained by Photo Science Inc. in 2012 (Photo Science, 2012). The hydrologic analysis was completed by Pioneer Technical Services, Inc. in 2015 (Pioneer, 2015) and approved by FEMA in 2015. The structure survey was completed by Morrison-Maierle, Inc. in the fall of 2015 (MMI, 2015) and submitted to FEMA in January 2016.

The detailed hydraulic analysis for Musselshell River for Petroleum County, Montana is summarized in this report. The flood study includes the 10%, 4%, 1%, and 0.2% annual-chance flood events. FEMA Standards (SID# 84) for Flood Risk Projects identify a requirement to model a 1-percent plus in riverine analyses and include the 1-percent plus in the Flood Profiles for the FIS Report. Discussions between DNRC and FEMA removed this requirement from the Mapping Activity Statement (MAS 2015-02) for the Musselshell Watershed Project, Phase II. Thus, no 1-percent plus hydrologic or hydraulic analyses were performed as part of this study and no flood profiles are presented for 1-percent plus in the FIS.

This is the first Flood Insurance Study (FIS) on this reach of the Musselshell River and no effective FIS or mapping exists as of 2016. The Montana Department of Natural Resources (DNRC) and the professional service contractor Morrison-Maierle, Inc. (MMI) have completed this study to meet the guidelines and standards published in the FEMA Resource and Document Library to ensure the limited detail study complies with the National Flood Insurance Program.

Figure 1. Study Limits



1.1 Watershed Description

The Musselshell River is located east of the continental divide in central Montana and originates in the Castle, Little Belt, and Crazy Mountains. The mainstem Musselshell River begins at the confluence of the North Fork and South Fork of the Musselshell Rivers near the town of Martinsdale, Montana and flows to the east and then north for approximately 335 miles to its confluence with the Missouri River and Fort Peck Reservoir. The entire Musselshell watershed area encompasses approximately 9,471 square miles (Pioneer, 2015).

The Musselshell River basin elevations range from approximately 9,000-feet in the Crazy Mountains to approximately 2,000-feet at the confluence with the Missouri River (Pioneer, 2015). The terrain varies from a high alpine environment in its headwaters to a prairie landscape in the eastern reaches with expansive grass and shrub lands, broken and rolling foothills, and low density drainage networks (Applied Geomorphology and RATT, 2012). The hydrology of the basin is primarily snowmelt driven although significant flows can result from summer precipitation events.

Land use in the Musselshell River basin is primarily agricultural with irrigated and dryland farming and ranching operations. Most of the intensely farmed land is located within the Musselshell River floodplain. Three irrigation storage reservoirs exist on the Musselshell: the Bair Reservoir on the North Fork; Martinsdale Reservoir an off channel reservoir fed by the South Fork Musselshell River near Martinsdale; and Deadman's Basin Reservoir an off channel reservoir between Shawmut and Ryegate. Martinsdale Reservoir and Deadman's Reservoir do not provide any flood protection due to their limited feeder canal capacity (Pioneer, 2015). Bair Reservoir is located in the headwaters of the North Fork Musselshell River and does not provide significant flood protection for the mainstem Musselshell River due to its limited capacity. During the summer and fall seasons, reaches of the Musselshell River are often dewatered due to irrigation withdrawals.

2.0 Previous Mapping

No effective Flood Hazard Boundary Maps (FHBM) or Flood Insurance Rate Maps (FIRMs) exist for Petroleum County, Montana at this time.

3.0 Hydrology

This detailed flood study covers approximately 14.3 river miles of the Musselshell River within Petroleum County (Figure 1). The beginning of the study is at river mile 0 near the crossing of southern boundary of the UL Bend (Charles M Russel) National Wildlife Refuge and extending upstream to approximately river mile 31. One active United States Geological Survey (USGS) gaging station is located in the vicinity of the study area. USGS gage 06130500 Musselshell River at Mosby, Montana, is at the Highway 200 Bridge and has been in operation since 1929. Figure 2 identifies the gaging station location and the summary data for the gage is listed in Table 1.

Table 1. USGS Gaging Stations

Gaging Station Number	Gaging Station Name	Period of Record	Number of Annual Peaks	Drainage Area (square miles)	Maximum Peak Discharge (cfs) / Year	Minimum Peak Discharge (cfs) / Year
06130500	Musselshell River at Mosby	1929 – 1931 1932 1934 – 1946 1948 – 2014	83	7,784	25,100 / 2011	90 / 2000

The hydrologic analyses included flood frequency analysis following the Interagency Advisory Committee on Water Data, Bulletin #17B (USGS, 1982b). Systematic flood frequency analyses were completed for 11 gages on the Musselshell River shown per USGS WRIR 03-4308 (Parrett & Johnson, 2004) and based on extended gage records to the year 2014 (Pioneer, 2015).

To accurately model the Musselshell River, locations of major tributary confluences and other flow change locations were identified in the hydrologic analyses (Pioneer, 2015). The peak flow frequency estimates at the ungagged flow change locations were calculated using the drainage area gage transfer method and the two site logarithmic interpolation methods in accordance with USGS WRIR 03-4308 (Parrett & Johnson, 2004).

The summary of peak flow estimates at the USGS gaged and ungaged locations for the Musselshell River in Petroleum County are presented in Table 2.

Figure 2. Flow Change Locations

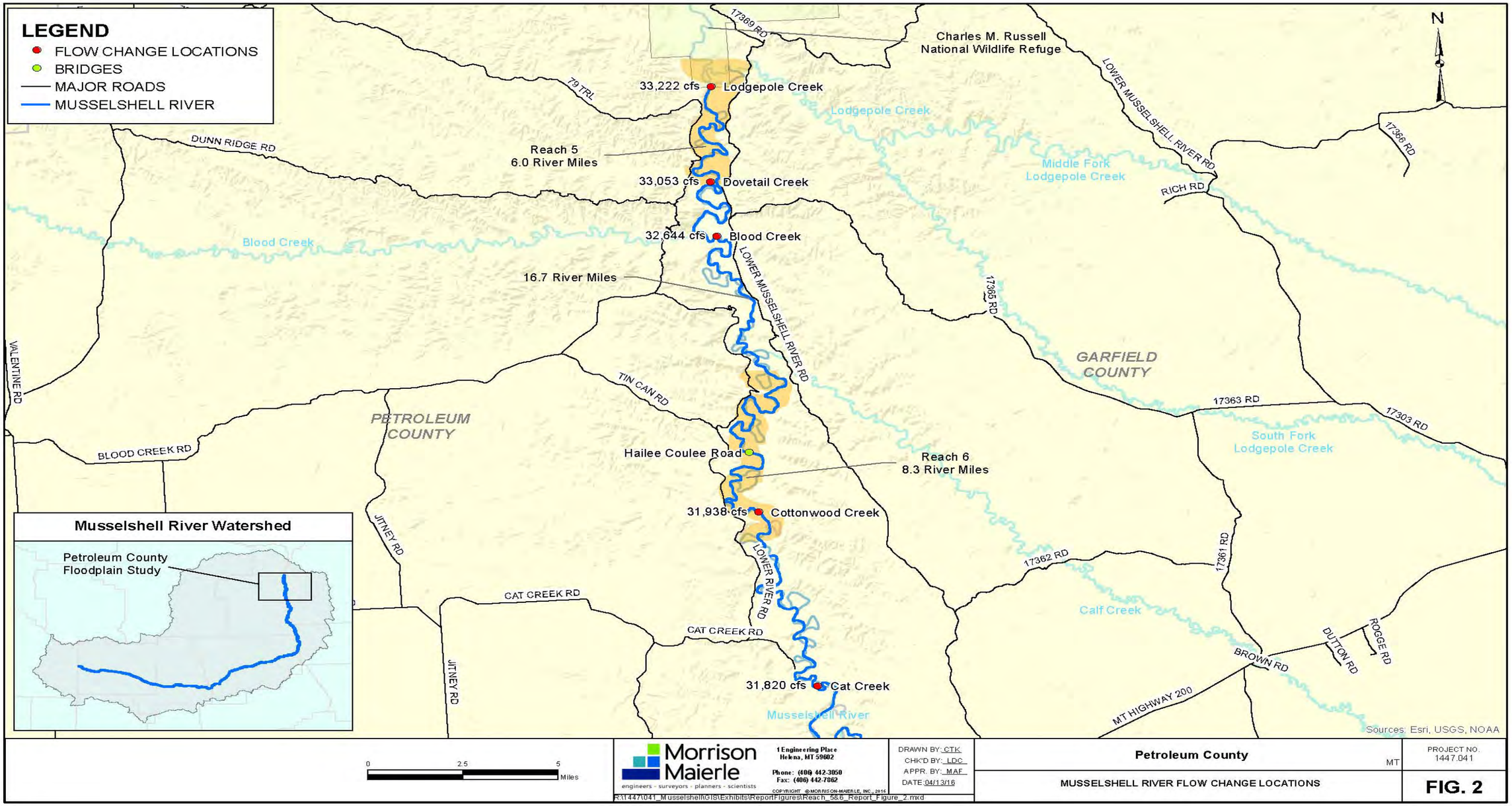


Table 2. Summary of Discharges for Musselshell River

River Station	County Segment	Location Description	Peak Flow Rate (cfs)				
			10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance5 500-year
-4461	Reach 5	Lodgepole Creek	12,619	19,604	25,922	33,222	54,388
26545	↓	Dovetail Creek	12,552	19,501	25,788	33,053	54,121
31665	↓	Blood Creek	12,388	19,251	25,463	32,644	53,473
155815	Reach 6	Cottonwood Creek	12,163	18,908	25,015	32,079	52,580
163692	↓	Cat Creek	12,107	18,822	24,904	31,938	52,357

4.0 Hydraulics

The methods and techniques used to complete the detailed hydraulic analysis of the Musselshell River are presented in the following sections.

4.1 Hydraulic Analysis

This floodplain study of the Musselshell River within Petroleum County, Montana consists Reach 5 and Reach 6. Reach 5 begins at the UL Bend (Charles M. Russel) National Wildlife Refuge and extends upstream approximately 6.0 river miles (Figure 2). Reach 6 begins approximately 16.7 river miles upstream of Reach 5 and extends upstream approximately 8.3 river miles. The total length of study within Petroleum County is 14.3 river miles.

Appendix C of FEMA Guidelines and Specifications (FEMA 2009) were followed for the hydraulic model development. The water surface elevations (WSEL's) were calculated with HEC-RAS, Version 4.1.0 hydraulic modeling software (USACE 2010a). HEC-RAS for steady flow analysis performs the standard step energy balance calculation between cross sections starting at the most downstream cross section and moving upstream for a fully subcritical analysis. Cross sections were placed with GeoHECRAS hydraulic computer modeling software (GeoHECRAS, 2016) at flow lengths ranging from approximately 100- to 1,000-feet and at structure locations along the floodplain. The length of each segment and location along the Musselshell River is summarized in Table 3.

Table 3. Reach Segment Summary

Segment	Starting River Mile	Ending River Mile	Length (River Miles)
Reach 5	0.0	6.0	6.0
Reach 6	22.7	31.0	8.3
Total			14.3

4.2 Topographic Data Acquisition

The Natural Resource Conservation Service (NRCS) contracted with Photo Sciences to acquire topographic Light Detection and Ranging (LiDAR) data for the project area in 2012. The LiDAR deliverables included 1-meter grid bare earth digital elevation models (DEM) for the entire length of the Musselshell River corridor (NRCS, 2012). The LiDAR data was collected with the following specifications:

Projection:	Montana State Plane	Units
Datum:	Horizontal – NAD83	International Feet
	Vertical – NAVD88	US Feet

NAD: North American Datum NAVD: North American Vertical Datum

4.3 Profile Baseline

The stream channel centerline for Reaches 5 and 6 of the Musselshell River was utilized to define the Profile Baseline of river stationing as stream distance in feet above the respective downstream limit. The profile baseline is shown on the Work Maps included in Appendix A. The stream centerlines (Profile Baselines) were created using the LiDAR and National Agricultural Imagery Program (NAIP) aerial imagery (USDA, 2012). The summary of key features along each reach of the Musselshell River for Reaches 5 and 6 are presented in Tables 4 and 5, respectively.

Table 4. Key Features along Reach 5 Profile Baseline

River Station	Feature	Description	1% AC Discharge (cfs)
-7219 *	Downstream Modeled XS	Furthest downstream cross section used for model Boundary Conditions.	33,222
-4461 *	Flow Change Location	Lodgepole Creek confluence with Musselshell River – part of model Boundary Conditions.	33,222
0	Downstream Limit of Study	Downstream limit of study near Musselshell River Mile 0.	33,053
26545	Flow Change Location	Dovetail Creek confluence with Musselshell River.	33,053
31665	Upstream Limit of Study	Furthest upstream cross section near Musselshell River Mile 6.	32,644

* Negative River Station reach for normal depth boundary condition.

Table 5. Key Features along Reach 6 Profile Baseline

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
112931	Downstream Modeled XS	Furthest downstream cross section used for model Boundary Conditions.	32,079
119712	Downstream Limit of Study	Downstream limit of study near Musselshell River Mile 22.7.	32,079
136220	Hailee Coulee Rd.	Structure B1 – two span bridge with a total span of 158-feet.	32,079
155815	Flow Change Location	Cottonwood confluence with Musselshell River.	32,079
163692	Upstream Limit of Study	Furthest upstream cross section near Musselshell River Mile 31.	31,938

4.4 Boundary Conditions

To establish a subcritical hydraulic analysis, HEC-RAS requires boundary condition input data at the first downstream cross section of the model reach. According to FEMA Guidelines and Specifications, Appendix C (FEMA, 2009), if the study is absent of an established downstream elevation or control cross section, then the starting water-surface elevation using normal depth boundary condition should be used at a cross section

sufficiently downstream of the study limits. Energy slopes of 0.00096 ft/ft (0.096%) and 0.00074 ft/ft (0.074%) are representative of the boundary condition flood profile slopes for Reaches 5 and 6, respectively. These boundary conditions were determined for the river approximately 7,220 and 6,780 feet downstream of the Reaches 5 and 6 study limits.

4.5 Cross Section Development

The terrain data in the GeoHECRAS (GeoHECRAS, 2016) model was predominately based on the aforementioned LiDAR data. Utilizing the GIS computer program ArcMap 10.1 (ESRI, 2012), cross sections were placed perpendicular to flow and along estimated equipotential lines. Cross sections were extended in order to capture the boundaries of the 0.2-percent annual-chance floodplain. Cross sections were placed at key locations along the reach, including: breaks in channel slope, abrupt changes in floodplain width, and at bridge and diversion structure locations. Cross sections were filtered to less than 500 points per cross section as required by HEC-RAS.

Stream channel bathymetry survey was completed by Morrison-Maierle, Inc. in 2015 and was combined with LiDAR using GeoHECRAS 'Conflate Point Data' tool to replace the LiDAR data with the stream channel bathymetry survey. Cross sections were filtered to less than 500 points per cross section as required by HEC-RAS.

The cross sections are shown on the Hydraulic Work Maps provided in Appendix A.

4.6 Hydraulic Structure

The field hydraulic structure survey for the Musselshell River was completed by Morrison-Maierle, Inc. in 2015. The survey included one hydraulic structure located at the Hailee Coulee Road Bridge crossing (Photograph 1).

The geometry for the hydraulic structure was modeled with the data obtained from the structure survey. The expansion and contraction coefficients of the two upstream cross sections along with the one downstream cross sections were increased from the natural channel value of 0.1 and 0.3, to 0.3 and 0.5, for a bridge constriction, respectively. This hydraulic modeling practice was made to account for the increased head loss associated with the relatively abrupt transitions and varying velocities that accompany the expansion and contraction of flows at a bridge.

The bridge modeling approach is set for both high and low flow methods based on the bridge characteristics. The high flow method is set at Pressure/Weir flow since the structure would be overtopped during a high flow event. The low flow methods is set at the Energy, Momentum or Yarnell methods, since the structure is constructed with mid-span circular piers. The momentum method requires setting the Drag Coefficient (CD) and the Yarnell equation requires setting the K Coefficient based on the pier shape. The CD and K coefficients set for the Hailee Coulee Road bridge are set at 1.20 and 1.05, respectively, for circular piers.

A summary of the Hailee Coulee Road bridge structure and settings for the hydraulic model are provided in Tables 6 and 7, respectively. Photograph 1 shows the bridge structure with additional photographs provided in Appendix C.

Table 6. Hailee Coulee Road Bridge

River Station	Spans	Total Span (feet)	Deck Width (feet)	Deck Thickness (feet)	Guardrail Height (feet)	Pier Type	Pier Width (feet)
136220	2	158	19	2.4	2.3	Circular	2, 3

Table 7. Hailee Coulee Road Bridge Model Settings

River Station	Contraction Coefficient	Expansion Coefficient	Pier Type	Low Flow Method	High Flow Method
136220	0.3	0.5	Circular	Energy, Momentum, Yarnell	Pressure/Weir

Photograph 1: Looking downstream at Hailee Coulee Road Bridge.

4.7 Manning's 'n' Values

Manning's 'n' values are roughness coefficients representing the frictional resistance water experiences when flowing overland or through a channel. The coefficients are used in the calculations to determine water surface elevations. Five land classes were developed for the study area to establish Manning's 'n' value based on ground and cover conditions. The land classes were developed through interpretations of aerial photographs and Montana Department of Revenue Land Classification Units. The classification work resulted in a spatial layer covering the study area. Manning's 'n' values assigned within the hydraulic

model were determined based on field observation, aerial photography, land-use mapping and the USGS publication, 'Guide to Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (USGS, 1982).

The USGS guide was used to develop minimum, maximum, and initial Manning's 'n' values for each land class. The initial land class Manning's 'n' values were assigned to the spatial land classification data set and the GeoHECRAS application was used to assign the spatial based roughness data to the model cross-sections.

Manning's 'n' values were evaluated at each cross-section in GeoHECRAS and adjustments to the horizontal limits were made to fit with the terrain data represented by the cross section. Adjustments to the Manning's 'n' values were also made as needed during hydraulic model development. The adjustments to the Manning's 'n' value remained within the range of acceptable values determined for each land class. Manning's 'n' values used in the study are provided in Table 8.

Table 8: Manning's 'n' Values

Roughness Area Land Class Type	Manning's 'n' Value	Description
Main Channel	0.039 – 0.058	Coarse gravel
Grass/Hay & Herbaceous Meadow	0.058 – 0.060	Normal/Native valley vegetation
Agricultural Cropped Area	0.060 – 0.070	Cropped & cultivated areas
Riparian Cottonwood & Willow	0.070	Heavy willow and cottonwood growth

4.8 Areas of Non-Conveyance

As indicated on the Hydraulic Work Maps in Appendix A, there are reaches where no flow or backwater conditions exist. These conditions provide limited or no conveyance in the downstream direction. For these areas, the ineffective Flow Area Method was implemented to model and calculate the total effective conveyance for each cross section. Review of the modeled cross sections in HEC-RAS identified depression areas that are not hydraulically connected to the stream body. These areas were also classified as ineffective flow areas in order for the model to correctly calculate the appropriate conveyance at the cross section.

Areas of flow expansion and contraction at the cross sections bounding structures were also assigned areas of non-conveyance in order to direct the one-dimensional steady state model to calculate the head loss due to two-dimensional flow contraction and expansion. The flow contraction and expansion areas were calculated using a 1:1 stream wise to lateral direction and a 2:1 ratio, respectively. The ratios of expansion and contraction were developed using the cross sectional velocities as recommended in the HEC-RAS Reference Manual (USCOE 2010).

The associated ineffective flow descriptions have been placed in the HEC-RAS text box for each cross section to document the non-conveyance areas implemented for the hydraulic model. The types of non-conveyance include the following:

- Backwater and ponded areas.
- Flow contraction or expansion.
- Areas isolated by non-accredited levees, abandoned railroad embankments or elevated roads.
- High topography that limits flow to lower area.

4.9 Model Calibration

The model calibration for Reaches 5 and 6 was completed with the NAIP imagery taken during the high water event which occurred on May 2011. The peak flow rate of 25,100 cfs was recorded at USGS gage 06130500 Musselshell River at Mosby, Montana on May 23, 2011. A comparison of the 1% annual-chance water surface elevations (WSE's) from the HEC-RAS model were compared to the photographs because the flow rate at the time the aerials were taken was representative of a 1% annual-chance event.

The comparison of WSE's was done at river stations in straight river segments away from structures, since they represent relatively uniform flow conditions without the local hydraulic influence from structures. The differences in WSE's was estimated by observing the extents of the high water on the NAIP imagery and comparing to the contour information from the LiDAR mapping. The differences in the Reach 5 model (Table 9), range from minimum of 0.1-feet to a maximum of 0.9-feet. The differences in Reach 6 model (Table 10), range from minimum of 0.1-feet to a maximum of 1.0-feet. Based on these differences, the HEC-RAS modeling is reasonably calibrated for the purposes of a floodplain study.

Table 9. Reach 5 Model Calibration

River Station	WSE 2011 NAIP Imagery (feet)	Modeled WSE (feet)	Difference (feet)	Comment
0	2,283.0	2,283.3	0.3	–
2584	2,285.0	2,285.3	0.3	–
5535	2,288.0	2,287.4	0.6	Difference from flux of the water surface during the flood flows.
7430	2,289.0	2,289.1	0.1	–
11189	2,291.0	2,291.1	0.1	–
13048	2,293.0	2,292.6	0.4	–
15336	2,295.0	2,294.9	0.1	–
17875	2,299.0	2,298.5	0.5	–
22007	2,301.0	2,300.6	0.4	–
23558	2,301.3	2,301.3	0.0	–
25907	2,305.0	2,304.1	0.9	–
31665	2,306.0	2,306.1	0.1	Difference from flux of the water surface during the flood flows.

