May 2011 Photo of Harlowton, MT - Kestrel Aerial Services, Inc.

Musselshell River Floodplain Study – Phase II

Hydraulic Analysis and Floodplain Mapping

Wheatland County, Montana

February 2017

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

Wheatland County, Montana

PREPARED FOR:

Montana Department of Natural Resources and Conservation

Federal Emergency Management Agency

February 17, 2017

PREPARD BY:

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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

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1.0 Introduction and Background

Morrison-Maierle, Inc. has completed a hydraulic analysis of the Musselshell River and Antelope Creek within Wheatland 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 the Musselshell River 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 most severe flooding event in the Antelope Creek watershed occurred on June 17, 1950. According to local residents, approximately eight to ten inches of rain fell within a 20-square mile area centered over Antelope Creek, about five miles north of Harlowton (DNRC 2016)

The study limits, as shown on Figures 1 and 2, consists of four segments, Reaches 3, 4, 9 and 10 along the Musselshell River and Antelope Creek. Reach 3 of the Musselshell River begins at the Wheatland County, Montana eastern boundary and extends upstream approximately thirty river-miles to near the eastern boundary of the town of Harlowton.

Reach 4 of Antelope Creek, a tributary to the Musselshell River, begins at the north boundary of the town of Harlowton and extends upstream for 3.2 river-miles north of Harlowton.

Reach 9 of the Musselshell River begins downstream of the Red Bridge Road crossing and extends upstream through the town of Harlowton including the Harlowton Overflow Channel for a combined total of eleven river-miles. The Harlowton Overflow Channel conveys split flows from overtopping of the Musselshell River bank near the abandoned railroad bridge structure B47 and enters the Harlowton corporate limits through a culvert crossing at the U.S. Highway 191 embankment. The channel passes through St. Joseph Park and a low-lying residential area north of the abandoned railroad embankment. The overflow channel is fed by local springs and flows year round and empties into the Musselshell River upstream of the confluence of Antelope Creek.

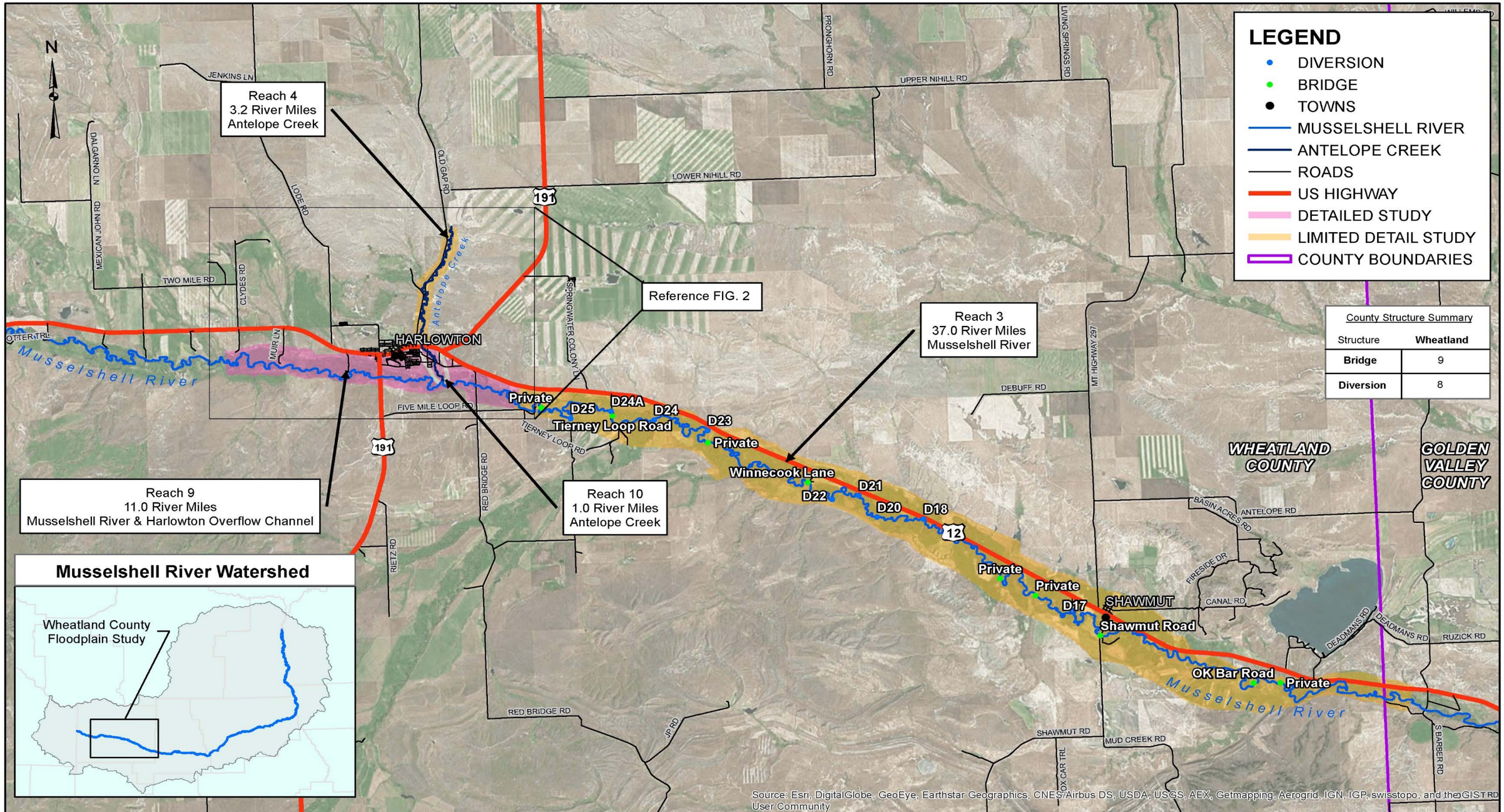
Reach 10 of Antelope Creek, a tributary to the Musselshell River, begins at the confluence of the Musselshell River and extends upstream one river-mile to Reach 4 of Antelope Creek. Reach 10 of Antelope Creek has two split flow reaches. The first split, as shown on Figure 2, is within the town of Harlowton and originates from overtopping of site topography to the west for approximately 3,340-feet of channel distance before rejoining to primary Antelope Creek channel upstream the confluence of the Musselshell River. The second split occurs north of the abandoned railroad grade from overtopping of the east bank and flows are conveyed away from the primary channel to the east along the abandoned railroad grade to the Red Bridge Road.