Table 10. Reach 6 Model Calibration

River Station	Appx. WSE 2011 NAIP Imagery (feet)	Modeled WSE (feet)	Difference (feet)	Comment
119712	2,381.5	2,382.2	0.7	–
122359	2,382.5	2,383.1	0.6	–
124597	2,384.5	2,385.2	0.7	–
130269	2,389.5	2,388.8	0.7	–
135852	2,393.0	2,393.8	0.8	–
138547	2,397.0	2,396.5	0.5	–
149977	2,407.0	2,406.1	0.9	–
153577	2,408.5	2,408.6	0.1	–
155815	2,411.0	2,410.4	0.6	–
160309	2,414.5	2,415.5	1.0	–
162213	2,417.0	2,416.9	0.1	–
163692	2,419.0	2,418.4	0.6	–

4.10 Floodways

Floodways were computed for the Musselshell River at each cross section. Between cross sections, the floodway boundaries were interpolated. The results of the floodway computations are tabulated for selected cross sections and are presented in the Floodway Data Tables in Appendix D. The work maps show only the floodway boundary, in cases where the floodway and 1% annual-chance floodplain are either close together or collinear.

In Montana, the designated floodway is developed using a 0.5-foot surcharge instead of the Federal maximum of 1.0-foot (DNRC, 2014). These criteria take precedence over the minimum Federal criteria for purposes of regulating development in the floodplain, as set forth in the Code of Federal Regulations, 24 CFR, 1910 (d).

For a variety of hydraulic modeling reasons, it is not technically possible to have 0.5-feet of surcharge allowance at all cross sections. The 0.5-foot allowance is a maximum limit that cannot be exceeded at any cross section throughout the study reach. Due to the equal conveyance reduction method of floodway modeling, the encroachment at cross sections both up and down gradient may produce a surcharge at the intermediate cross section that exceeds the 0.5-foot maximum limit. Therefore, some cross sections as shown in the Floodway Data Table have surcharges of less than the 0.5-foot maximum allowable limit.

4.11 cHECk-RAS

FEMA's automated review software cHECk-RAS, Version 2.0.1 (FEMA, 2011) was utilized to verify the acceptability of the hydraulic analyses described above. The computer program checks five categories:

- NT (Manning's roughness coefficients and transition loss coefficients)
- XS (Cross sections)
- Floodways
- Structures
- Profiles

The cHECk-RAS output messages for the Petroleum County reach of the Musselshell River were reviewed and each issue was either resolved or investigated and confirmed that the modeling was correct. Appendix E includes the list of cHECk-RAS messages and responses to each message.

5.0 Floodplain Mapping

Floodplain mapping was prepared using ESRI ArcMap 10.1 (ESRI, 2012) and HEC-GeoRAS 10.1 toolbar (USACR, 2009). HEC-GeoRAS determines the floodplain area by intersecting the LiDAR Digital Elevation Model (NRCS, 2012) with a separate Digital Elevation Model (DEM) representing the water surface elevations of the 1% and 0.2% annual-chance events. The results of the hydraulic modelling and topographic data are used to create a number of output that are described in the following sections.

5.1 Floodplain Work Maps

The resulting floodplains for the 1% and 0.2% annual-chance flood events are displayed on the hydraulic work maps provided in Appendix A. The base map used for the hydraulic work map is the 2012 NAIP aerial photograph. Along with the flooding extents, the work map also displays the stream profile baseline along with the cross sections utilized during the hydraulic analysis. The layout of the cross sections and the same structure under existing conditions are presented on the work maps.

Typically, islands that were determined to be higher than the adjacent 1% annual-chance water surface profile and less than one-half acre in size were not delineated. Large backwater areas that extended through multiple cross sections were also modified to represent the elevation associated with the location where the backwater initiates from the man channel. These two adjustments provide a slight variance in the mapped widths versus the top widths described by the HEC-RAS mode at selected locations. A table of the 1% AC and 0.2% AC backwater elevations and the corresponding profile baseline station is included in Table 11 below.

Table 11. Backwater Elevation Summary

River Station	1% AC	0.2% AC	County
23267	2,301.1	2,302.5	Petroleum
27065	2,304.6	2,306.4	Petroleum
144821	2,401.5	2,403.6	Petroleum
145126	2,401.7	2,403.8	Petroleum

The floodplain and floodway delineations at residential structure locations are based on local topographic grading and associated Base Flood Elevations (BFE's). Detailed mapping for one location along Reach 5 and three locations along Reach 6 locations are summarized in Table 12.

Table 12. Residential Structures

Reach	River Station	Comment
5	16128	Permanent structure mapped out of 1% AC floodplain and floodway. High ground is approximately two acres and finish floor elevation of the structure is approximately 2.5-feet above BFE.
6	143688	Permanent structure mapped out of 1% AC floodplain and floodway. High ground is approximately 4,600-square feet and finish floor elevation is approximately 3-feet above BFE.
6	143961	Recreational vehicle at location mapped within the 1% AC floodplain and floodway. High ground is approximately 2,600-square feet and finish floor elevation is approximately 5-feet above BFE.
6	148439	Permanent structure mapped out of 1% AC floodplain and floodway. High ground is approximately 5,000-square feet and finish floor elevation is approximately 2-feet above BFE.

5.2 Map Tie-In Locations

There are no map tie-in locations, since this is the first floodplain study for the Musselshell River in Petroleum County, Montana.

5.3 Changes Since Last FIRM Mapping

The proposed physical map revision based on these analyses results in significant changes to the floodplain and floodway boundaries. These changes are a result of technological improvements in modeling and mapping, better detailed topographic information, and other factors which overall, better represent current conditions in the area. No previous studies have been performed for Petroleum County, therefore all flood boundaries are new.

5.4 Letters of Map Change

There are no effective Letters of Map Change (LOMC), since this is the first floodplain study for the Musselshell River in Petroleum County, Montana.

5.5 Floodplain Boundary Standard Audit

The Floodplain Boundary Standard (FBS) audit is a process to provide reliable and defendable flood hazard mapping to incorporate into the FIRM. The FBS audit verifies that the floodplain delineations are accurate by comparing the water surface elevations generated by the hydraulic modeling to the best available terrain data. For this study, the water surface elevations were created using the best available terrain data and the results met the criteria in SID 113. However, the process necessarily lends itself to exceptions based on several factors. These exceptions

can be attributed to issues associated with a confluence, tributary, or backwater areas, and around hydraulic structures. The FBS self-certification forms are included with the QA/QC documentation for this study.

5.6 Depth Grids

Flood depth grids have been created for the 10-, 4-, 2-, 1-, and 0.2-percent-annual chance flood events to show the inundation depths at these flood frequencies throughout the mapped floodplain. The flood depth grids are a tool that communities can use to identify, prepare, and evaluate actions that can be taken to reduce flood risk. The flood depth grids are included in the digital datasets that accompany this report.

6.0 Flood Insurance Study Products

Digital profiles for the 10%, 4%, 2%, 1%, and 0.2% annual-chance water surface elevations were created using FEMA's RASPLOT software (FEMA 2013). Additional information, edits and formatting were made using AutoCAD. Profiles were developed following Appendix J, Section J.2.2 of FEMA Guidelines and Specifications (FEMA 2003). The profiles illustrating the results of the study are provided in Appendix B.

7.0 References

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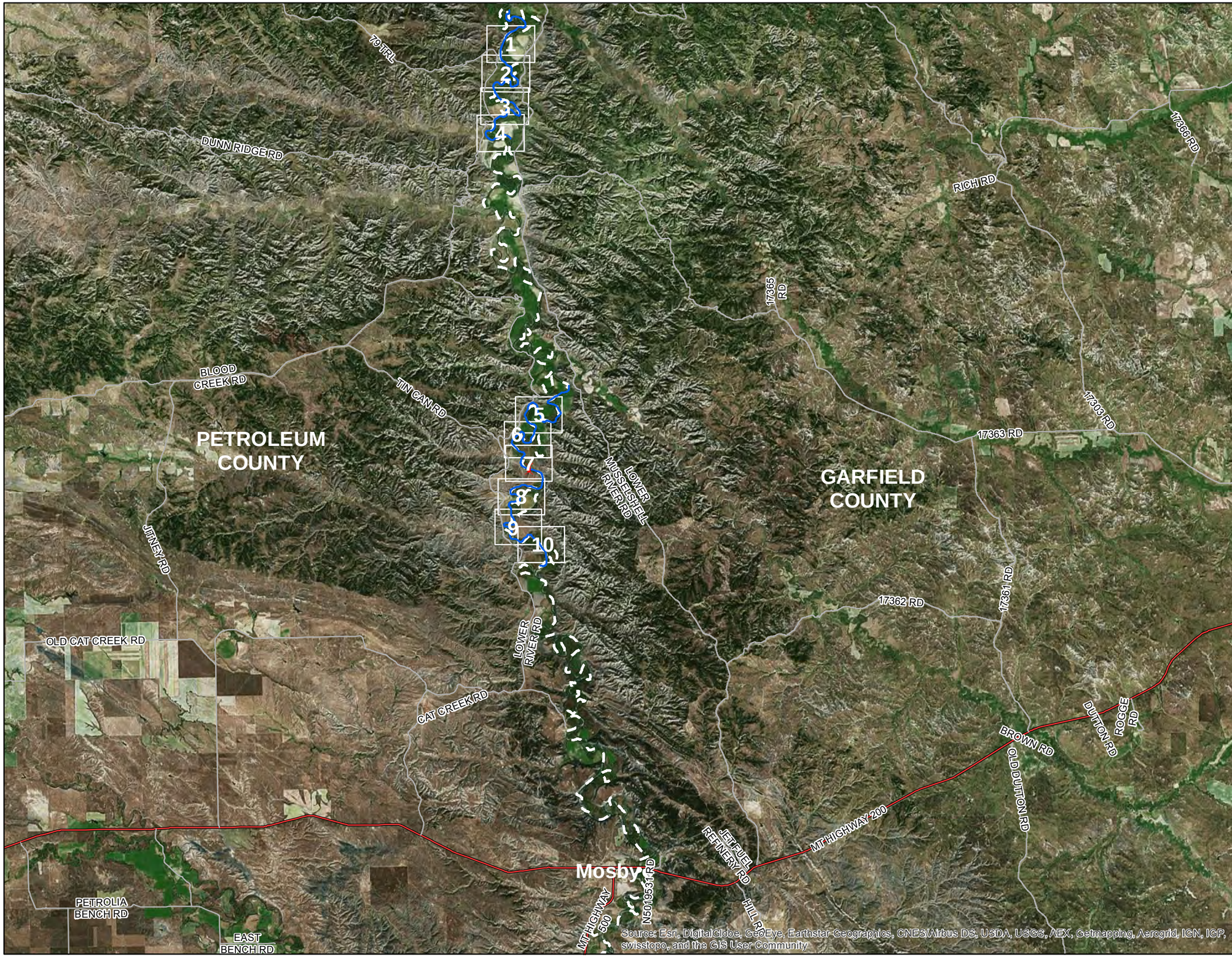
APPENDICES

Appendix A – Hydraulic Work Maps

- Reach 5
- Reach 6

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP INDEX



LEGEND

- Roadway Crossings
- Musselshell River
- 10' Contour
- 5' Contour

Proposed Flood Hazard Area

- 0.2% AC
- AE - 1% AC
- FLOODWAY
- County
- Backwater BFE

Labels

- A Cross Section Letter — 79,726 River Station
- 4,700.0 Water Surface Elevation
- 100 Feet Along Profile Baseline

0 6,500 13,000 19,500 Feet

Hydraulic Work Map - Musselshell Watershed Project - Ph. II
Petroleum County, MT Risk MAP - MAS No. 2015-02
NAIP 2013, Horizontal Datum: NAD83
Topographic Data, LiDAR 2012
Hozontal Datum: NAD83, Vertical Datum: NAVD88, Feet
Submitted: 11/21/2016

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PETROLEUM COUNTY MONTANA

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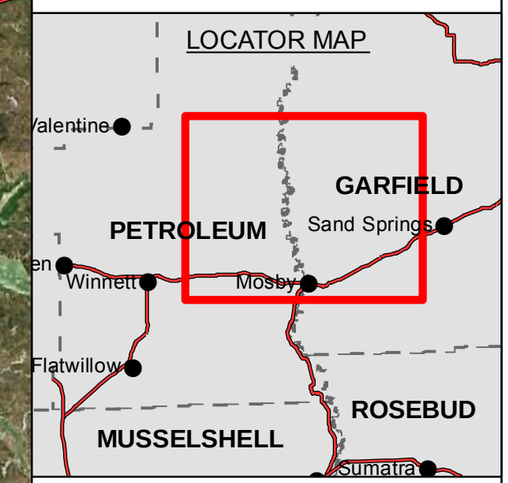
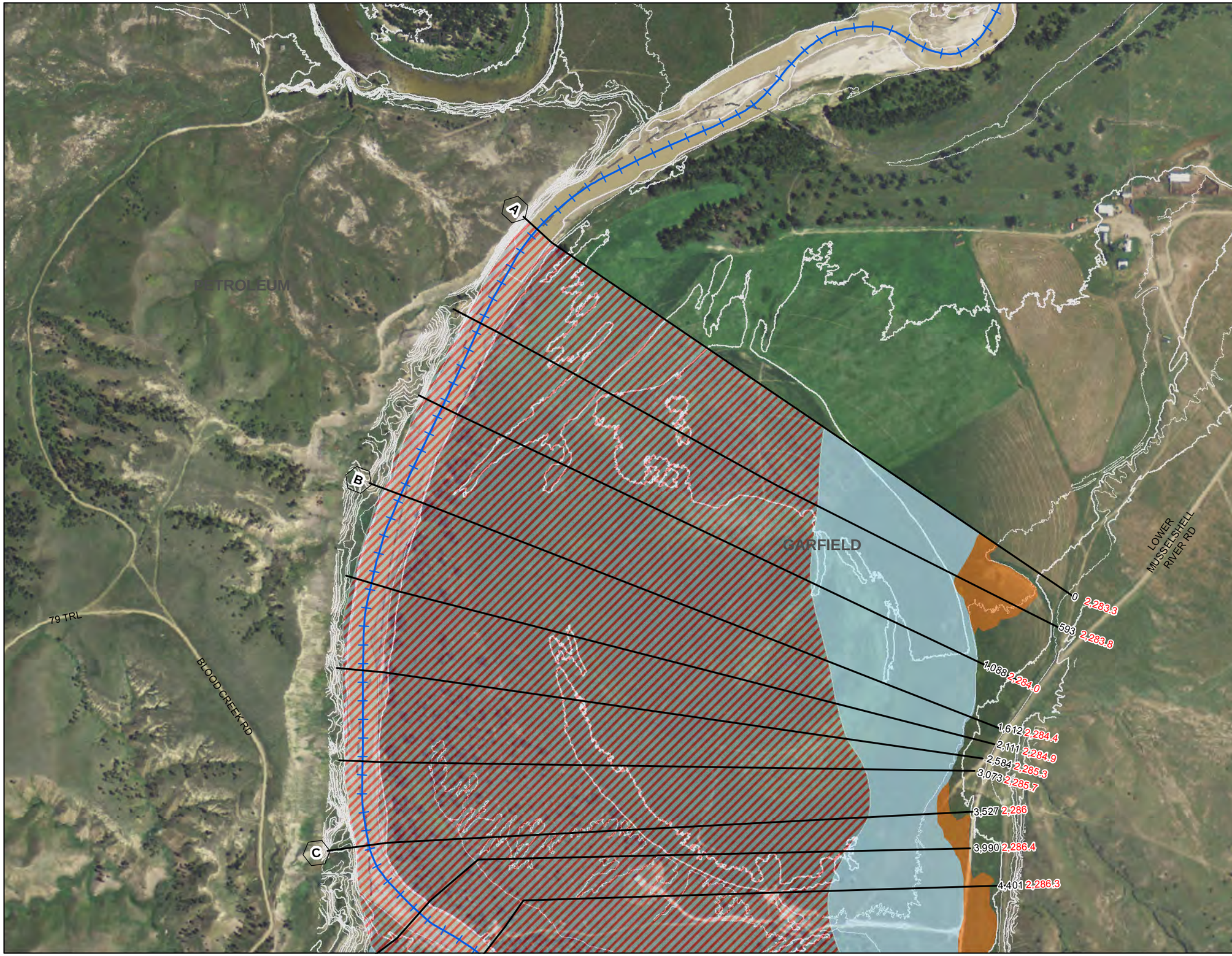
LOCATOR MAP



Musselshell River Index Map

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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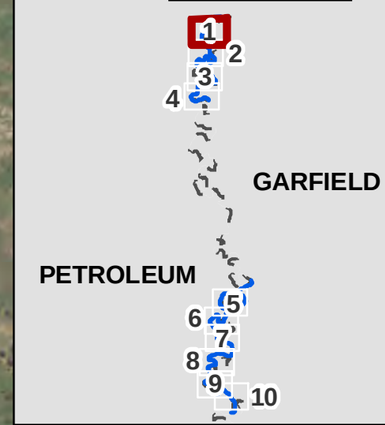
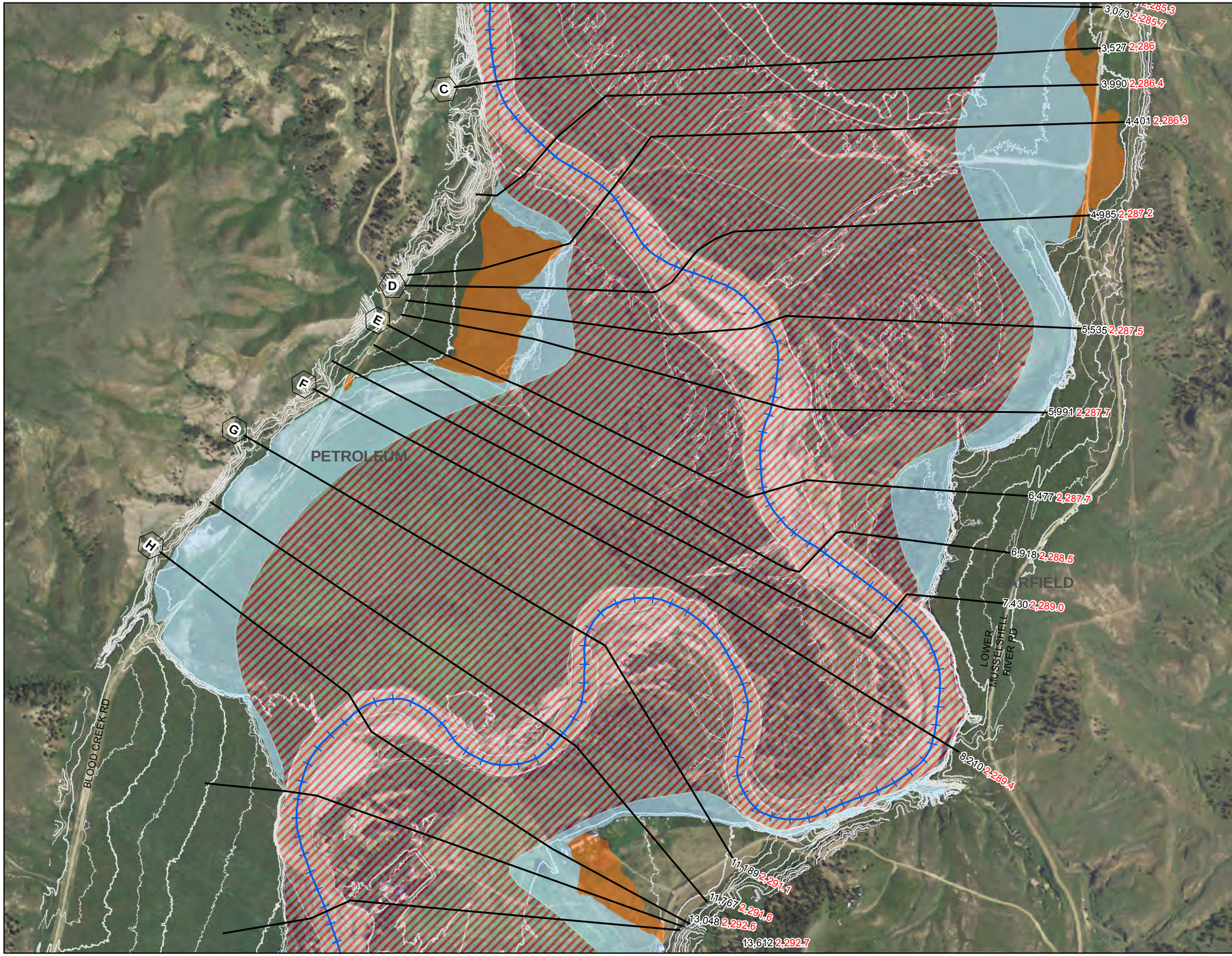