Reach 3 of the Musselshell River updates approximately seven river-miles of Zone A floodplain and creates thirty river-miles for a total of thirty-seven river-miles of limited detail Zone AE floodplain. Reach 4 of Antelope Creek creates limited detail Zone AE floodplain for a previously unmapped reach. Reach 9 of the Musselshell River updates approximately 5.6-river-miles of Zone A2 floodplain, 1.1 river-miles of Zone A4 floodplain on the Harlowton Overflow channel and creates 4.3 river-miles of previously unmapped floodplain for a total of eleven river-miles of detailed Zone AE floodplain. Reach 10 of Antelope Creek updates one river-mile of Zone A8 floodplain with detailed Zone AE floodplain within the town of Harlowton. An area of Zone AO floodplain is also included to account for shallow flooding downstream of Logan Street SE as shown on the Hydraulic work maps provided in Appendix A.

This Summary Report presents the information and methods used to develop the one-percent-annual-chance (100-year) and 0.2-percent-annual-chance (500-year) floodplains. This 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 for the Musselshell River was completed by Pioneer Technical Services, Inc. in 2015 (Pioneer, 2015a) and approved by FEMA in 2015. The hydrologic analysis for Antelope Creek was completed by the Montana Department of Natural Resource in 2016 (DNRC 2016) and was approved by FEMA in 2016. Reach 3 hydraulic structure assessment was completed by Pioneer Technical Services, Inc. in 2015 (Pioneer, 2015b). Reaches 4, 9, and 10 structure survey were completed by Morrison-Maierle, Inc. in the fall of 2015 (MMI, 2015) and submitted to FEMA in January 2016.

The hydraulic analysis for Musselshell River and Antelope Creek within Wheatland County, MT is summarized in this report. The flood study includes the 10%, 4%, 2%, 1%, and 0.2% annual-chance flood events. FEMA Standards (SID# 84) for Flood Risk Projects identify a requirement to model a one-percent plus (1% plus) annual-chance flood event in riverine analyses and include the 1% 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% plus hydrologic or hydraulic analyses were performed as part of this study and no flood profiles will be presented for 1% plus in the FIS.