Musselshell River Map 1 of 10

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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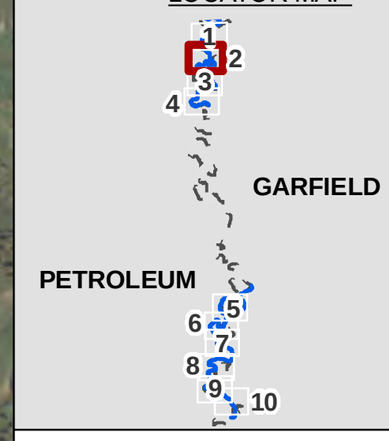
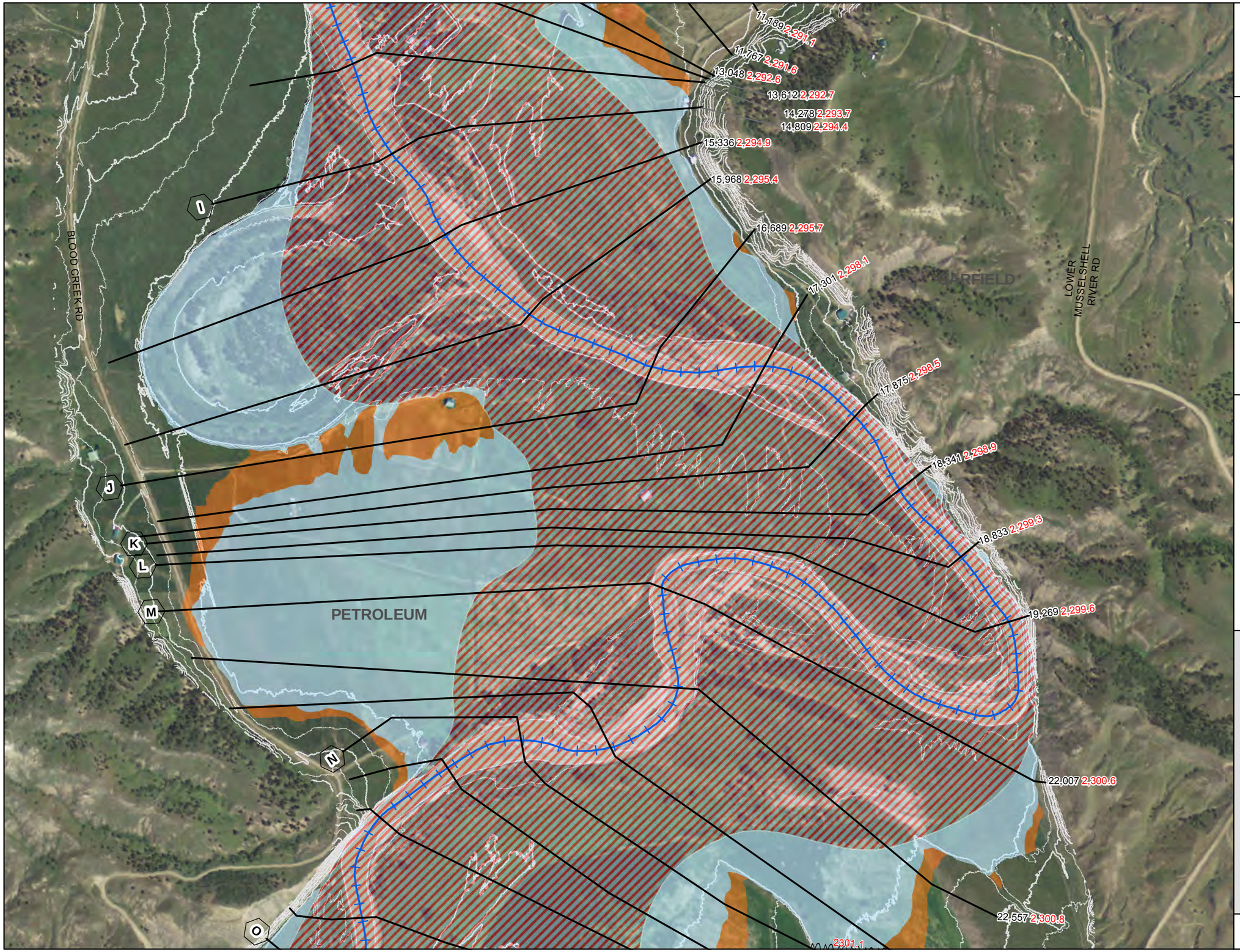


Musselshell River Map 2 of 10

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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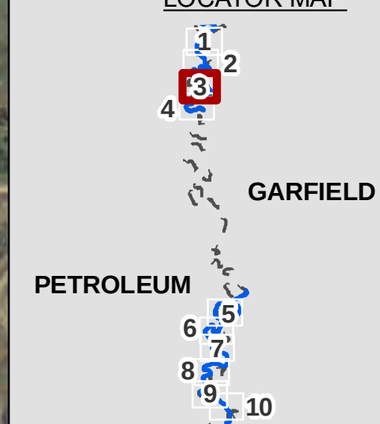
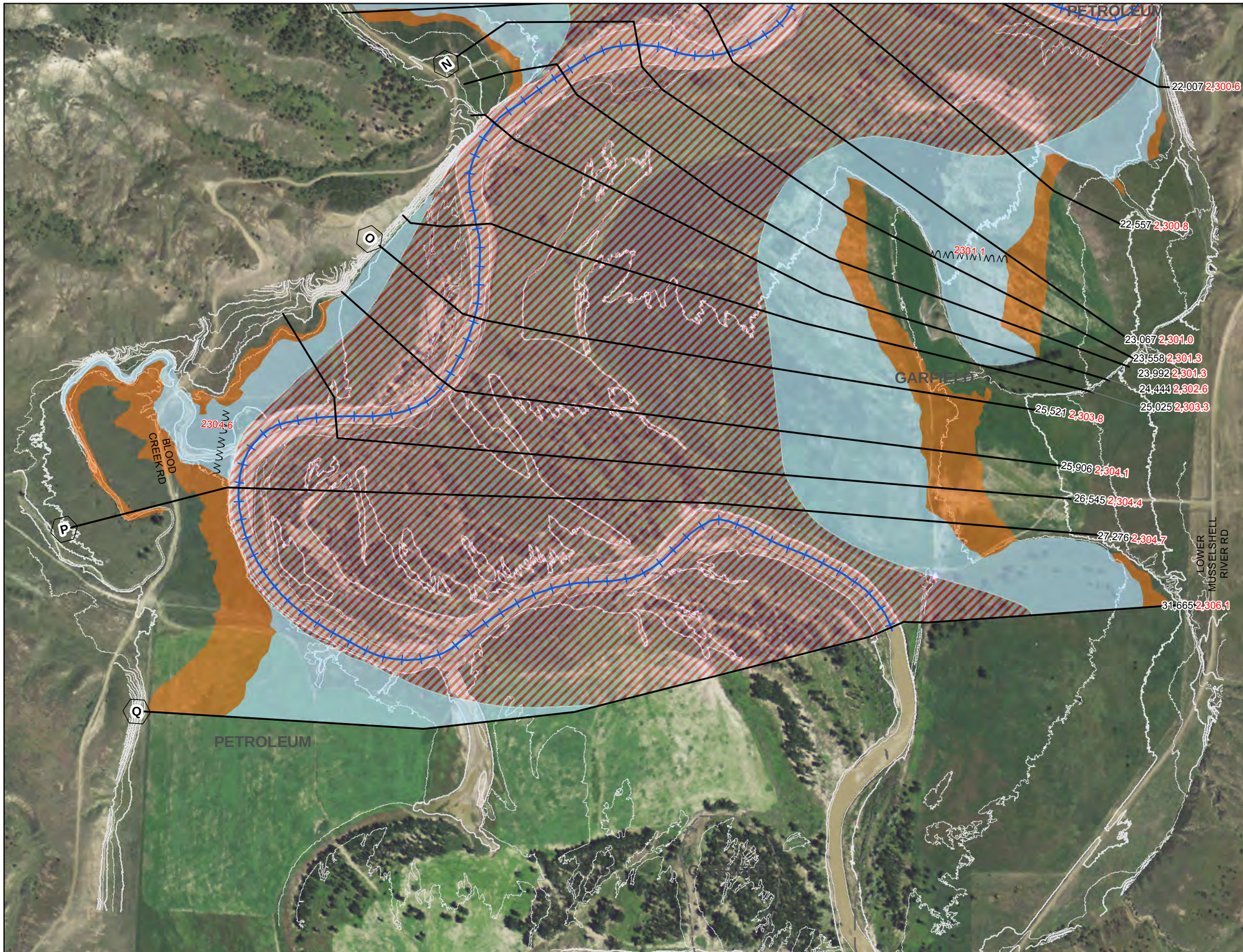


Musselshell River Map 3 of 10



PETROLEUM COUNTY TOPOGRAPHIC WORKMAP

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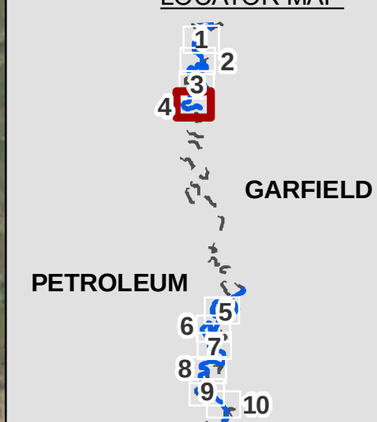
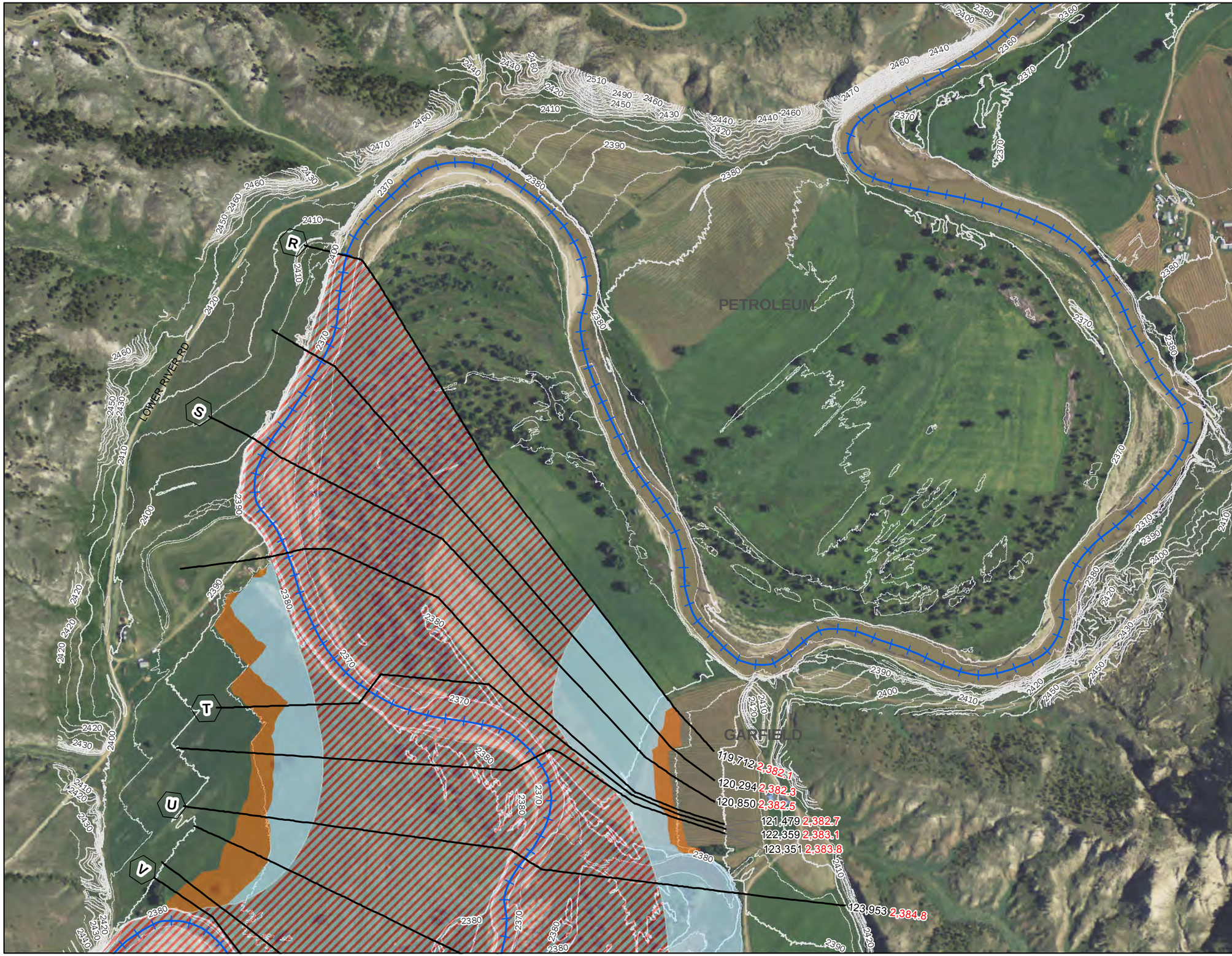


Musselshell River Map 4 of 10



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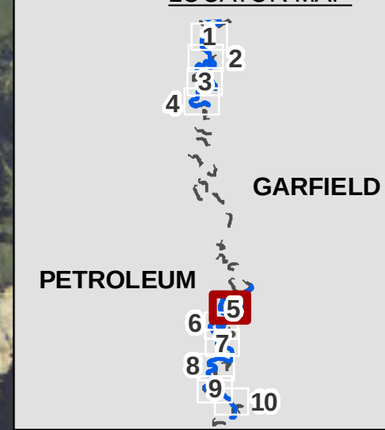
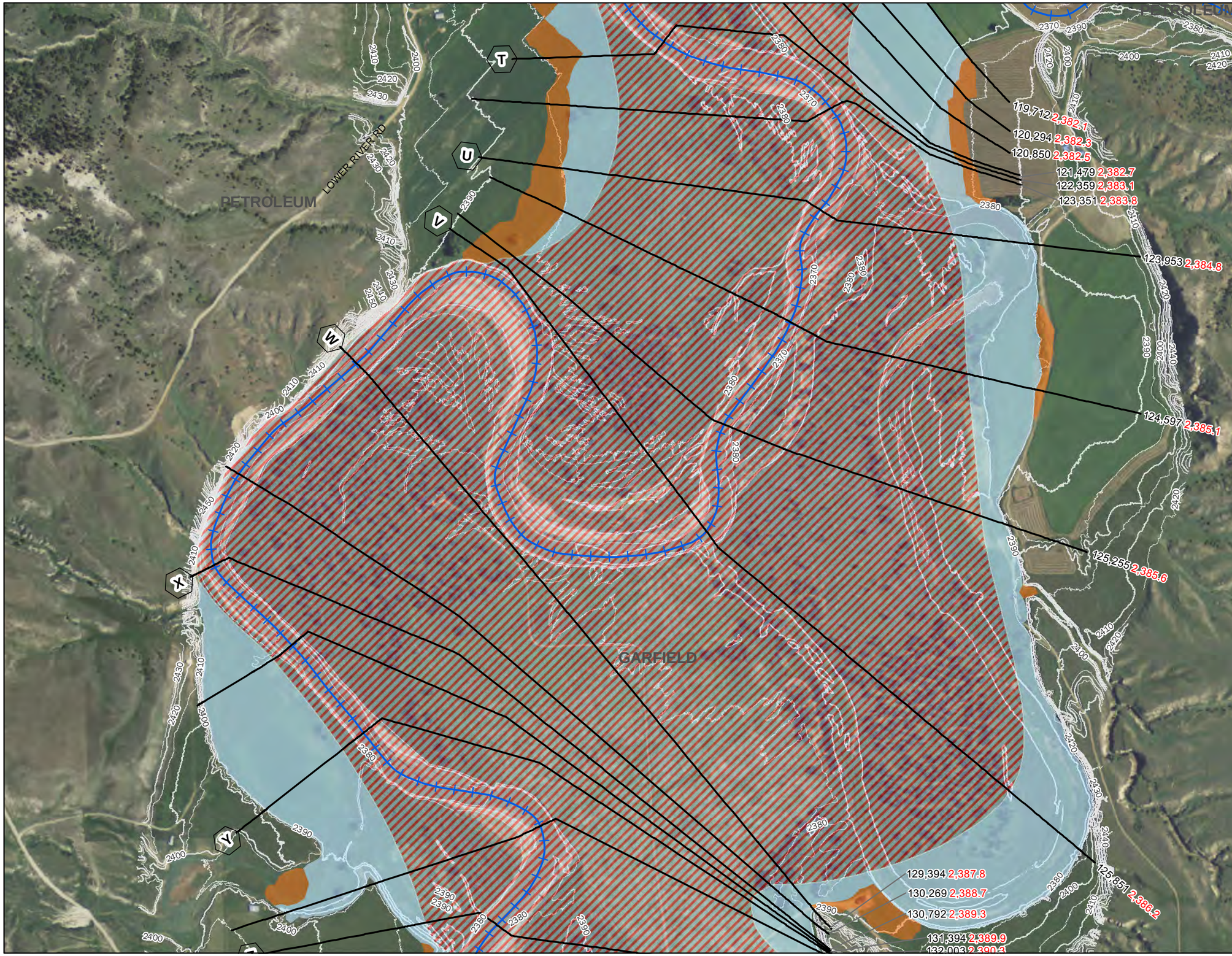


Musselshell River Map 5 of 10

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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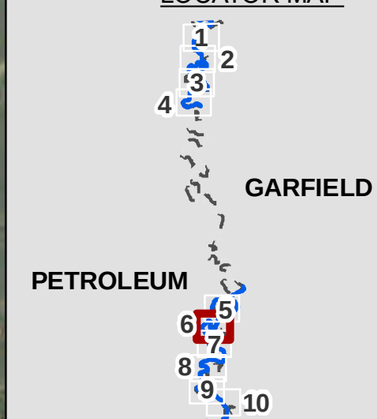

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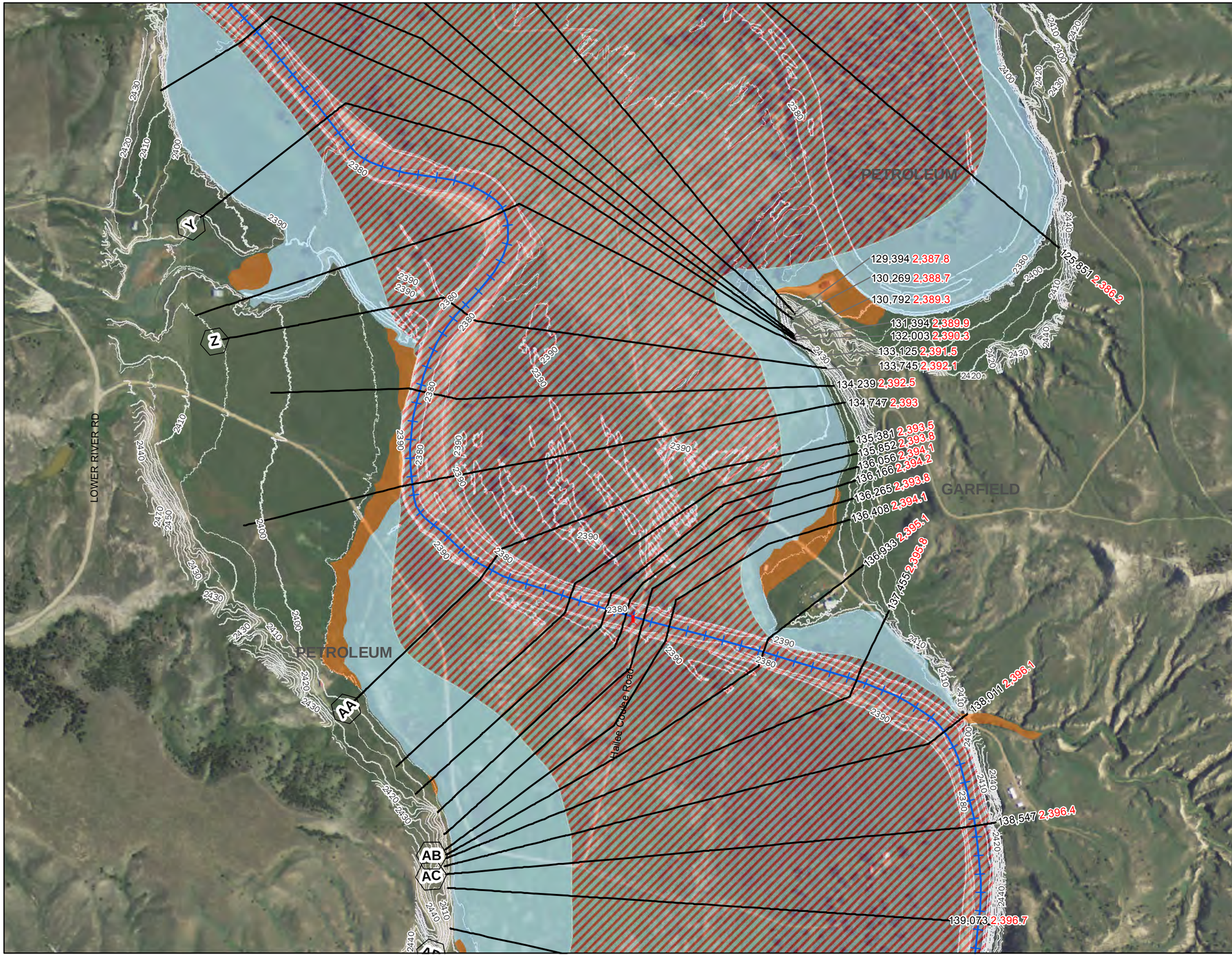