The Montana Department of Natural Resources (DNRC) and the professional service contractor Morrison-Maierle, Inc. (MMI) have completed this study using guidelines and standards published in the FEMA Resource and Document Library to ensure the study complies with the National Flood Insurance Program.



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Wheatland County MT

Study Limits

PROJECT NO. 1447.041

FIG. 1

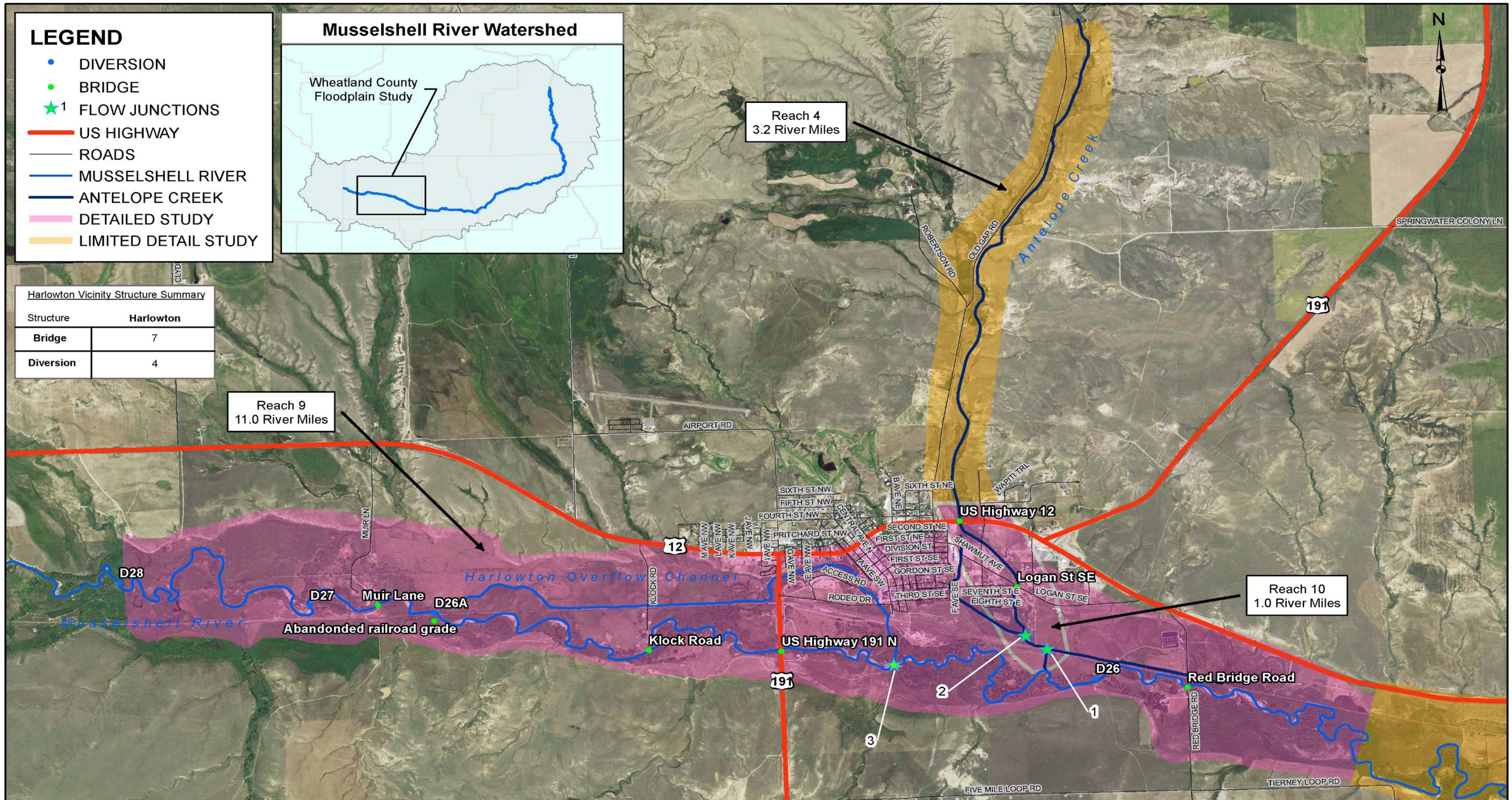

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FIG. 2

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, MT 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).