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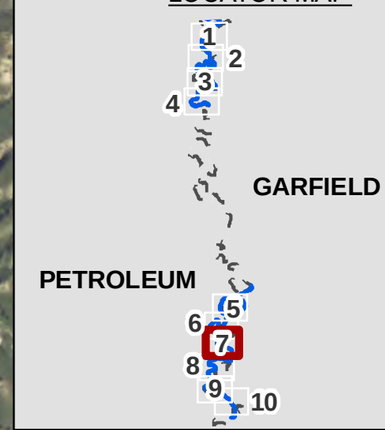
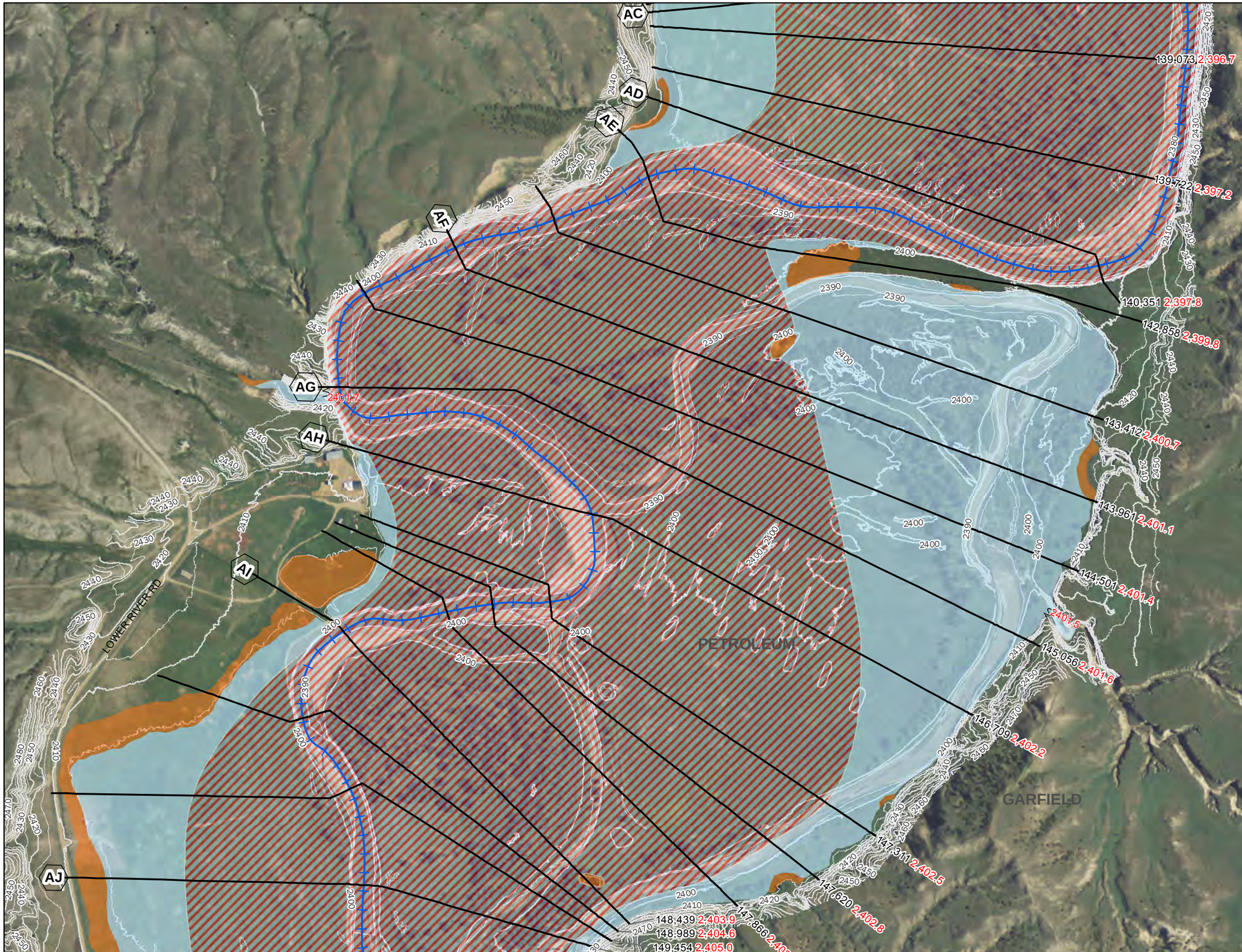


Musselshell River Map 7 of 10

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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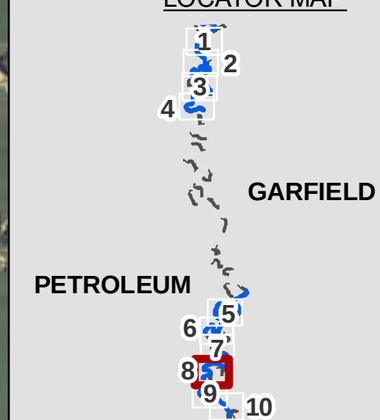
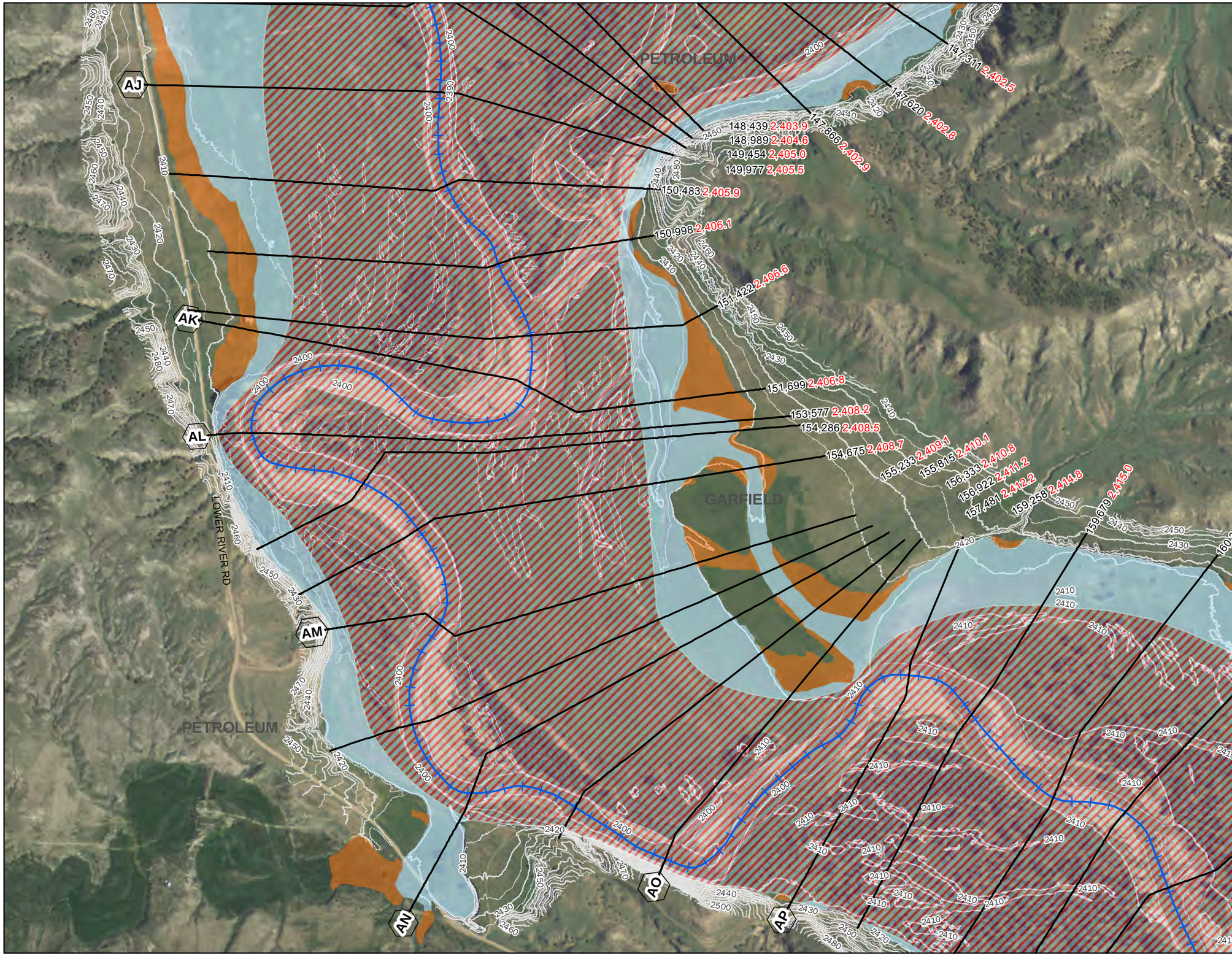


Musselshell River Map 8 of 10



PETROLEUM COUNTY TOPOGRAPHIC WORKMAP

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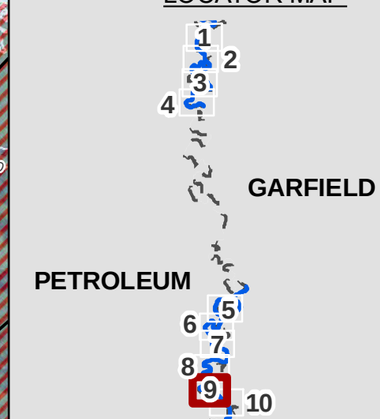
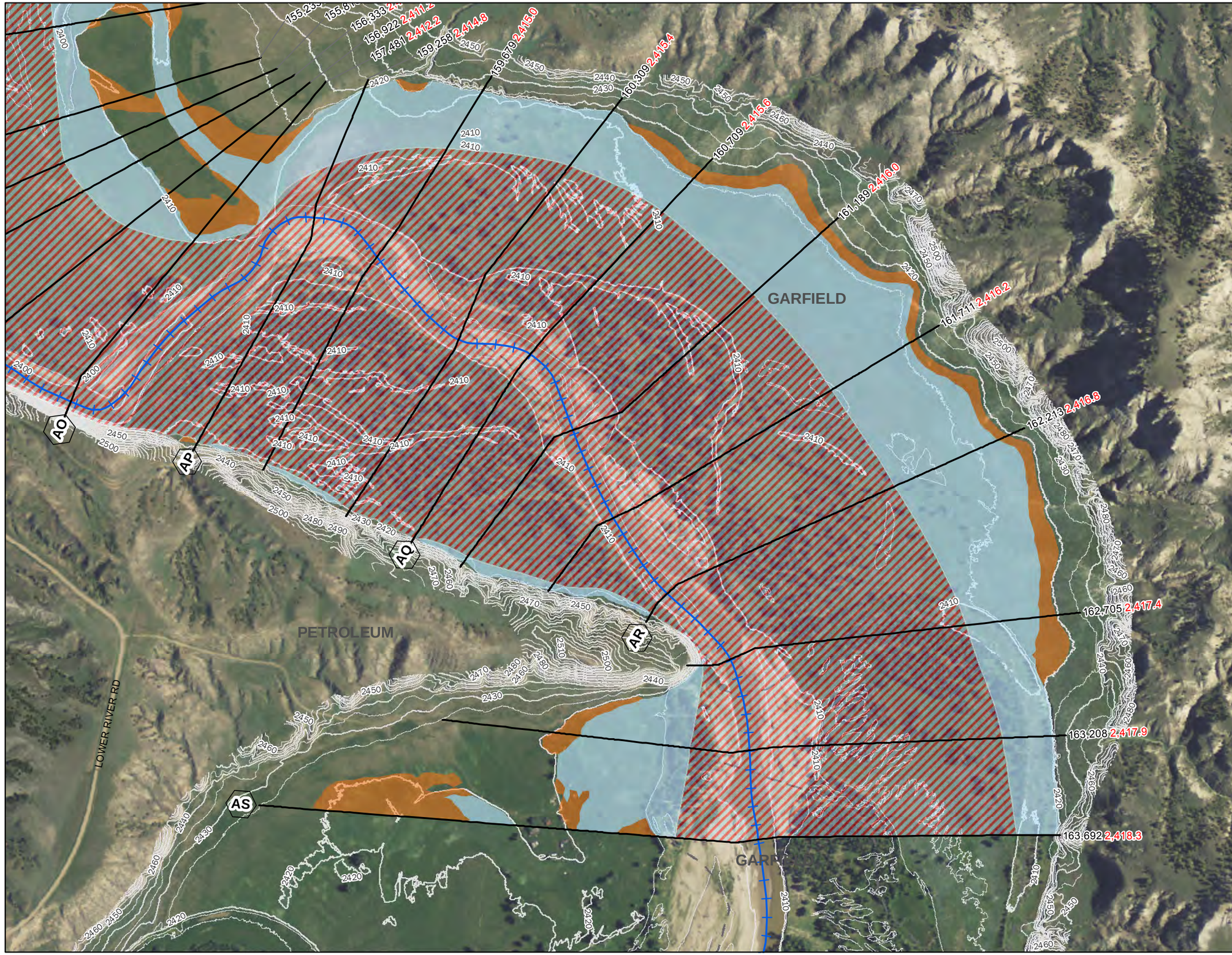


Musselshell River Map 9 of 10

PETROLEUM COUNTY TOPOGRAPHIC WORKMAP



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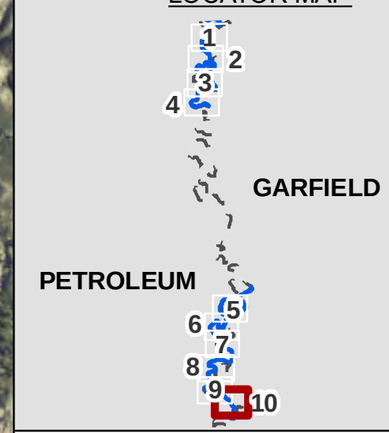
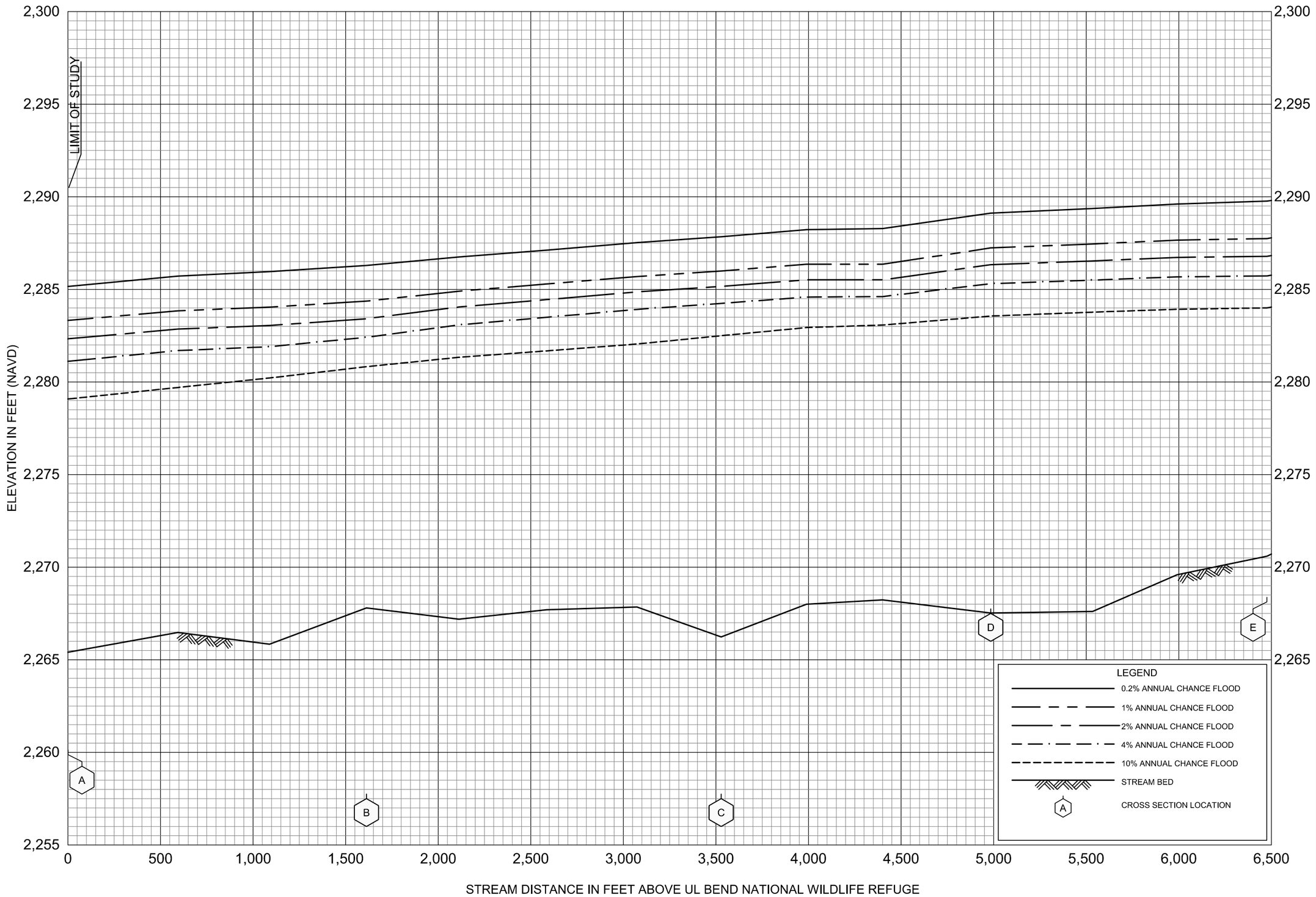


Musselshell River Map 10 of 10

Appendix B – Profiles

- Reach 5
- Reach 6



FLOOD PROFILES

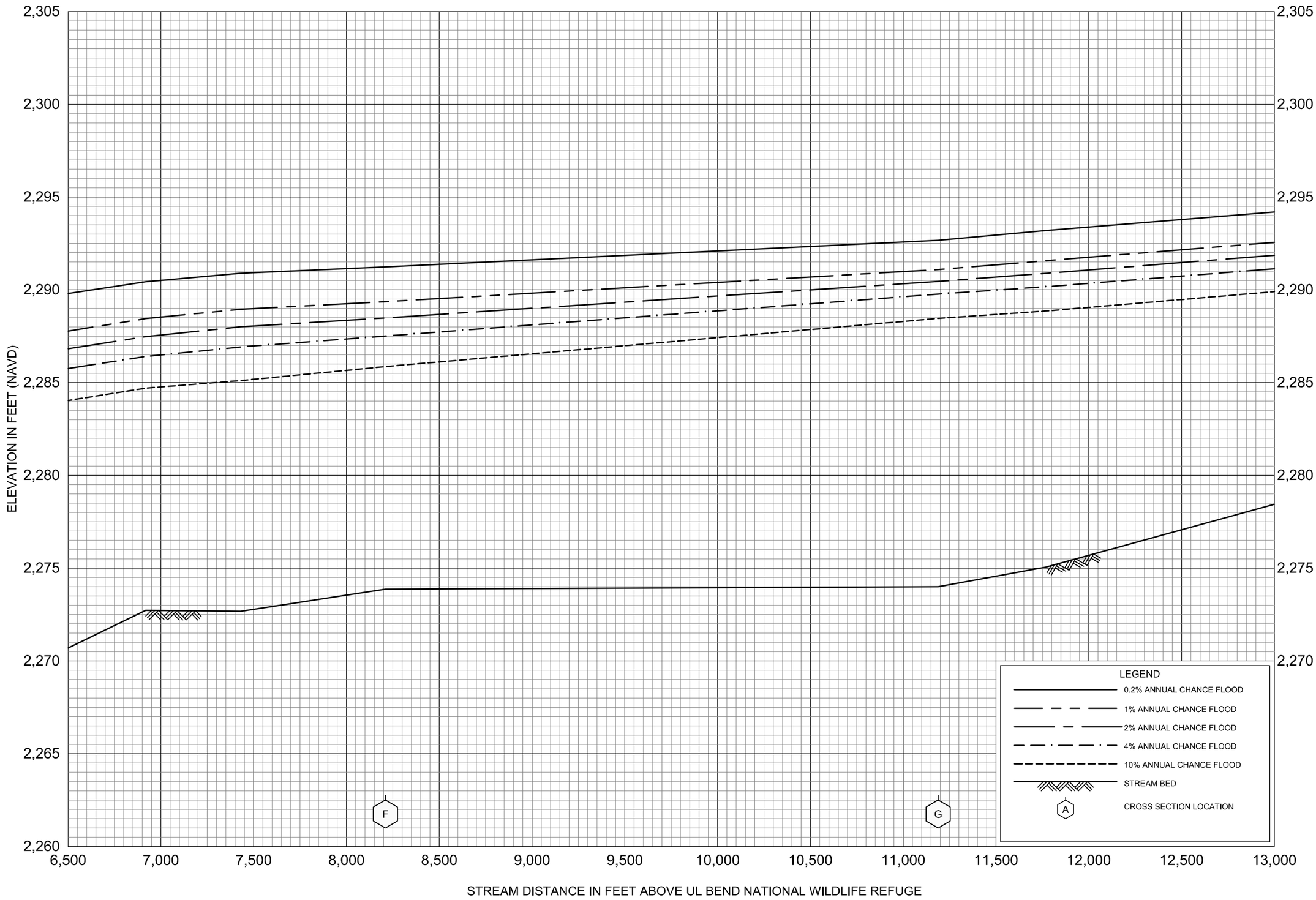
MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

01P



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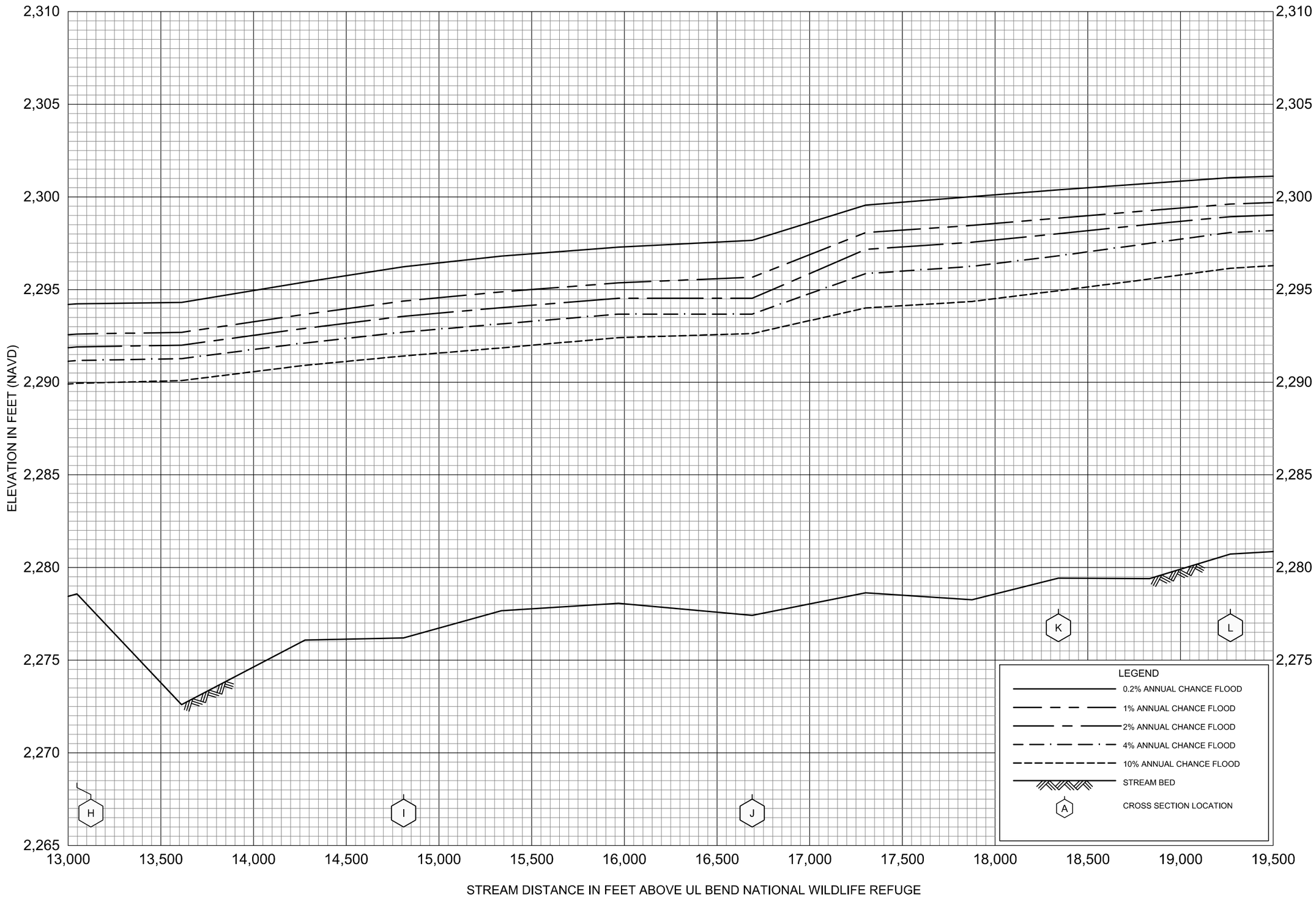