Elevations in the Musselshell River basin 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 occasionally 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 valley. Three irrigation storage reservoirs exist on the Musselshell: the Bair Reservoir on the North Fork; Martinsdale Reservoir an off-stream reservoir fed by the South Fork Musselshell River near Martinsdale; and Deadman's Basin Reservoir an off-stream 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 storage capacity. During the summer and fall seasons, reaches of the Musselshell River are often dewatered due to irrigation withdrawals.

Antelope Creek originates in the Little Belt Mountains near the northwestern Wheatland County boundary and flows southeasterly for approximately 28 miles before its confluence with the Musselshell River just south of the town of Harlowton, MT. The total watershed area at the confluence is approximately 91 square miles. Many small tributaries contribute to the flow of Antelope Creek including Alkali Creek (DNRC 2016).

2.0 Previous Mapping

Flood Insurance Rate Maps (FIRMs) were completed for Wheatland County, MT with an effective date of September 16, 1981. The flood hazards currently mapped for the Musselshell River is Zone A for approximately seven river-miles within Wheatland County, Montana. Zone A2 mapping is available for 5.6 river-miles within the town of Harlowton. Zone A4 mapping is available for 1.1 river-miles of the Harlowton Overflow Channel. The flood hazards currently mapped for Antelope Creek are Zone A for approximately 3.2 river-miles and Zone A8 for approximately one river-mile.

Zone A is a flood hazard zone without detailed hydraulic modeling and base flood elevations. Zone A2, A4, and A8 are a flood hazard zone with detailed hydraulic modeling and base flood elevations. This floodplain study will change the flood zones on the maps to Zone AE for Wheatland County, MT.

3.0 Hydrology

This detailed flood study, as shown on Figures 1 and 2, covers approximately 49.5 river-miles of the Musselshell River and 4.2 river-miles of Antelope Creek within Wheatland County, MT. The hydrology for each reach is discussed below.

3.1 Musselshell River

The beginning of the study along the Musselshell River is at the Wheatland County, MT eastern boundary, river-mile zero, and extends upstream to approximately river-mile 45 west of the town of Harlowton. Two active United States Geological Survey (USGS) gaging stations on the Musselshell River are located in the vicinity of the study area. USGS gage 06123030 *Musselshell River above Mud Creek near Shawmut*, is approximately four miles east of Shawmut along U.S. Highway 12 and has been in operation since 1998. USGS gage 06120500 *Musselshell River at Harlowton, MT,* is located at the U.S. 191 bridge crossing approximately one-half mile south of the town of Harlowton and has been in operation since 1909. Figures 3 and 4 identifies the gaging station locations and the summary data for the gages are listed in Table 1.

Table 1. USGS Gaging Stations for Musselshell River

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
06123030	*Musselshell River above Mud Creek near Shawmut*	1998 - 2015	18	1,518	8,900 / 2011	72 / 2000
06120500	*Musselshell River at Harlowton, MT*	1909 - 2015	107	1,108	5,520 / 2011	93 / 1961

The hydrologic analyses for the Musselshell River 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 ungaged flow change locations were calculated using the drainage area gage transfer method and 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 Wheatland County, Montana are presented in Table 2 and the 1% annual-chance flow change locations are shown on Figure 4.

Table 2. Summary of Discharges for Musselshell River

River Station	HEC-RAS Model 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 Chance (500-year)
25770	Reach 3	USGS Station 06123030	3,495	5,673	7,665	9,968	16,580
68803	↓	River-mile 262	3,449	5,568	7,500	9,729	16,110
103737	↓	River-mile 268.7	3,356	5,360	7,174	9,258	15,190
161024	↓	American Fork	2,863	4,290	5,533	6,925	10,770
195296	↓	USGS Station 06120500	2,610	3,768	4,756	5,848	8,816
212531	Reach 9	USGS Station 06120500	2,610	3,768	4,756	5,848	8,816
228203	↓	Milton Creek	2,595	3,742	4,722	5,804	8,747
239663	↓	Mud Creek	2,522	3,617	4,552	5,586	8,407

3.2 Antelope Creek

The hydrologic analyses for Antelope Creek was completed as part of the Phase II Musselshell River Watershed Project by the Montana Department of Natural Resources and Conservation (DNRC, 2016). Three inactive United States Geological Survey (USGS) gaging stations are located in the vicinity of the study area. USGS gage 06120900 *Antelope Creek at Harlowton, MT*, is located near the east end of Harlowton just south of the U.S. Hwy 12 bridge and was inactivated in 1980. USGS gage 06120700 *Antelope Creek tributary near mouth near Harlowton, MT* and USGS gage 06120700 *Antelope Creek tributary near Harlowton, MT* are 15 and 20 miles north of Harlowton and were inactivated in 1973. The summary recorded data for the gages are listed in Table 3.