FLOOD PROFILES

MUSSELSHELL RIVER

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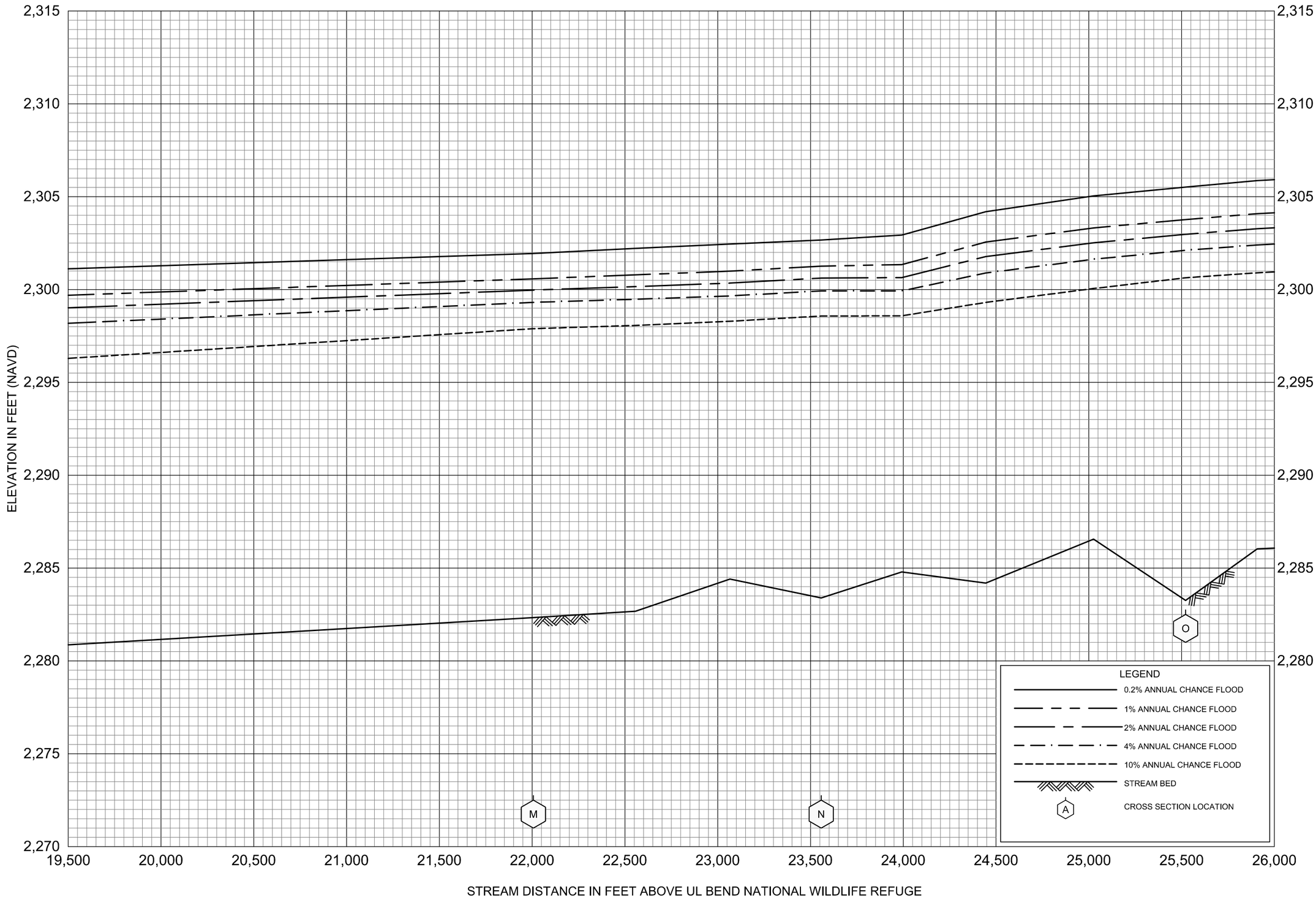
PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

03P



FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

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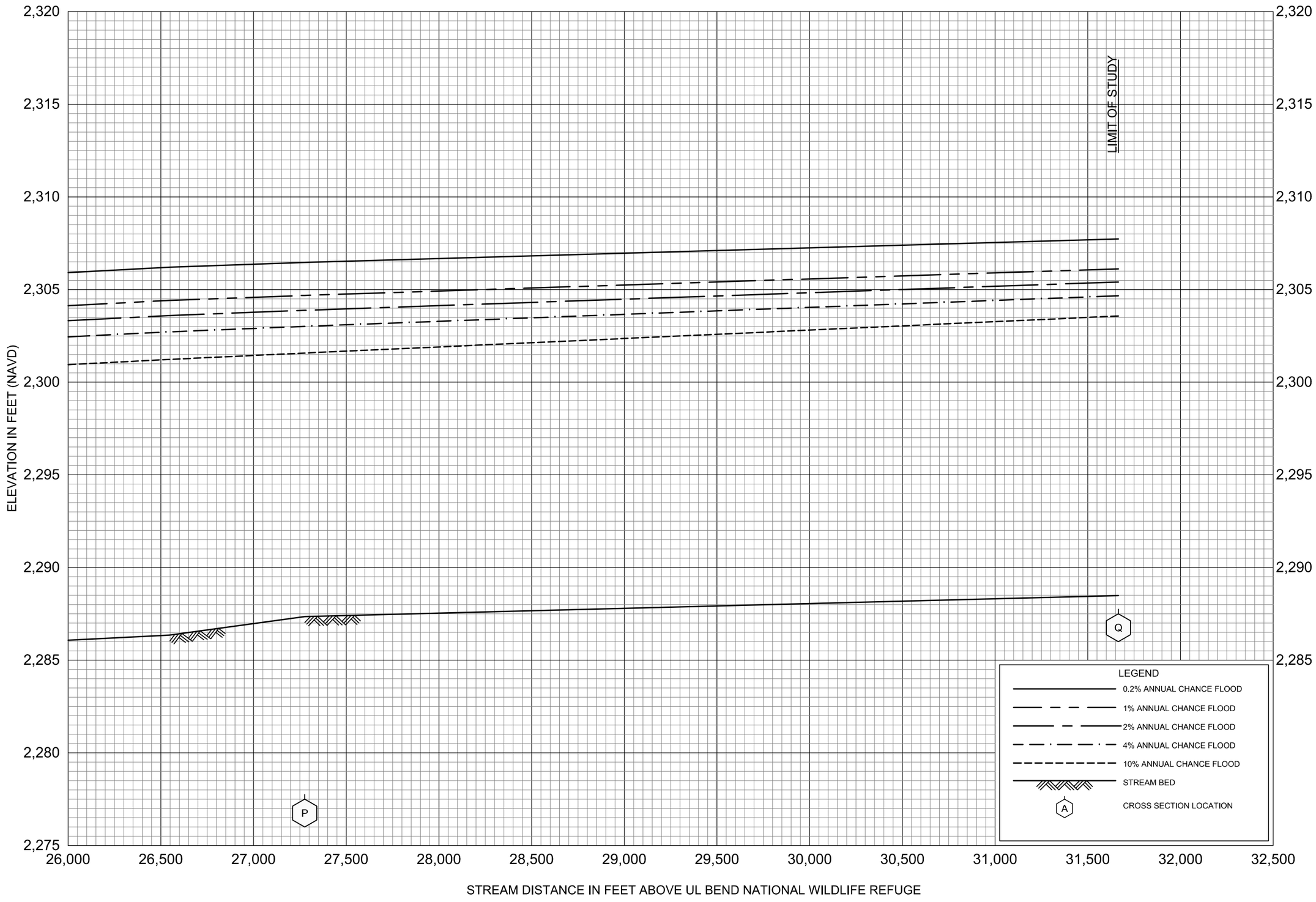

FLOOD PROFILES

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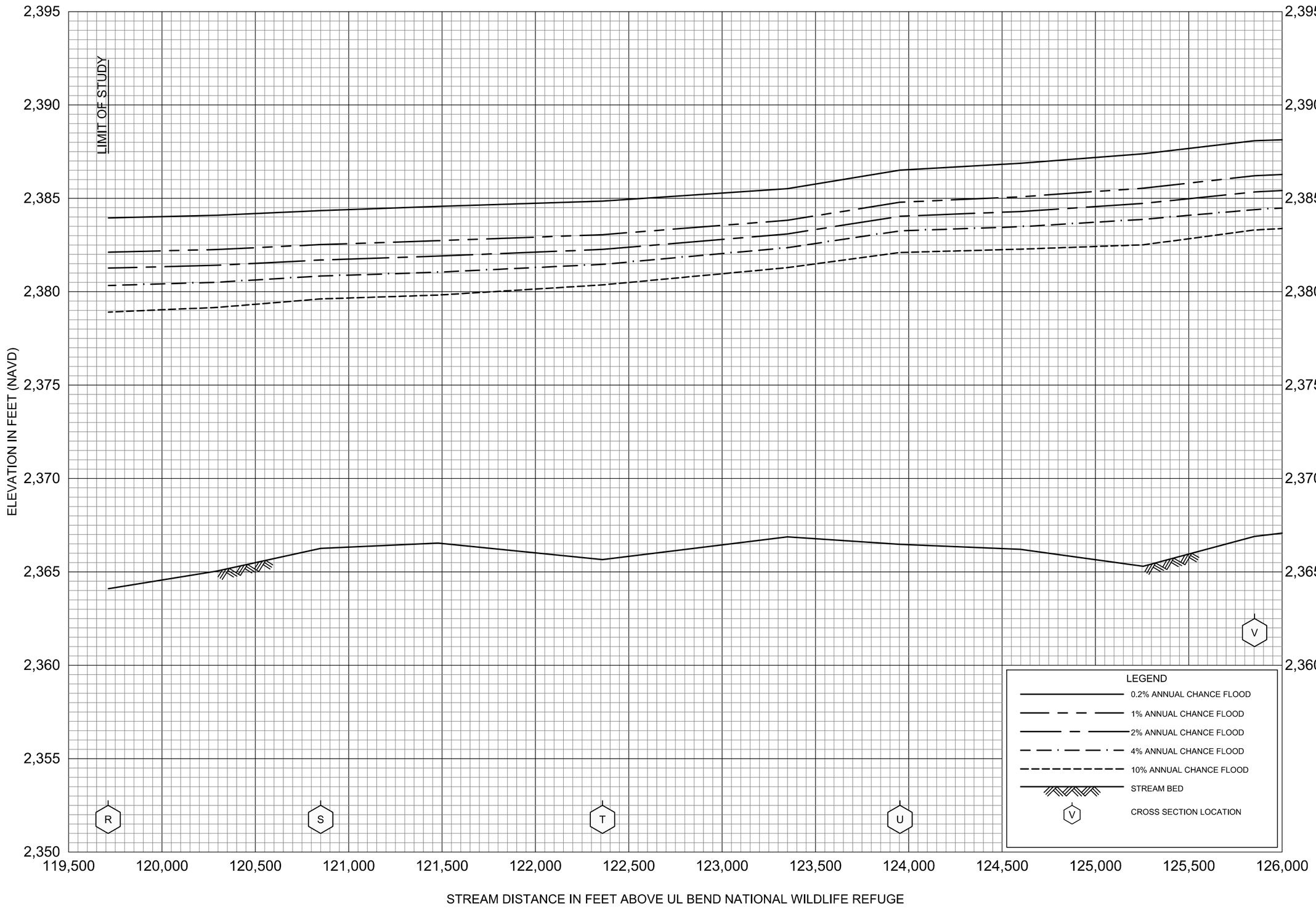

FLOOD PROFILES

MUSSELSHELL RIVER

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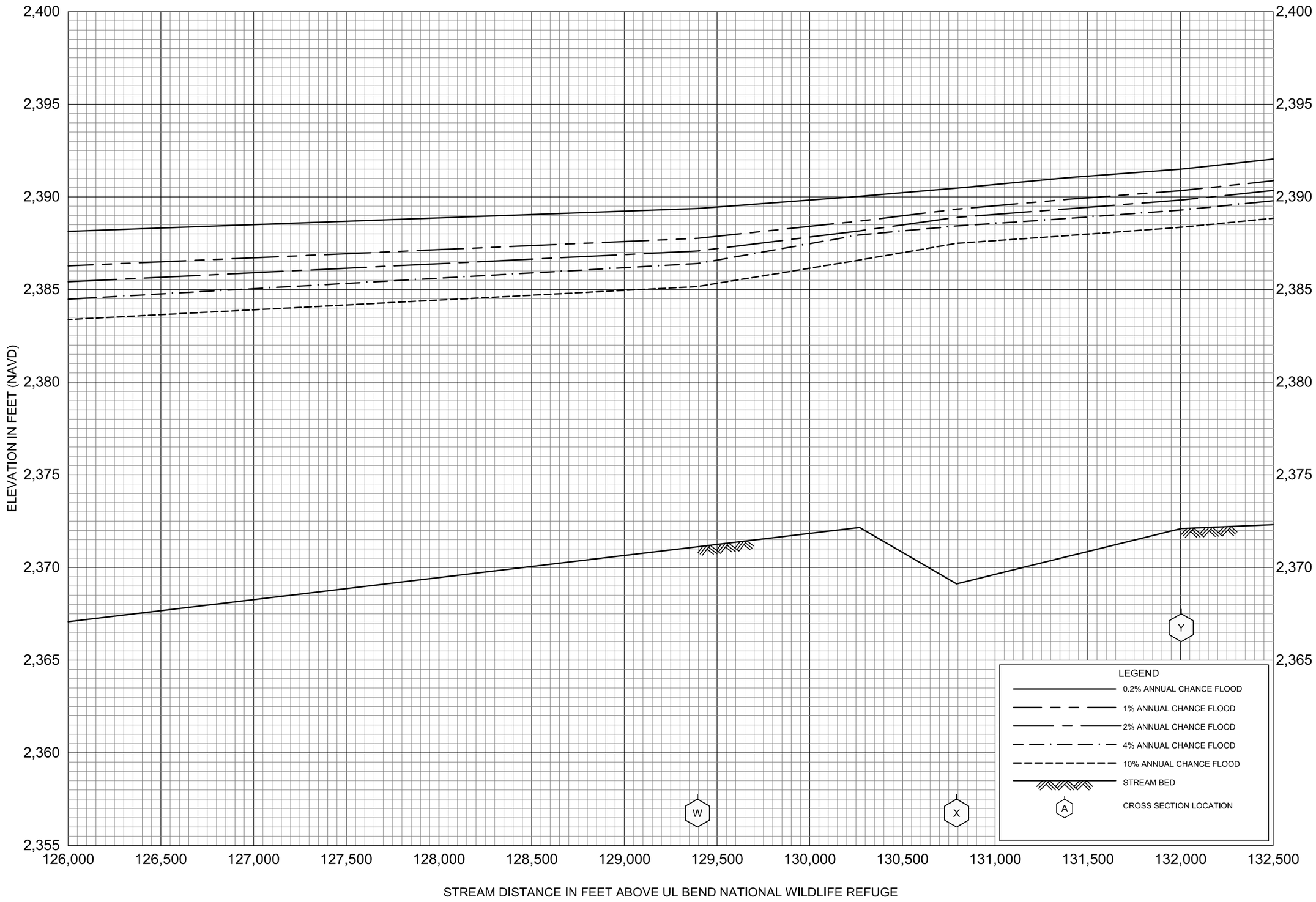
PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

06P



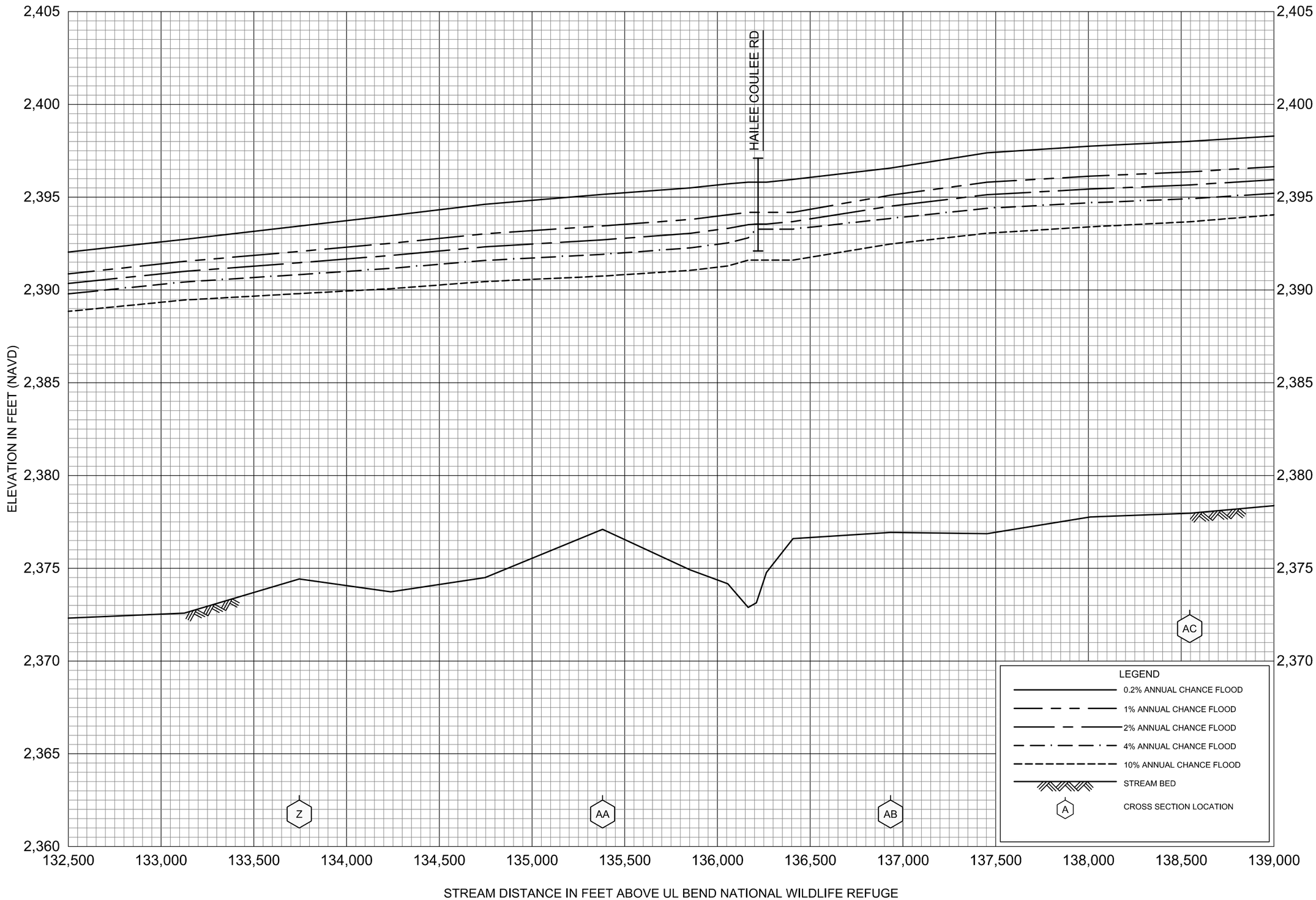
FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS



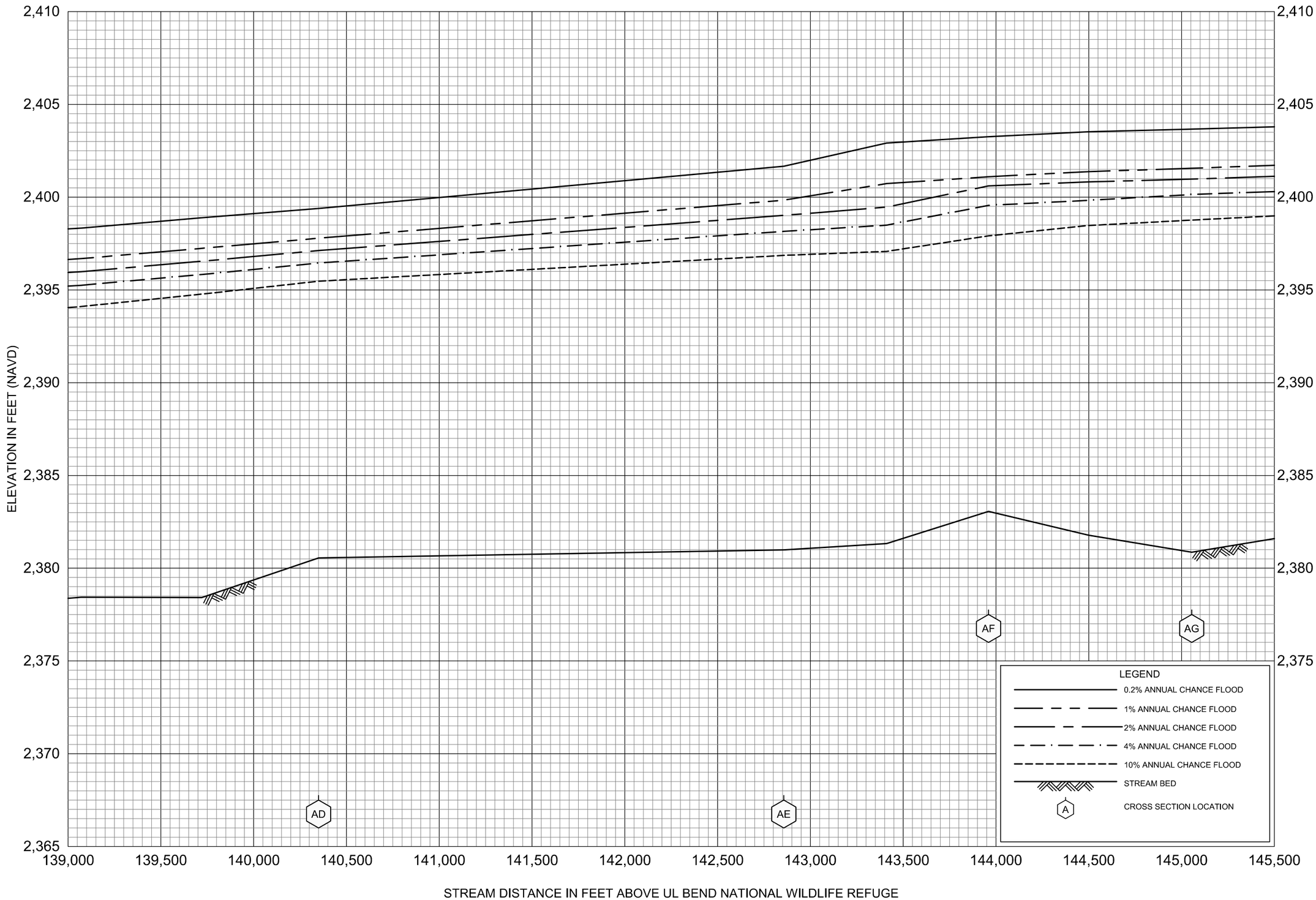
FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS



FLOOD PROFILES

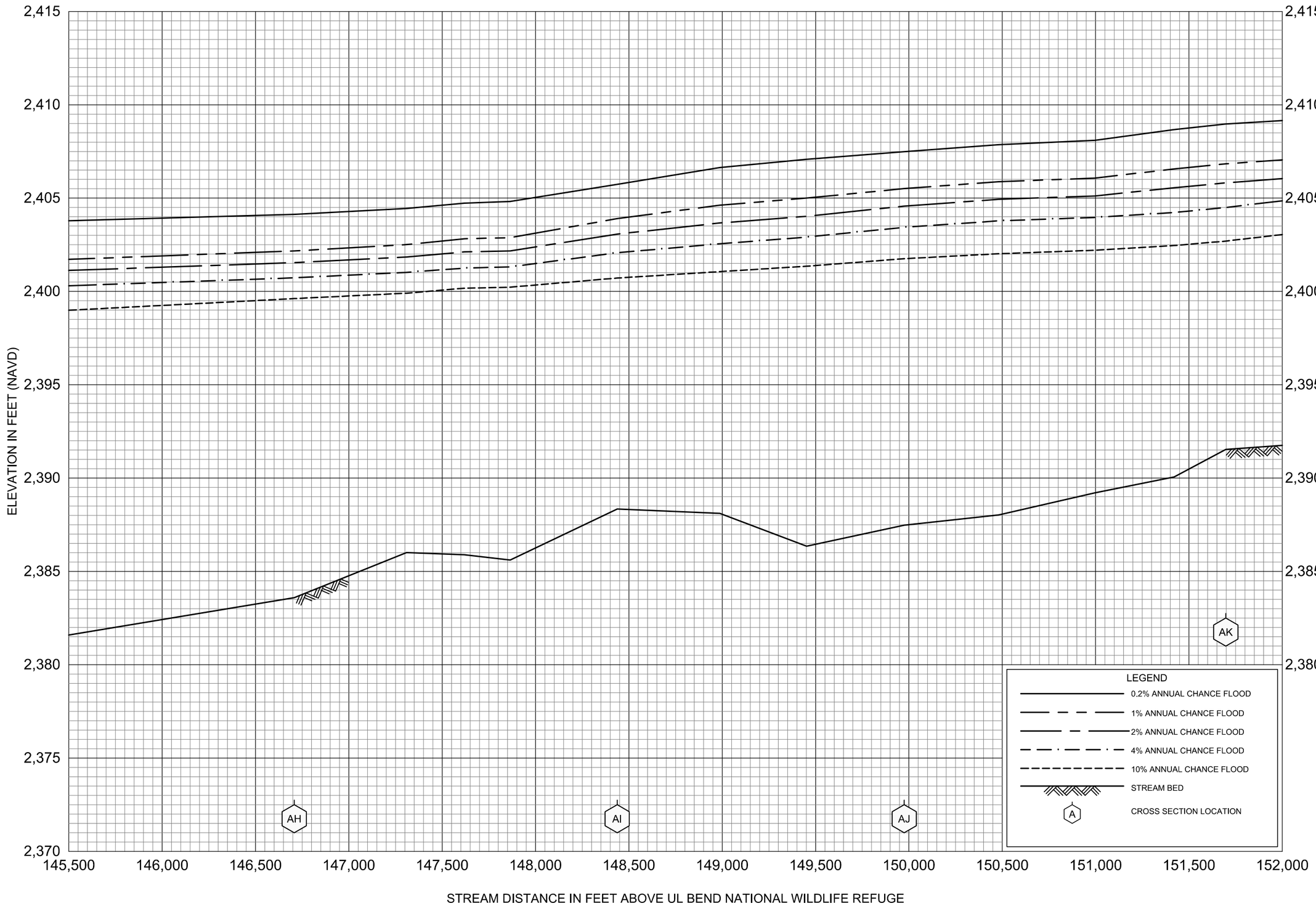
MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

09P



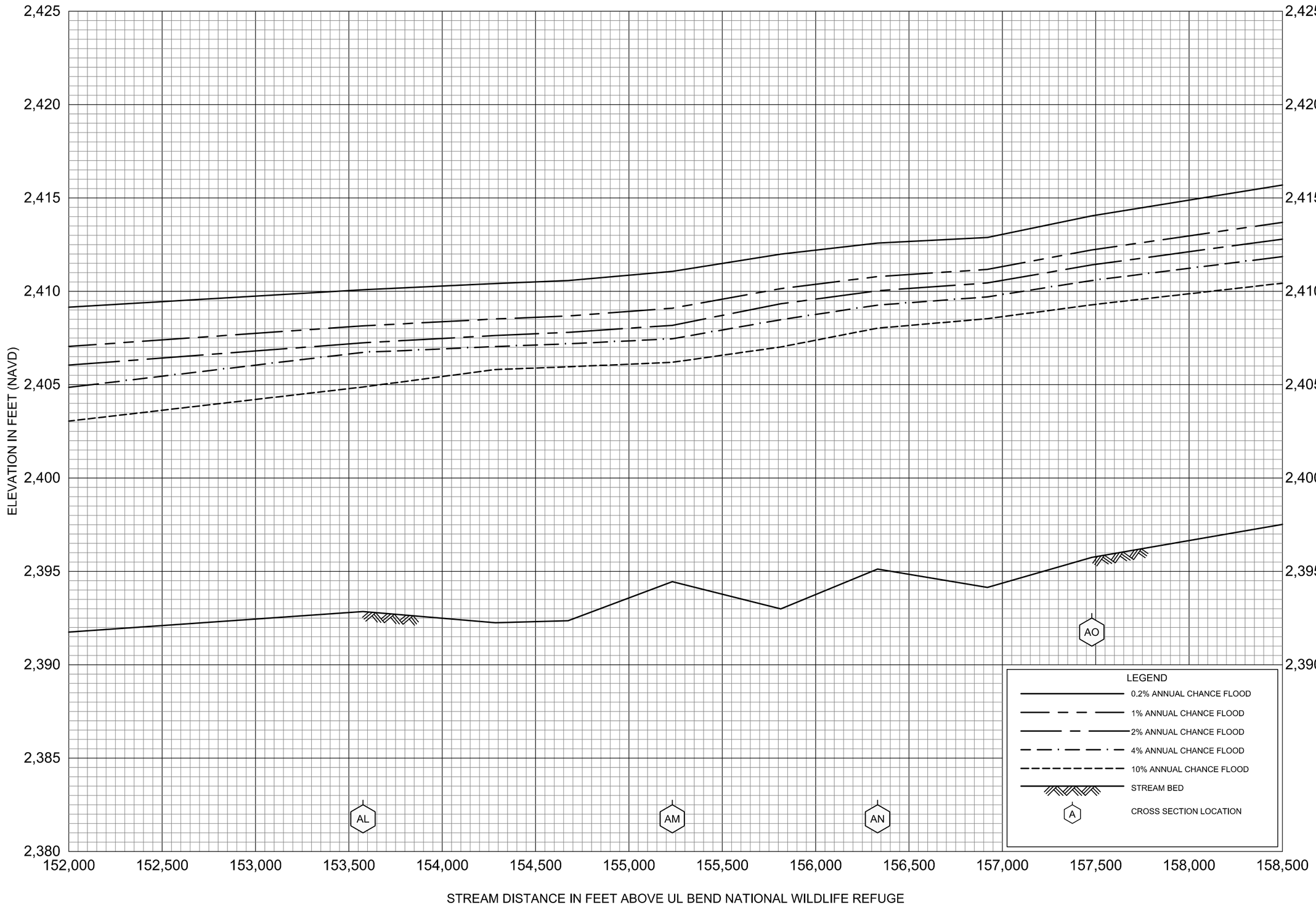
FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS



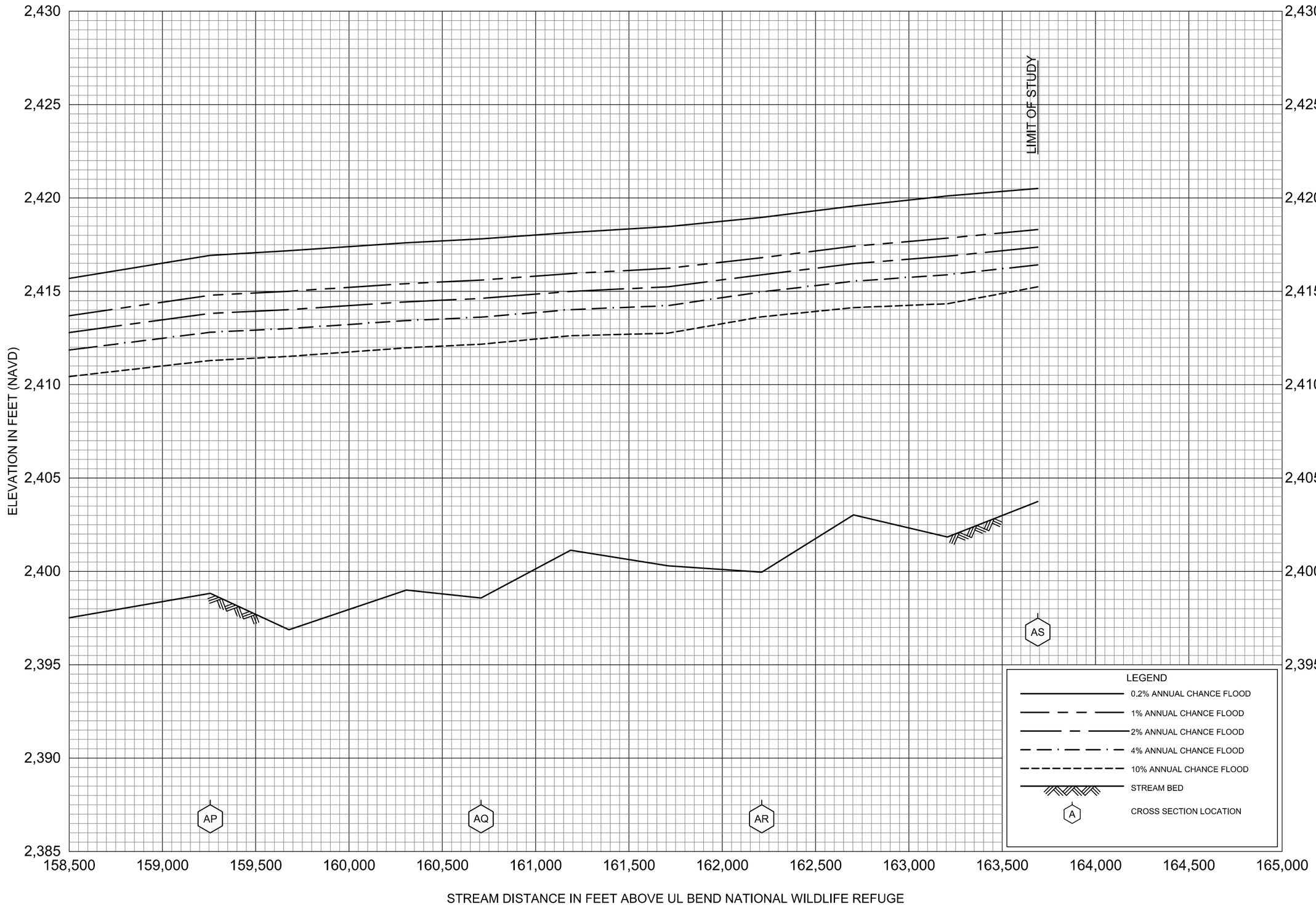
FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS



FLOOD PROFILES

MUSSELSHELL RIVER

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

Appendix C – Bridge Structure Photographs

Petroleum County
Musselshell River B1 Structure Photographs
Mapping Activity Statement (MAS): No 2015-02

Photo No.	Description	RS	Spans	Total Span (feet)
1	Downstream Guardrail	136220	2	158
2	Upstream Face	↓	↓	↓
3	East Abutment			
4	Downstream Face			
5	Upstream Channel			
6	Downstream Channel			
7	Upstream Guardrail			

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Appendix D – Floodway Data Tables

- Reach 5
- Reach 6

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (**FEET**)	SECTION AREA (**SQ. FEET**)	MEAN VELOCITY (**FEET/ SEC**)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
MUSSELSHELL RIVER								
A	0	1948	10296	3.2	2283.3	2283.3	2283.4	0.1
B	1,612	2562	9134	3.6	2284.4	2284.4	2284.7	0.3
C	3,527	2760	12452	2.7	2286.0	2286.0	2286.5	0.5
D	4,985	2350	13157	2.5	2287.2	2287.2	2287.7	0.5
E	6,477	2154[2]	7237	4.6	2287.7	2287.7	2288.2	0.5
F	8,210	3382	13125	2.5	2289.4	2289.4	2289.8	0.4
G	11,189	2632	10800	3.1	2291.1	2291.1	2291.5	0.4
H	13,048	2070	12776	2.6	2292.6	2292.6	2293.1	0.5
I	14,809	1856	10593	3.1	2294.4	2294.4	2294.8	0.4
J	16,689	1611[2]	4793	6.9	2295.7	2295.7	2296.1	0.4
K	18,341	2153	8983	3.7	2298.9	2298.9	2299.0	0.1
L	19,269	2734	11196	3.0	2299.6	2299.6	2299.9	0.3
M	22,007	3157	18183	1.8	2300.6	2300.6	2301.0	0.4
N	23,558	1577	8494	3.9	2301.3	2301.3	2301.7	0.4
O	25,521	2117	10578	3.1	2303.8	2303.8	2304.1	0.3
P	27,276	3072	15865	2.1	2304.7	2304.7	2305.0	0.3
Q	31,665	2350	10856	3.0	2306.1	2306.1	2306.5	0.4

[1] Feet upstream of UL Bend National Wildlife Refuge
[2]Floodway topwidth includes width of high ground area

TABLE 1

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

FLOODWAY DATA

MUSSELSHELL RIVER

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (**FEET**)	SECTION AREA (**SQ. FEET**)	MEAN VELOCITY (**FEET/ SEC**)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
MUSSELSHELL RIVER								
R	119,712	2380	14380	2.2	2382.1	2382.1	2382.6	0.5
S	120,850	2071	13057	2.5	2382.5	2382.5	2383.0	0.5
T	122,359	1580	8453	3.8	2383.1	2383.1	2383.5	0.4
U	123,953	1900	11346	2.8	2384.8	2384.8	2385.2	0.4
V	125,851	3996	14527	2.2	2386.2	2386.2	2386.6	0.4
W	129,394	3758	12090	2.7	2387.8	2387.8	2388.3	0.5
X	130,792	3578	10631	3.0	2389.3	2389.3	2389.5	0.2
Y	132,003	2515	8284	3.9	2390.3	2390.3	2390.5	0.2
Z	133,745	2050	9489	3.4	2392.1	2392.1	2392.5	0.4
AA	135,381	2346	9928	3.2	2393.5	2393.5	2393.8	0.3
AB	136,933	1430	7409	4.3	2395.1	2395.1	2395.4	0.3
AC	138,547	2255	11043	2.9	2396.4	2396.4	2396.8	0.4
AD	140,351	2137	10040	3.2	2397.8	2397.8	2398.3	0.5
AE	142,858	930	6577	4.9	2399.8	2399.8	2400.2	0.4
AF	143,961	2153	11595	2.8	2401.1	2401.1	2401.5	0.4
AG	145,056	2927	13643	2.4	2401.6	2401.6	2402.1	0.5
AH	146,709	2860	12142	2.6	2402.2	2402.2	2402.7	0.5
AI	148,439	2131[2]	7267	4.4	2403.9	2403.9	2404.4	0.5
AJ	149,977	2111	9739	3.3	2405.5	2405.5	2406.0	0.5
AK	151,699	1955	8254	3.9	2406.8	2406.8	2407.3	0.5
AL	153,577	2273	11113	2.9	2408.2	2408.2	2408.6	0.4
AM	155,233	1750	7183	4.5	2409.1	2409.1	2409.6	0.5

[1] Feet upstream of UL Bend National Wildlife Refuge
[2]Floodway topwidth includes width of high ground area

TABLE 1

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

FLOODWAY DATA

MUSSELSHELL RIVER

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (**FEET**)	SECTION AREA (**SQ. FEET**)	MEAN VELOCITY (**FEET/ SEC**)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
MUSSELSHELL RIVER								
AN	156,333	1532	8097	3.9	2410.8	2410.8	2411.2	0.4
AO	157,481	1130	5919	5.4	2412.2	2412.2	2412.7	0.5
AP	159,258	1655	10997	2.9	2414.8	2414.8	2415.1	0.3
AQ	160,709	2210	12614	2.5	2415.6	2415.6	2416.1	0.5
AR	162,213	1490	8381	3.8	2416.8	2416.8	2417.2	0.4
AS	163,692	1840	9441	3.4	2418.3	2418.3	2418.8	0.5

[1] Feet upstream of UL Bend National Wildlife Refuge southern boundary

TABLE 1

FEDERAL EMERGENCY MANAGEMENT AGENCY

PETROLEUM COUNTY, MT

AND INCORPORATED AREAS

FLOODWAY DATA

MUSSELSHELL RIVER

Appendix E – cHECk-RAS Checklists

- Reach 5
- Reach 6

cHECk-RAS Report (Reach 5)

HEC-RAS Project: *musselshelldetreach5_v6b2.prj*
Plan File: *musselshelldetreach5_v6b2.p01*
Geometry File: *musselshelldetreach5_v6b2.g02*
Flow File: *musselshelldetreach5_v6b2.f03*
Report Date: *2/5/2016*

Message ID	Message	Cross sections affected	Comments
XS DF 01L	Divided flow. Flow code will be DL. The $assignedname$ flood discharge has a divided flow. The starting and ending stations of the cross section should not extend beyond the watershed boundary of the studied stream. Please review the extent of the cross section. If the cross section extends beyond the watershed boundary then the cross sections need to be trimmed and the HEC-RAS geometry file may need to be recreated using a GIS program. Or use the ineffective flow option, if it has not been considered, to limit the extent of the cross section or to block the divided flow area if it is a local depression.	-3800; 5991	No Action - Cross sections placed appropriately and/or ineffective areas appropriately used.
XS DT 02R	The Right overbank distance of rob is greater than the channel distance of chl by more than two times. The Right overbank distance may be in error. Please review the creation of left overbank, channel and right overbank distances. The HEC-RAS geometry file may need to be recreated using a GIS program. Please resolve the differences between the distances.	-3147	No Action - Overbank distances are correct.

cHECk-RAS Report (Reach 6)

HEC-RAS Project: *musselshelldetreach6_v3.prj*
Plan File: *musselshelldetreach6_v3.p01*
Geometry File: *musselshelldetreach6_v3.g01*
Flow File: *musselshelldetreach6_v3.f01*
Report Date: *1/27/2016*