Table 3. USGS Gaging Stations for Antelope Creek

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
06120900	*Antelope Creek at Harlowton, MT*	1950 - 1980	25	90.9	24,400 / 1950	10 / 1970
06120700	*Antelope Creek tributary near mouth near Harlowton, MT*	1956 - 1973	18	1.83	307 / 1969	0 / 1961
06120600	*Antelope Creek tributary near Harlowton, MT*	1956 - 1973	18	0.53	68 / 1969	0 / 1958 0 / 1961 0 / 1964

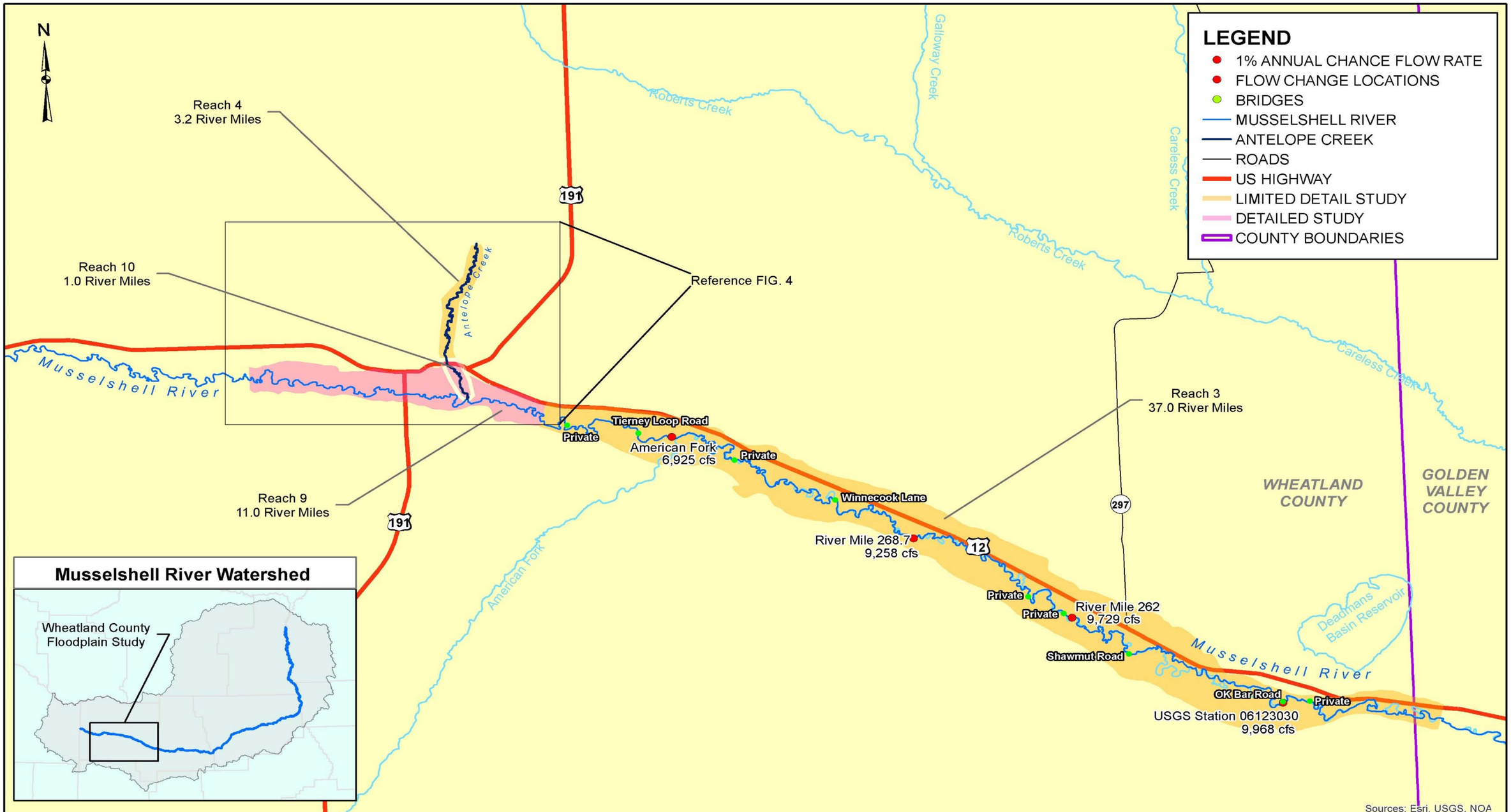
Several methods for estimating flood frequency discharge were analyzed in the study. Published discharges and methods from USGS WRIR 03-4308 (Parrett & Johnson, 2004) and SIR 2015-5019 (USGS, 2015) were evaluated as well as the Expected Moments Algorithm (EMA) estimation method computed with the USGS PeakFQ version 7.1 computer program was calculated for USGS gage 06120900.