Message ID	Message	Cross sections affected	Comments
BR LF 01	This is ($strucname$). The selected profile is $profilename$. Type of flow is low flow because, 1. EGEL 3 of $egel3$ is less than or equal to MinTopRd of $minelweirflow$. 2. EGEL 3 of $egel3$ is less than MxLoCdU of $mxlocdu$.	136220(Bridge-UP)	No Action - This is a statement not an error
BR LW 01	This is a Bridge Section. The selected profile is $profilename$. Type of flow is low and weir flow because, 1. EGEL 3 of $egel3$ is greater than MinTopRd of $minelweirflow$. 2. EGEL 3 of $egel3$ is less than MxLoCdU of $mxlocdu$.	136220(Bridge-UP)	No Action - This is a statement not an error
BR PW 01	This is a Bridge Section. The selected profile is $profilename$. Type of flow is sluice gate pressure and weir flow because, 1. EGEL 3 of $egel3$ is greater than MinTopRd of $minelweirflow$. 2. EGEL 3 of $egel3$ is equal to or greater than MxLoCdU of $mxlocdu$. 3. WSEL 2 of $wsel2$ is less than MxLoCdD of $mxlocdd$.	136220(Bridge-UP)	No Action - This is a statement not an error
BR PW 02	This is a Bridge Section. The selected profile is $profilename$. Type of flow is submerged pressure and weir flow because, 1. EGEL 3 of $egel3$ is greater than MinTopRd of $minelweirflow$. 2. EGEL 3 of $egel3$ is equal to or greater than MxLoCdU of $mxlocdu$. 3. WSEL 2 of $wsel2$ is equal to or greater than MxLoCdD of $mxlocdd$.	136220(Bridge-UP)	No Action - This is a statement not an error
ST DT 03	This is ($Structure$) section. The Contraction Length is longer than the Expansion Length. Section 4 channel distance of $Length_Chnl4$ is longer than Section 2 channel distance of $Length_Chnl2$. Section 4 and Section 1 should be relocated. The HEC-RAS geometry file may need to be recreated using a GIS program.	136220(Bridge-UP)	No Action - Cross sections are appropriately placed
ST GD 02BD	This is the Downstream Bridge Section. There is only one bridge. However, the low cord line crosses the ground line at more than two locations. The ground and deck/roadway data should be checked.	136220(Bridge)	No Action - Structure is appropriately modeled
ST GD 02BU	This is the Upstream Bridge Section. There is only one bridge. However, the low cord line crosses the ground line at more than two locations. The ground and deck/roadway data should be checked.	136220(Bridge)	No Action - Structure is appropriately modeled

ST IF 07S1L	This is Section 1. Left Ineffective flow option was considered at this section. However, it should be a fully expanded cross section. Ineffective flow stations and elevations should be cleared from this section, unless the areas beyond the ineffective flow stations are not within the flow path of the stream. This message should be ignored if this section is Section 3 of the downstream structure.	136056(Bridge)	No Action - Cross sections placed appropriately and/or ineffective areas appropriately used
ST IF 07S1R	This is Section 1. Right Ineffective flow option was considered at this section. However, it should be a fully expanded cross section. Ineffective flow stations and elevations should be cleared from this section, unless the areas beyond the ineffective flow stations are not within the flow path of the stream. This message should be ignored if this section is Section 3 of the downstream structure.	136056(Bridge)	No Action - Cross sections placed appropriately and/or ineffective areas appropriately used
XS DF 01R	Divided flow. Flow code will be DR. The $assignedname$ flood discharge has a divided flow. The starting and ending stations of the cross section should not extend beyond the watershed boundary of the studied stream. Please review the extent of the cross section. If the cross section extends beyond the watershed boundary then the cross section needs to be trimmed and the HEC-RAS geometry file may need to be recreated using a GIS program. Or use the ineffective flow option, if it has not been considered, to limit the extent of the cross section or to block the divided flow area if it is a local depression.	143961; 154675	No Action - Cross sections placed appropriately and/or ineffective areas appropriately used
XS IF 02R	Flow code will be MIR. Multiple (block) Ineffective Stations are selected for the right overbank at this River Station. This is not Section 2 or Section 3 of Multiple Openings or Multiple Culverts. Please justify why the Multiple Blocks Ineffective Flow option was used. Consider using the normal Ineffective Flow option.	143961; 144501; 145056	No Action - Ineffective areas appropriately used

Appendix F – QA/QC Checklists

- Reach 5
- Reach 6

HEC-RAS
QA Review Checklist

Project Name:	Musselshell Watershed Phase II Floodplain Study	Model:	Reach 5
Project Number:	1447.041	MAS:	2015-02
Completed By:	Mark Franchi	Date:	February 4, 2016
Changes Made:	Kristyn Mayernik	Date:	February 5, 2016

HEC-RAS Model Items:
Check appropriate box: *(If "NA" is checked, an explanation should be entered below item.)*

Yes	No	N/A	
☐	☒	☐	Does the model go through Critical Depth for any of the flows? If no, then go to next item. If yes, is this reasonable? If so, go to errors and check whether critical depth was calculated or assumed. If critical depth was calculated, run under mixed flow. If critical depth was assumed, model should be revised.
☒	☐	☐	Model has been calibrated (if possible). *(Calibrated to 2011 flood aerial photographs.)*
☒	☐	☐	2-year (50% Annual-Chance) event water surface is within channel.
☒	☐	☐	Multiple Critical Depth Search has been set.
☒	☐	☐	Energy Grade Line decreases is in downstream direction.
☒	☐	☐	Ineffective flows overtopping at correct elevation (roadway and other sections).
☒	☐	☐	Continuity between X-SECs, especially when overtopping occurs.
☒	☐	☐	Flow widths are appropriate and/or calibrated.
☒	☐	☐	Right overbank flow at an acceptable event.
☒	☐	☐	Flow in channel.
☒	☐	☐	Left overbank flow at an acceptable event?
☒	☐	☐	Ineffective flow locations & elevations entered and checked.
☒	☐	☐	Contraction/Expansion coefficients checked.
☐	☐	☒	Entrance loss coefficients checked. *(No culverts in this model reach.)*
☒	☐	☐	Structure X-SECs located at 1:1 upstream and 2:1 downstream and are fully expanded.

HEC-RAS Model Items:
Check appropriate box: (If "NA" is checked, an explanation should be entered below item.)

Yes	No	N/A	
☒	☐	☐	Reach distances between X-SECs checked. (Use an aerial photograph with surveyed X-SEC locations for reference. The X-SECs should be labeled with stations used in HEC-RAS and/or the U/S and D/S distances).
☒	☐	☐	Manning's "n" values checked and at each cross-section.
☒	☐	☐	Bank stations checked and are appropriate for each cross-section.
☒	☐	☐	Energy Method set for bridges in pressure flow or if ratio of EGL to Existing ground/Low chord to Existing Ground is less than or equal to 1.2. If ratio is greater than 1.2, use Pressure/Weir Method. If overtopping of the roadway is occurring, Pressure/Weir may need to be selected to calculate the weir flow over the road even if the bridge is not in pressure flow.
☐	☐	☒	Culvert calculation method set at highest "Upstream EG" or explain otherwise. *(No culverts in this model reach.)*
☐	☐	☒	Scour calculations have been checked. *(No scour calculations with a floodplain study.)* *(No scour calculations with a floodplain study.)*
☐	☐	☒	Contraction Scour bank points are set outside of Bridge Opening. (This make HEC-RAS determine flows, depths, widths, etc). *(No scour calculations with a floodplain study.)*
☐	☐	☒	Pier Scour K2 Coefficient set at 1, if angle of attack of the flow is 0 degrees and bridge is not skewed or flow is parallel with the pier. Otherwise check HEC-18 for K2 based on L/a ratio. *(No scour calculations with a floodplain study.)*
☐	☐	☒	HEC-RAS error for Abutment Scour been accounted for by entering all of the data for the Abutment Scour calculation. *(No scour calculations with a floodplain study.)*
☐	☐	☒	Independent check of HEC-RAS scour calculations using Excel spreadsheets. *(No scour calculations with a floodplain study.)*
☐	☐	☒	Plot toes and tops of slope for proposed bridge on the topographic mapping for project to check for skew, channel centerline, and overall layout. Show skew of bridge and the roadway stationing (if available). *(No proposed bridge with a floodplain study.)*
☐	☐	☒	Multiple opening crossings set with conveyances only at the left and right extents of cross section. *(No multiple opening in this model reach)*

Hydraulics Report Items:
Check appropriate box: *(If "NA" is checked, an explanation should be entered below item.)*

Yes	No	N/A	
☒	☐	☐	Check HEC-RAS output Errors, Warnings and Notes.
☒	☐	☐	Version of HEC-RAS listed in report.
☒	☐	☐	High water events and floodplain risks within project limits discussed in the report.
☐	☐	☒	Existing and proposed overtopping events discussed in the report. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Water surface elevation(s) on the date of survey listed in report and the Bridge Rec Memo. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Hydraulic Data Summary Sheet completed. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Channel width modeled in HEC-RAS matches Report & Bridge Recommendation Memo. *(No proposed bridge in a floodplain study.)*

HEC-RAS
QA Review Checklist

Project Name:	Musselshell Watershed Phase II Floodplain Study	Model:	Reach 6
Project Number:	1447.041	MAS:	2015-02
Completed By:	Mark Franchi	Date:	January 10, 2016
Changes Made:	Luke Carlson	Date:	January 28, 2016

HEC-RAS Model Items:
Check appropriate box: *(If "NA" is checked, an explanation should be entered below item.)*

Yes	No	N/A	
☐	☒	☐	Does the model go through Critical Depth for any of the flows? If no, then go to next item. If yes, is this reasonable? If so, go to errors and check whether critical depth was calculated or assumed. If critical depth was calculated, run under mixed flow. If critical depth was assumed, model should be revised.
☒	☐	☐	Model has been calibrated (if possible). *(Calibrated to 2011 flood aerial photographs.)*
☒	☐	☐	2-year (50% Annual-Chance) event water surface is within channel.
☒	☐	☐	Multiple Critical Depth Search has been set.
☒	☐	☐	Energy Grade Line decreases is in downstream direction.
☒	☐	☐	Ineffective flows overtopping at correct elevation (roadway and other sections).
☒	☐	☐	Continuity between X-SECs, especially when overtopping occurs.
☒	☐	☐	Flow widths are appropriate and/or calibrated.
☒	☐	☐	Right overbank flow at an acceptable event.
☒	☐	☐	Flow in channel.
☒	☐	☐	Left overbank flow at an acceptable event?
☒	☐	☐	Ineffective flow locations & elevations entered and checked.
☒	☐	☐	Contraction/Expansion coefficients checked.
☐	☐	☒	Entrance loss coefficients checked. *(No culverts in this model reach.)*
☒	☐	☐	Structure X-SECs located at 1:1 upstream and 2:1 downstream and are fully expanded.

HEC-RAS Model Items:
Check appropriate box: (If "NA" is checked, an explanation should be entered below item.)

Yes	No	N/A	
☒	☐	☐	Reach distances between X-SECs checked. (Use an aerial photograph with surveyed X-SEC locations for reference. The X-SECs should be labeled with stations used in HEC-RAS and/or the U/S and D/S distances).
☒	☐	☐	Manning's "n" values checked and at each cross-section.
☒	☐	☐	Bank stations checked and are appropriate for each cross-section.
☒	☐	☐	Energy Method set for bridges in pressure flow or if ratio of EGL to Existing ground/Low chord to Existing Ground is less than or equal to 1.2. If ratio is greater than 1.2, use Pressure/Weir Method. If overtopping of the roadway is occurring, Pressure/Weir may need to be selected to calculate the weir flow over the road even if the bridge is not in pressure flow.
☐	☐	☒	Culvert calculation method set at highest "Upstream EG" or explain otherwise. *(No culverts in this model reach.)*
☐	☐	☒	Scour calculations have been checked. *(No scour calculations with a floodplain study.)* *(No scour calculations with a floodplain study.)*
☐	☐	☒	Contraction Scour bank points are set outside of Bridge Opening. (This make HEC-RAS determine flows, depths, widths, etc). *(No scour calculations with a floodplain study.)*
☐	☐	☒	Pier Scour K2 Coefficient set at 1, if angle of attack of the flow is 0 degrees and bridge is not skewed or flow is parallel with the pier. Otherwise check HEC-18 for K2 based on L/a ratio. *(No scour calculations with a floodplain study.)*
☐	☐	☒	HEC-RAS error for Abutment Scour been accounted for by entering all of the data for the Abutment Scour calculation. *(No scour calculations with a floodplain study.)*
☐	☐	☒	Independent check of HEC-RAS scour calculations using Excel spreadsheets. *(No scour calculations with a floodplain study.)*
☐	☐	☒	Plot toes and tops of slope for proposed bridge on the topographic mapping for project to check for skew, channel centerline, and overall layout. Show skew of bridge and the roadway stationing (if available). *(No proposed bridge with a floodplain study.)*
☐	☐	☒	Multiple opening crossings set with conveyances only at the left and right extents of cross section. *(No multiple opening in this model reach)*

Hydraulics Report Items:
Check appropriate box: *(If "NA" is checked, an explanation should be entered below item.)*

Yes	No	N/A	
☒	☐	☐	Check HEC-RAS output Errors, Warnings and Notes.
☒	☐	☐	Version of HEC-RAS listed in report.
☒	☐	☐	High water events and floodplain risks within project limits discussed in the report.
☐	☐	☒	Existing and proposed overtopping events discussed in the report. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Water surface elevation(s) on the date of survey listed in report and the Bridge Rec Memo. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Hydraulic Data Summary Sheet completed. *(No proposed bridge in a floodplain study.)*
☐	☐	☒	Channel width modeled in HEC-RAS matches Report & Bridge Recommendation Memo. *(No proposed bridge in a floodplain study.)*

Morrison Maierle
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Hydraulic Data

Quality Assurance (QA) Tracking

Project Name: Musselshell Watershed Project Phase II Flood Study

Model: Petroleum County Reach 5

Mapping Activity Statement No.: 2015-02

Task Completed: February 16, 2016

Submission Date:

QC Review Activity		
1. Ready for QC	LTP: Kristyn Mayernik	Date: February 4, 2016
2. QC Review	QCR: Mark Franchi	Date: February 5, 2016
3. Concurrence	LTP: Kristyn Mayernik	Date: February 12, 2016
4. Changes Made	LTP: Kristyn Mayernik	Date: February 15, 2016
5. Changes Verified	QCR: Mark Franchi	Date: February 16, 2016

LTP – Lead Technical Professional:

QCR – Quality Control Reviewers:

Morrison Maierle
engineers · surveyors · planners · scientists

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
01	Is the computer program used for hydraulic modeling approved by FEMA, and is it a current model version?	The list of models approved by FEMA can be found at www.fema.gov/fhm/en_modl.shtm	Pass ☒ Fail ☐ N/A ☐	HEC-RAS v4.1.0
02	Does the model cover the reach of detailed study shown on the workmap?		Pass ☒ Fail ☐ N/A ☐	
03	Were both Multiple and Floodway models run?		Pass ☒ Fail ☐ N/A ☐	
04	Does the flow used in the hydraulic model match with the Summary of Discharges table?		Pass ☒ Fail ☐ N/A ☐	
05	Do split flow reaches check with master flow diagram and table and check for continuity with hydrology?		Pass ☐ Fail ☐ N/A ☒	No split flow reaches.
06	Are the 1% AC flows identical for both multiple & floodway models?		Pass ☒ Fail ☐ N/A ☐	
07	Is the starting water surface boundary condition of the model appropriate?		Pass ☐ Fail ☐ N/A ☒	Normal depth boundary condition since no effective WSE's have been established.
08	Is the Starting Water Surface Elevation for floodway run within 0.5 foot surcharge limit?		Pass ☐ Fail ☐ N/A ☒	Normal depth boundary condition since no effective WSE's have been established.
09	Are all floodway surcharges less than or equal to 0.5 foot?		Pass ☒ Fail ☐ N/A ☐	
10	Are all bridges visible on the workmap modeled or is a reason for not modeling provided?		Pass ☐ Fail ☐ N/A ☒	No bridges exist on this reach.

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
11	Are bridges/culverts correctly modeled with high and low flow methods selection?		Pass ☐ Fail ☐ N/A ☒	No bridges exist on this reach.
12	Are bridges/culverts coded with correct low chord, high chord, pier widths, coefficients and centerline stations?		Pass ☐ Fail ☐ N/A ☒	No bridges exist on this reach.
13	Have ineffective flow areas, if any, been identified and blocked?		Pass ☒ Fail ☐ N/A ☐	
14	Does the River Stationing match the downstream channel reach lengths in the model?		Pass ☒ Fail ☐ N/A ☐	
15	Does the model's stationing as represented on the profile, match the stream distances shown on the map?		Pass ☒ Fail ☐ N/A ☐	
16	Are the left and right overbank distances adjusted for flow around curves?		Pass ☒ Fail ☐ N/A ☐	
17	Are cross-sections placed perpendicular to channel?		Pass ☒ Fail ☐ N/A ☐	
18	Are cross-section bank stations set at top of main channel bank?		Pass ☒ Fail ☐ N/A ☐	
19	Do cross-sections extend beyond the 0.2% AC floodplain?		Pass ☒ Fail ☐ N/A ☐	
20	Are cross-sections spaced correctly for general criteria of 500-600 feet maximum between cross-sections?		Pass ☒ Fail ☐ N/A ☐	

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
21	Are split flow paths unencroached and identified?		Pass ☐ Fail ☐ N/A ☒	No split flow paths.
22	Are all cHECk-RAS error messages resolved?		Pass ☒ Fail ☐ N/A ☐	
23	Are the Manning's n values used in the model within reasonable ranges?		Pass ☒ Fail ☐ N/A ☐	
24	Are Levees, if present, modeled appropriately based on whether they are certified according to NFIP (65.10)?		Pass ☐ Fail ☐ N/A ☒	No levees in model reach.
25	Are expansion/contraction coefficients set at 0.3 and 0.5 at correct river stations for bridge/culvert crossings?		Pass ☐ Fail ☐ N/A ☒	No bridge/culverts in model reach.
26	For areas where non-certified levees are shown on the workmap has analysis been provided for With & Without Levee conditions?		Pass ☐ Fail ☐ N/A ☒	No levees in model reach.
27	Have sufficient backup hydraulic analysis been provided for any shallow flooding, or coastal areas, if any?		Pass ☐ Fail ☐ N/A ☒	No shallow flooding or coastal areas in model reach.
28	HEC-RAS Model Metadata file is completed?		Pass ☒ Fail ☐ N/A ☐	
29	Hydraulic model is calibrated to available high water?		Pass ☒ Fail ☐ N/A ☐	

Profiles:

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
30	Do the profiles meet FEMA format & font criteria?		Pass ☒ Fail ☐ N/A ☐	
31	Have appropriate vertical and horizontal scales been chosen?		Pass ☒ Fail ☐ N/A ☐	
32	Are elevations referenced to NAVD88 and shown?		Pass ☒ Fail ☐ N/A ☐	
33	Does the title block show the correct community or county and State names?		Pass ☒ Fail ☐ N/A ☐	
34	Does the beginning station reference match the labeling of the left side of the first profile for each flooding source?		Pass ☒ Fail ☐ N/A ☐	
35	Is the backwater or influence from the receiving stream shown on the profile?		Pass ☐ Fail ☐ N/A ☒	
36	Do the profiles have appropriately spaced lettered cross-sections?		Pass ☒ Fail ☐ N/A ☐	
37	Are all the corporate limits and confluences shown on the profile?		Pass ☐ Fail ☐ N/A ☒	No corporate limits or confluences in model reach.
38	Do the bridge and culvert labels match with the labels shown on the base map?		Pass ☐ Fail ☐ N/A ☒	No bridge/culverts in model reach.
39	Do bridge low chord, high chord, and river station match HEC-RAS model?		Pass ☐ Fail ☐ N/A ☒	No bridges in model reach.