In comparison to the effective FIS value and regression equation estimates, the EMA method calculated peak discharge flow rates are significantly higher. The extreme difference in discharge values were attributed to how the historic peak data was handled in each method (DNRC, 2016). The WRIR 03-4308 (Parrett & Johnson, 2004) analysis did not include the 1950 historic peak, as was included in the SIR 2015-5019 (USGS, 2015) analysis.

The EMA analysis was determined to be the preferred method for Antelope Creek at the study limits. The at-site discharge values were transferred to the respective study extents with the USGS gage transfer equation. The summary of peak flow estimates at the study reaches for the Antelope Creek in Wheatland County, Montana are presented in Table 4 and the 1% annual-chance flow change locations are shown on Figure 4.

Table 4. Summary of Discharges for Antelope Creek

River Station	HEC-RAS Model 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 Chance (500-year)
13303	Reach 10	Alkali Creek	1,520	4,920	10,640	21,490	91,550
13303	Reach 4	Alkali Creek	1,520	4,920	10,640	21,490	91,550
20784		Antelope Creek	1,290	4,230	9,230	18,800	81,310



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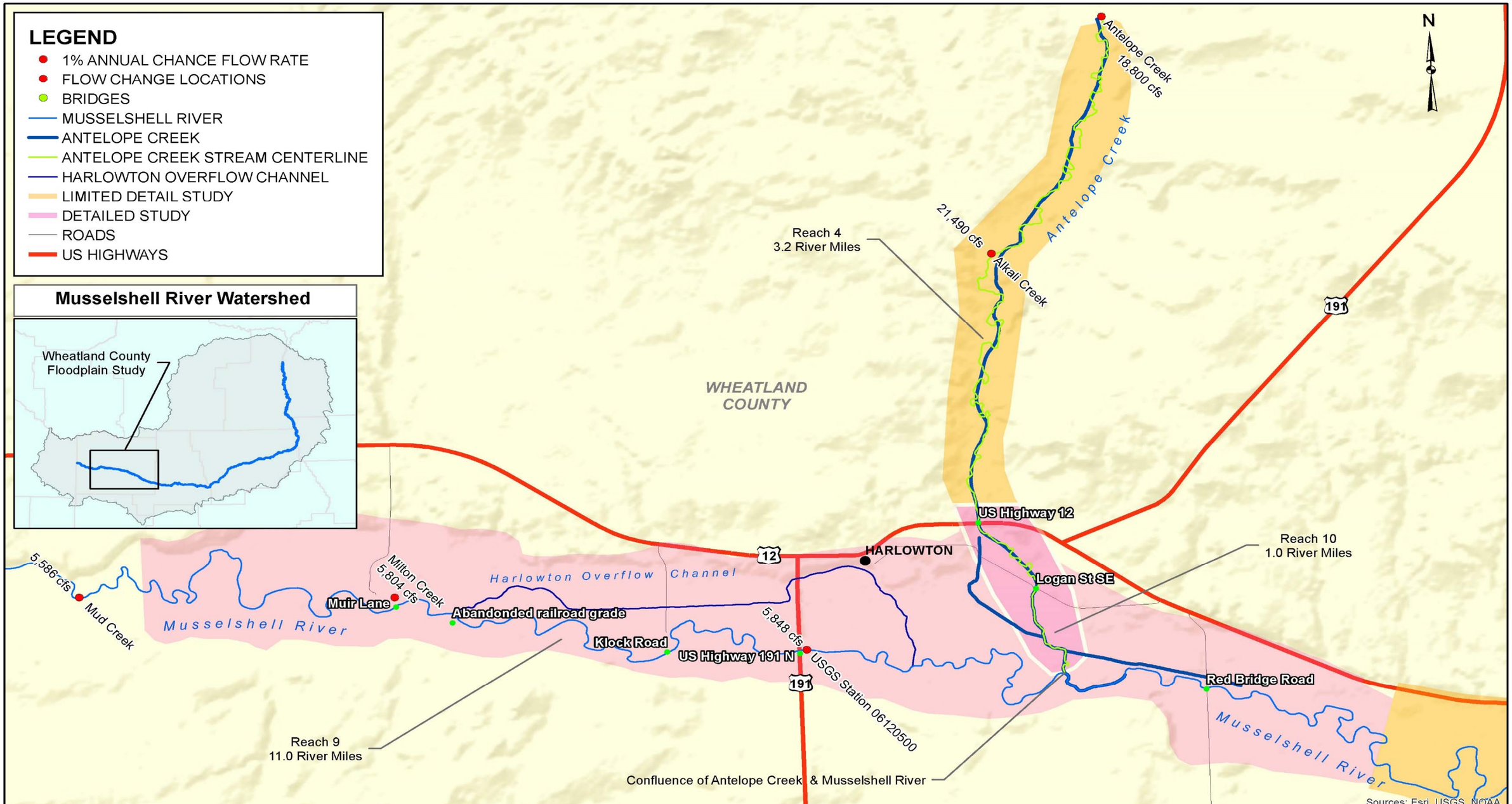
MUSSELSHELL RIVER 1% AC FLOW CHANGE LOCATIONS

FIG. 3



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MUSSELSHELL RIVER 1% AC FLOW CHANGE LOCATIONS

FIG. 4

4.0 Hydraulics

The methods and techniques used to complete the hydraulic analysis of the Musselshell River and Antelope Creek in Wheatland County, Montana are presented in the following sections. The limited detail for the Reaches 3 and 4 analysis utilized the LiDAR mapping and hydraulic structure assessment to develop 1% and 0.2% AC Zone AE mapping without a floodway. The detailed analysis for Reaches 9 and 10 utilized the LiDAR mapping, bathymetric surveys, and hydraulic structure surveys to develop 1% and 0.2% AC Zone AE mapping and 1% AC floodway.

The confluence of Antelope Creek with the Musselshell River is a unique floodplain risk location since the regulatory flood flow rate for the tributary (Antelope Creek) is significantly larger than the flood flow rate for the primary stream (Musselshell River) as shown in Table 5.

Table 5: Antelope Creek and the Musselshell River Flow Rate Comparison

Stream	1% AC Flow Rate (cfs)
Antelope Creek	21,490
Musselshell River	5,848

The Antelope Creek Flood of Record occurred on June 17, 1950 and a flow rate of 24,400 cubic feet per second (cfs) was calculated by the USGS using indirect methods (DNRC, 2016). Review of the gage records on the Musselshell River during the flood of record at Antelope Creek in 1950 indicate a relatively low volume of water from the event since the peak attenuated to approximately 3,000 cfs at the Musselshell River gage approximately 30 miles downstream (USGS gage 06123500). The typical time frame for flooding on the two systems indicates concurrence of the flood peaks is unlikely.

To address these significant difference in flow rates, the modeling of Antelope Creek to the confluence of the Musselshell River includes a lateral weir to model a split flow reach along the north side of the abandoned railroad grade embankment to Red Bridge Road and use a gutter flow technique to model differing Base Flood Elevations (BFEs) between the north and south sides of the abandoned railroad grade. This option approximates potential flood risk in the vicinity of the confluence and allows floodway and floodplain tie-in between Antelope Creek and the Musselshell River. The HEC-RAS analysis for Reach 10 of Antelope Creek is discussed in Section 4.1 of the report.