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
40	Do the locations of the lettered cross sections with respect to bridges and confluences match with the mapped locations?		Pass ☐ Fail ☐ N/A ☒	No bridges in model reach.
Floodway Data Tables:				
41	Do the overall font & formatting meet FEMA criteria?		Pass ☒ Fail ☐ N/A ☐	
42	Is the proper community name and stream name shown?		Pass ☒ Fail ☐ N/A ☐	
43	Do the beginning station and measurement units match the profile?		Pass ☒ Fail ☐ N/A ☐	
44	Do the Cross Section Letter distances match the stations shown on the Profile?	(rounded to nearest foot)	Pass ☒ Fail ☐ N/A ☐	
45	Are the WIDTH and SECTION AREA in FDT exactly the same as the model output?	(rounded to nearest foot)	Pass ☒ Fail ☐ N/A ☐	
46	Do the Velocity numbers match the Mean Velocity output?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	
47	Are backwater elevations or influence elevations from the profile, if any, shown in the Regulatory Column?	(rounded to one decimal point)	Pass ☐ Fail ☐ N/A ☒	
48	Are the With and Without Floodway WSELs shown “without consideration of backwater”, and do they match the model output?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
49	Is the correct Datum shown?	Must match Profile and FIRM	Pass ☒ Fail ☐ N/A ☐	
50	Does the INCREASE column, equal the difference between WITH & WITHOUT columns?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	

Morrison Maierle
engineers · surveyors · planners · scientists

Hydraulic Data

Quality Assurance (QA) Tracking

Project Name: Musselshell Watershed Project Phase II Flood Study

Model: Petroleum County Reach 6

Mapping Activity Statement No.: 2015-02

Task Completed: January, 28, 2016

Submission Date:

QC Review Activity		
1. Ready for QC	LTP: Luke Carlson	Date: January 5, 2016
2. QC Review	QCR: Mark Franchi	Date: January 15, 2016
3. Concurrence	LTP: Luke Carlson	Date: January 15, 2016
4. Changes Made	LTP: Luke Carlson	Date: January 18, 2016
5. Changes Verified	QCR: Mark Franchi	Date: January 28, 2016

LTP – Lead Technical Professional:

QCR – Quality Control Reviewers:

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
01	Is the computer program used for hydraulic modeling approved by FEMA, and is it a current model version?	The list of models approved by FEMA can be found at www.fema.gov/fhm/en_modl.shtm	Pass ☒ Fail ☐ N/A ☐	HEC-RAS v4.1.0
02	Does the model cover the reach of detailed study shown on the workmap?		Pass ☒ Fail ☐ N/A ☐	
03	Were both Multiple and Floodway models run?		Pass ☒ Fail ☐ N/A ☐	
04	Does the flow used in the hydraulic model match with the Summary of Discharges table?		Pass ☒ Fail ☐ N/A ☐	
05	Do split flow reaches check with master flow diagram and table and check for continuity with hydrology?		Pass ☐ Fail ☐ N/A ☒	
06	Are the 1% AC flows identical for both multiple & floodway models?		Pass ☒ Fail ☐ N/A ☐	
07	Is the starting water surface boundary condition of the model appropriate?		Pass ☐ Fail ☐ N/A ☒	Normal depth boundary condition since no effective WSE's have been established.
08	Is the Starting Water Surface Elevation for floodway run within 0.5 foot surcharge limit?		Pass ☐ Fail ☐ N/A ☒	Normal depth boundary condition since no effective WSE's have been established.
09	Are all floodway surcharges less than or equal to 0.5 foot?		Pass ☒ Fail ☐ N/A ☐	
10	Are all bridges visible on the workmap modeled or is a reason for not modeling provided?		Pass ☒ Fail ☐ N/A ☐	

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
11	Are bridges/culverts correctly modeled with high and low flow methods selection?		Pass ☒ Fail ☐ N/A ☐	
12	Are bridges/culverts coded with correct low chord, high chord, pier widths, coefficients and centerline stations?		Pass ☒ Fail ☐ N/A ☐	
13	Have ineffective flow areas, if any, been identified and blocked?		Pass ☒ Fail ☐ N/A ☐	
14	Does the River Stationing match the downstream channel reach lengths in the model?		Pass ☒ Fail ☐ N/A ☐	
15	Does the model's stationing as represented on the profile, match the stream distances shown on the map?		Pass ☒ Fail ☐ N/A ☐	
16	Are the left and right overbank distances adjusted for flow around curves?		Pass ☒ Fail ☐ N/A ☐	
17	Are cross-sections placed perpendicular to channel?		Pass ☒ Fail ☐ N/A ☐	
18	Are cross-section bank stations set at top of main channel bank?		Pass ☒ Fail ☐ N/A ☐	
19	Do cross-sections extend beyond the 0.2% AC floodplain?		Pass ☒ Fail ☐ N/A ☐	
20	Are cross-sections spaced correctly for general criteria of 500-600 feet maximum between cross-sections?		Pass ☒ Fail ☐ N/A ☐	

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
21	Are split flow paths unencroached and identified?		Pass ☐ Fail ☐ N/A ☒	No split flow paths.
22	Are all Check-RAS error messages resolved?		Pass ☒ Fail ☐ N/A ☐	
23	Are the Manning's n values used in the model within reasonable ranges?		Pass ☒ Fail ☐ N/A ☐	
24	Are Levees, if present, modeled appropriately based on whether they are certified according to NFIP (65.10)?		Pass ☐ Fail ☐ N/A ☒	No levees in model reach.
25	Are expansion/contraction coefficients set at 0.3 and 0.5 at correct river stations for bridge/culvert crossings?		Pass ☒ Fail ☐ N/A ☐	
26	For areas where non-certified levees are shown on the workmap has analysis been provided for With & Without Levee conditions?		Pass ☐ Fail ☐ N/A ☒	No levees in model reach.
27	Have sufficient backup hydraulic analysis been provided for any shallow flooding, or coastal areas, if any?		Pass ☐ Fail ☐ N/A ☒	No shallow flooding or coastal areas in model reach.
28	HEC-RAS Model Metadata file is completed?		Pass ☒ Fail ☐ N/A ☐	
29	Hydraulic model is calibrated to available high water?		Pass ☒ Fail ☐ N/A ☐	

Profiles:

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
30	Do the profiles meet FEMA format & font criteria?		Pass ☒ Fail ☐ N/A ☐	
31	Have appropriate vertical and horizontal scales been chosen?		Pass ☒ Fail ☐ N/A ☐	
32	Are elevations referenced to NAVD88 and shown?		Pass ☒ Fail ☐ N/A ☐	
33	Does the title block show the correct community or county and State names?		Pass ☒ Fail ☐ N/A ☐	
34	Does the beginning station reference match the labeling of the left side of the first profile for each flooding source?		Pass ☒ Fail ☐ N/A ☐	
35	Is the backwater or influence from the receiving stream shown on the profile?		Pass ☐ Fail ☐ N/A ☒	
36	Do the profiles have appropriately spaced lettered cross-sections?		Pass ☒ Fail ☐ N/A ☐	
37	Are all the corporate limits and confluences shown on the profile?		Pass ☐ Fail ☐ N/A ☒	No corporate limits or confluences in model reach.
38	Do the bridge and culvert labels match with the labels shown on the base map?		Pass ☒ Fail ☐ N/A ☐	
39	Do bridge low chord, high chord, and river station match HEC-RAS model?		Pass ☒ Fail ☐ N/A ☐	

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
40	Do the locations of the lettered cross sections with respect to bridges and confluences match with the mapped locations?		Pass ☒ Fail ☐ N/A ☐	
Floodway Data Tables:				
41	Do the overall font & formatting meet FEMA criteria?		Pass ☒ Fail ☐ N/A ☐	
42	Is the proper community name and stream name shown?		Pass ☒ Fail ☐ N/A ☐	
43	Do the beginning station and measurement units match the profile?		Pass ☒ Fail ☐ N/A ☐	
44	Do the Cross Section Letter distances match the stations shown on the Profile?	(rounded to nearest foot)	Pass ☒ Fail ☐ N/A ☐	
45	Are the WIDTH and SECTION AREA in FDT exactly the same as the model output?	(rounded to nearest foot)	Pass ☒ Fail ☐ N/A ☐	
46	Do the Velocity numbers match the Mean Velocity output?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	
47	Are backwater elevations or influence elevations from the profile, if any, shown in the Regulatory Column?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	
48	Are the With and Without Floodway WSELs shown “without consideration of backwater”, and do they match the model output?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	

QA Review Checklist for Hydraulics

No.	Hydraulic Review	Definition	Pass Fail N/A	Reviewer Comments
49	Is the correct Datum shown?	Must match Profile and FIRM	Pass ☒ Fail ☐ N/A ☐	
50	Does the INCREASE column, equal the difference between WITH & WITHOUT columns?	(rounded to one decimal point)	Pass ☒ Fail ☐ N/A ☐	

Mapping Data

Quality Control Tracking

Project Name: Musselshell Watershed Project – Phase II, Reach 5

Mapping Activity Statement No.: 2015-02

Task Completed: 6/7/2016

Submission Date: 6/15/2016

Review 1 Comments Addressed: 8/26/2016

Review 1 Resubmittal: 8/26/2016

Review 2 Comments Addressed: 11/18/2016

Review 2 Resubmittal: 11/21/2016

QC Review Activity		
1. Ready for QC	LTP: Tracy Campbell	Date: 6/7/2016
2. QC Review	QCR: Kristyn Mayernik	Date: 6/8/2016
3. Concurrence	LTP: Tracy Campbell	Date: 6/8/2016
4. Changes Made	LTP:	Date:
5. Changes Verified	QCR:	Date:
FEMA PTS Review 1 Response		
6. Changes Made	LTP: Zachariah Campbell	Date: 8/26/2016
7. Changes Verified	QCR: Russ Anderson	Date: 8/26/2016
FEMA PTS Review 2 Response		
8. Changes Made	LTP: Luke Carlson	Date: 11/09/2016
9. Changes Verified	QCR: Kristyn Mayernik	Date: 11/16/2016

LTP – Lead Technical Professional: Tracy Campbell – TLC
Zachariah Campbell – ZC
Luke Carlson – LDC

QCR – Quality Control Reviewers: Kristyn Mayernik – KKM
Luke Carlson – LDC

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
01	Has a clear index of workmaps been provided, and are all workmaps available? Are all studied flood sources clearly identified?	The list of models approved by FEMA can be found at www.fema.gov/fhm/en_modl.shtm	Pass ☒ Fail ☐ N/A ☐	
02	Is the datum of the workmap topography shown?		Pass ☒ Fail ☐ N/A ☐	
03	Does the range of the identified cross sections for each flood source match the range in the model?		Pass ☒ Fail ☐ N/A ☐	Note: The model actually has more cross-sections that are prior to the study reach
04	Are the mapped floodway widths within 5% of the floodway model top-widths?		Pass ☒ Fail ☐ N/A ☐	
05	Is the new floodway designed to match and tie in to the effective floodway if any?		Pass ☒ Fail ☐ N/A ☐	Note: This is the first Floodplain study in Petroleum County.
06	Do the floodplain boundaries of the individual flood sources tie in to other flood sources or to effective floodplain data, and are they smooth with sufficient vertices?		Pass ☒ Fail ☐ N/A ☐	
07	Does the range of BFEs on the workmap agree with the range of BFEs on the Profile?		Pass ☒ Fail ☐ N/A ☐	
08	Do the BFEs and floodplain boundaries agree with the contours?		Pass ☒ Fail ☐ N/A ☐	
09	Are BFEs properly placed near the confluences of the streams?	The first whole foot BFE upstream of the confluence should be shown on both streams.	Pass ☐ Fail ☐ N/A ☒	BFE's are only used at Backwater locations. XS plotted and labeled w/ WSELs.
10	Are BFEs plotted at each significant break in Profile slope?	The BFEs plotted should reproduce the 1% profile within ½ foot	Pass ☐ Fail ☐ N/A ☒	BFE's are only used at Backwater locations. XS plotted and labeled w/ WSELs.
11	Check the relationship of vector or DOQQ images to flooding.		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
	DEPTH GRIDS		Pass ☐ Fail ☐ N/A ☐	
12	The grids cover the entire project area.		Pass ☒ Fail ☐ N/A ☐	
13	If the flood risk data extends outside the project area, then the grid data is not clipped at the project area boundary.		Pass ☒ Fail ☐ N/A ☐	
14	Flood Risk Database contains grid data to the full extent of the underlying modeling.		Pass ☒ Fail ☐ N/A ☐	
15	Depth and Analysis Grids share the same terrain and bathymetry source datasets as the engineering models.		Pass ☒ Fail ☐ N/A ☐	
16	Riverine depth grids for new studies include the 10%, 4% 2%, 1%, and 0.2% annual chance flood events.		Pass ☒ Fail ☐ N/A ☐	
17	The pixels of all the grids are aligned (raster snapping).		Pass ☒ Fail ☐ N/A ☐	
18	New coastal studies include depth grid for at least the 1% annual chance flood event.		Pass ☐ Fail ☐ N/A ☒	
19	Depth grids for open water reflect the depth of flooding above normal pool.		Pass ☐ Fail ☐ N/A ☒	
20	Coastal depth grids for open water areas use the modeling bathymetry source data (when available) to the full extent of the flood hazard zone shown on the FIRM.		Pass ☐ Fail ☐ N/A ☒	
21	Depth grid cell size is based on the density of the ground elevation data used and the appropriate precision that can be supported by the data (e.g., 2-ft contour => 2-m cell).		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
22	Depth grids in the FRD (Flood Risk Database) use the Universal Transverse Mercator (UTM) zone in which the majority of the project area lies.		Pass ☐ Fail ☐ N/A ☒	
23	The horizontal datum of the depth grid(s) is NAD83[NSRS-2007].		Pass ☒ Fail ☐ N/A ☐	
24	The depth grid is floating point with data rounded to the nearest tenth of a unit (i.e., 0.1 feet, 0.1 feet/second, or 0.1%).		Pass ☒ Fail ☐ N/A ☐	
25	The depth grid(s) have the same spatial reference, origin, resolution, and rotation.		Pass ☒ Fail ☐ N/A ☐	
26	All grids have the same spatial extent and data type.		Pass ☒ Fail ☐ N/A ☐	
27	For the 1% annual chance depth grid, the depth grid covers the horizontal extent of the respective 1% annual chance floodplain.		Pass ☒ Fail ☐ N/A ☐	
28	For the 0.2% annual chance depth grid, the depth grid covers the horizontal extent of the respective 0.2% annual chance floodplain		Pass ☒ Fail ☐ N/A ☐	
29	Depth grids of the 10%, 4% 2% (or other lower frequencies) are contained within the 1% annual chance floodplain.		Pass ☒ Fail ☐ N/A ☐	.
30	The data value ranges for all depth grids are reasonable.		Pass ☒ Fail ☐ N/A ☐	
31	All resulting grid values are positive values (i.e. subtract the higher frequency grid from the lower frequency grid).		Pass ☒ Fail ☐ N/A ☐	
32	Calculated depth at intersection of cross sections and floodplain matches depth grid (or valid value is found within the range of cell values within 1 cell).		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
33	Supporting documentation is included for locations where the flood depth grid has large gaps due to issues with the underlying terrain data.		Pass ☐ Fail ☐ N/A ☒	
34	All gaps and voids within the applicable grid boundary appear correct.		Pass ☒ Fail ☐ N/A ☐	
35	All slivers where two intermediate depth grids have been merged are removed.		Pass ☒ Fail ☐ N/A ☐	
36	Dataset is present in Database and naming convention is correct.		Pass ☒ Fail ☐ N/A ☐	
37	All Rasters are Floating Point, resolution of 0.1 units (except Hillshade Raster, an integer raster).		Pass ☒ Fail ☐ N/A ☐	
38	Depth Grids for all reaches have been combined into a study-wide grid.		Pass ☒ Fail ☐ N/A ☐	The two reaches in this study were separated by miles and modeled separately, therefore were not combined together.
39	Values for 10% Depth Grid are less than values for 4% Depth Grid (which is < 2%, which is < 1%, which is < than 0.2%)in corresponding cells.		Pass ☒ Fail ☐ N/A ☐	
40	The cst_dpthxxxpct raster dataset represents water depth in feet for a coastal type of analysis.		Pass ☒ Fail ☐ N/A ☒	
41	The depth_xxxpct raster dataset represents water depth in feet for a non-coastal type of analysis.		Pass ☒ Fail ☐ N/A ☐	
42	Water Surface Change Grid has the same spatial reference, origin, resolution, and rotation as depth grids (and/or other rasters).		Pass ☐ Fail ☐ N/A ☒	
FEMA PTS Review 1 Response				

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
43	Floodplain Boundary Smoothing (eliminate islands < ½ acres, eliminate slivers < 31 ft)		Pass ☒ Fail ☐ N/A ☐	
FEMA PTS Review 2 Response				
44	Floodplain Boundary Smoothing (Correct fringes, topology and overlaps)		Pass ☒ Fail ☐ N/A ☐	

Mapping Data

Quality Control Tracking

Project Name: Musselshell Watershed Project – Phase II, Reach 6

Mapping Activity Statement No.: 2015-02

Task Completed: 6/7/2016

Submission Date: 6/15/2016

Review 1 Comments Addressed: 8/26/2016

Review 1 Resubmittal: 8/26/2016

Review 2 Comments Addressed: 11/18/2016

Review 2 Resubmittal: 11/21/2016

QC Review Activity		
1. Ready for QC	LTP: Tracy Campbell	Date: 6/7/2016
2. QC Review	QCR: Kristyn Mayernik	Date: 6/8/2016
3. Concurrence	LTP: Tracy Campbell	Date: 6/8/2016
4. Changes Made	LTP:	Date:
5. Changes Verified	QCR:	Date:
FEMA PTS Review 1 Response		
6. Changes Made	LTP: Zachariah Campbell	Date: 8/26/2016
7. Changes Verified	QCR: Russ Anderson	Date: 8/26/2016
FEMA PTS Review 2 Response		
8. Changes Made	LTP: Luke Carlson	Date: 11/09/2016
9. Changes Verified	QCR: Kristyn Mayernik	Date: 11/16/2016

LTP – Lead Technical Professional: Tracy Campbell – TLC
Zachariah Campbell – ZC
Luke Carlson – LDC

QCR – Quality Control Reviewers: Kristyn Mayernik – KKM
Luke Carlson – LDC

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
01	Has a clear index of workmaps been provided, and are all workmaps available? Are all studied flood sources clearly identified?	The list of models approved by FEMA can be found at www.fema.gov/fhm/en_modl.shtm	Pass ☒ Fail ☐ N/A ☐	
02	Is the datum of the workmap topography shown?		Pass ☒ Fail ☐ N/A ☐	
03	Does the range of the identified cross sections for each flood source match the range in the model?		Pass ☒ Fail ☐ N/A ☐	Note: The model actually has more cross-sections that are prior to the study reach
04	Are the mapped floodway widths within 5% of the floodway model top-widths?		Pass ☒ Fail ☐ N/A ☐	
05	Is the new floodway designed to match and tie in to the effective floodway if any?		Pass ☒ Fail ☐ N/A ☐	Note: This is the first Floodplain study in Petroleum County.
06	Do the floodplain boundaries of the individual flood sources tie in to other flood sources or to effective floodplain data, and are they smooth with sufficient vertices?		Pass ☒ Fail ☐ N/A ☐	
07	Does the range of BFEs on the workmap agree with the range of BFEs on the Profile?		Pass ☒ Fail ☐ N/A ☐	
08	Do the BFEs and floodplain boundaries agree with the contours?		Pass ☒ Fail ☐ N/A ☐	
09	Are BFEs properly placed near the confluences of the streams?	The first whole foot BFE upstream of the confluence should be shown on both streams.	Pass ☐ Fail ☐ N/A ☒	BFE's are only used at Backwater locations. XS plotted and labeled w/ WSELs.
10	Are BFEs plotted at each significant break in Profile slope?	The BFEs plotted should reproduce the 1% profile within ½ foot	Pass ☐ Fail ☐ N/A ☒	BFE's are only used at Backwater locations. XS plotted and labeled w/ WSELs.
11	Check the relationship of vector or DOQQ images to flooding.		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
	DEPTH GRIDS		Pass ☐ Fail ☐ N/A ☐	
12	The grids cover the entire project area.		Pass ☒ Fail ☐ N/A ☐	
13	If the flood risk data extends outside the project area, then the grid data is not clipped at the project area boundary.		Pass ☒ Fail ☐ N/A ☐	
14	Flood Risk Database contains grid data to the full extent of the underlying modeling.		Pass ☒ Fail ☐ N/A ☐	
15	Depth and Analysis Grids share the same terrain and bathymetry source datasets as the engineering models.		Pass ☒ Fail ☐ N/A ☐	
16	Riverine depth grids for new studies include the 10%, 4% 2%, 1%, and 0.2% annual chance flood events.		Pass ☒ Fail ☐ N/A ☐	
17	The pixels of all the grids are aligned (raster snapping).		Pass ☒ Fail ☐ N/A ☐	
18	New coastal studies include depth grid for at least the 1% annual chance flood event.		Pass ☐ Fail ☐ N/A ☒	
19	Depth grids for open water reflect the depth of flooding above normal pool.		Pass ☐ Fail ☐ N/A ☒	
20	Coastal depth grids for open water areas use the modeling bathymetry source data (when available) to the full extent of the flood hazard zone shown on the FIRM.		Pass ☐ Fail ☐ N/A ☒	
21	Depth grid cell size is based on the density of the ground elevation data used and the appropriate precision that can be supported by the data (e.g., 2-ft contour => 2-m cell).		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
22	Depth grids in the FRD (Flood Risk Database) use the Universal Transverse Mercator (UTM) zone in which the majority of the project area lies.		Pass ☐ Fail ☐ N/A ☒	
23	The horizontal datum of the depth grid(s) is NAD83[NSRS-2007].		Pass ☒ Fail ☐ N/A ☐	
24	The depth grid is floating point with data rounded to the nearest tenth of a unit (i.e., 0.1 feet, 0.1 feet/second, or 0.1%).		Pass ☒ Fail ☐ N/A ☐	
25	The depth grid(s) have the same spatial reference, origin, resolution, and rotation.		Pass ☒ Fail ☐ N/A ☐	
26	All grids have the same spatial extent and data type.		Pass ☒ Fail ☐ N/A ☐	
27	For the 1% annual chance depth grid, the depth grid covers the horizontal extent of the respective 1% annual chance floodplain.		Pass ☒ Fail ☐ N/A ☐	
28	For the 0.2% annual chance depth grid, the depth grid covers the horizontal extent of the respective 0.2% annual chance floodplain		Pass ☒ Fail ☐ N/A ☐	
29	Depth grids of the 10%, 4% 2% (or other lower frequencies) are contained within the 1% annual chance floodplain.		Pass ☒ Fail ☐ N/A ☐	.
30	The data value ranges for all depth grids are reasonable.		Pass ☒ Fail ☐ N/A ☐	
31	All resulting grid values are positive values (i.e. subtract the higher frequency grid from the lower frequency grid).		Pass ☒ Fail ☐ N/A ☐	
32	Calculated depth at intersection of cross sections and floodplain matches depth grid (or valid value is found within the range of cell values within 1 cell).		Pass ☒ Fail ☐ N/A ☐	

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
33	Supporting documentation is included for locations where the flood depth grid has large gaps due to issues with the underlying terrain data.		Pass ☐ Fail ☐ N/A ☒	
34	All gaps and voids within the applicable grid boundary appear correct.		Pass ☒ Fail ☐ N/A ☐	
35	All slivers where two intermediate depth grids have been merged are removed.		Pass ☒ Fail ☐ N/A ☐	
36	Dataset is present in Database and naming convention is correct.		Pass ☒ Fail ☐ N/A ☐	
37	All Rasters are Floating Point, resolution of 0.1 units (except Hillshade Raster, an integer raster).		Pass ☒ Fail ☐ N/A ☐	
38	Depth Grids for all reaches have been combined into a study-wide grid.		Pass ☐ Fail ☐ N/A ☒	The two reaches in this study were separated by miles and modeled separately, therefore were not combined together.
39	Values for 10% Depth Grid are less than values for 4% Depth Grid (which is < 2%, which is < 1%, which is < than 0.2%)in corresponding cells.		Pass ☒ Fail ☐ N/A ☐	
40	The cst_dpthxxxpct raster dataset represents water depth in feet for a coastal type of analysis.		Pass ☐ Fail ☐ N/A ☒	
41	The depth_xxxpct raster dataset represents water depth in feet for a non-coastal type of analysis.		Pass ☒ Fail ☐ N/A ☐	
42	Water Surface Change Grid has the same spatial reference, origin, resolution, and rotation as depth grids (and/or other rasters).		Pass ☐ Fail ☐ N/A ☒	
FEMA PTS Review 1 Response				

No.	Mapping Review	Definition	Pass Fail N/A	Reviewer Comments
43	Floodplain Boundary Smoothing (eliminate islands < ½ acres, eliminate slivers < 31 ft)		Pass ☒ Fail ☐ N/A ☐	
FEMA PTS Review 2 Response				
44	Floodplain Boundary Smoothing (Correct fringes, topology and overlaps)		Pass ☒ Fail ☐ N/A ☐	