4.1 Hydraulic Analysis

This floodplain study of the Musselshell River and Antelope Creek within Wheatland County, MT, as shown on Figures 1 and 2, consists of four segments; Reach 3, Reach 4, Reach 9 and Reach 10. The limited detail analysis for Reach 3 of the Musselshell River begins at the Wheatland County eastern boundary and extends upstream approximately 37.0 river-miles to near the town of Harlowton, Montana (Figure1). The limited detail analysis for Reach 4 of Antelope Creek begins one river-mile upstream of the confluence with the Musselshell River

and extends upstream approximately 3.2 river-miles north of Harlowton (Figure 2). The detailed analysis for Reach 9 Musselshell River begins at river-mile station 37.0 and extends eight river-miles upstream to river-mile station 45.0 (Figure 2). The detailed analysis for Reach 10 of Antelope Creek begins at the confluence with the Musselshell River and extends one river-mile upstream to Reach 4 (Figure 2).

The HEC-RAS model for Reach 9 of the Musselshell River (Figure 2) was set up into three segments. Reach 9A model extends from river-mile station 37.0 to the junction with the Harlowton Overflow channel. Reach 9B model extends from the junction with the Harlowton Overflow channel to river-mile station 45.0. The Harlowton Overflow segment models the split flow channel from the downstream junction with the Musselshell River to the upstream diversion with Musselshell River.

The HEC-RAS model for Reach 10 of Antelope Creek (Figure 2) was set up into five segments. The downstream segment of Reach 10 extends from the confluence of the Musselshell River to the Junction 1 with the Railroad Split. The Railroad Split is a split flow reach from Red Bridge Road to the Junction 1 with Antelope Creek and receives flows from overtopping the east bank of Antelope Creek before is crosses the abandoned railroad grade. The middle segment of Reach 10 extends from the Junction 1 with the Railroad Split to the Junction 2 with the Antelope Overflow reach. The Antelope Overflow is a split flow reach from Junction 2 to the approximately U.S. Highway 12 and receives flows from the overtopping of topography to the south of U.S. Highway 12. The upstream segment of Reach 10 extends from Antelope Overflow to Reach 4 of Antelope Creek

The reaches are shown on Figures 1 and 2 and length of each segment is summarized in Table 6.

Table 6. Reach Segment Summary

Segment	Starting River-mile	Ending River-mile	Length (River-miles)
Reach 3	0.0	37.0	37.0
Reach 4	1.0	4.2	3.2
Reach 9A	37.0	39.4	2.6
Reach 9B	39.4	45.0	5.6
Harlowton Overflow Channel	0.0	2.8	2.8
Reach 10	0.0	1.0	1.0
		Total	52.2

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 distances or reach lengths ranging from approximately 100- to 1,000-feet and at structure locations along the floodplain.

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 the Musselshell River Reaches 3, 9, and the Harlowton Overflow channel were utilized to define the Profile Baseline of river stationing as stream distance in feet above the respective downstream limit. The estimated flood flow channel centerline for Antelope Creek Reaches 4 and 10 was utilized to define the Profile Baseline due the significant difference from bank full to flood flow discharges. The profile baseline is shown on the Work Maps included in Appendix A. The 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 3, 9, and the Harlowton Overflow are presented in Tables 7, 8, and 9, respectively. The summary of key features along Antelope Creek, Antelope Overflow and the Abandoned Railroad Grade Split are presented in Tables 10, 11, and 12, respectively.

Table 7. Key Features along Reach 3 Profile Baseline

River Station	Feature	Description	1% AC Discharge (cfs)
0	Downstream Limit of Study	Beginning of model reach – near Musselshell River station mile 0.	9,968
21730	Private Road	Structure B35 – clear span wood structure and wood deck bridge, total span approx. 85-feet.	9,968
25732	OK Bar Road	Structure B36 – clear span steel and wood structure with gravel deck, total span approx. 91-feet.	9,968
25770	Flow Change Location	USGS Station 06123030 – Musselshell River above Mud Creek near Shawmut.	9,968
53376	Shawmut Road	Structure B37 – two span steel and wood structure with concrete deck, total span approx.132-feet.	9,729
65595	Headgate location	Headgate D17 – concrete structure not included in hydraulic model.	–
68803	Flow Change Location	River-mile 262 – tributary flows into Musselshell River.	9,729
70736	Private Road	Structure B38 – clear span steel truss structure and concrete deck, total span approx.81-feet.	9,258
80118	Private Road	Structure B39 – two span steel and wood structure with wood deck, total span approx.84-feet.	9,258
98592	Diversion location	Diversion D18 – concrete construction, total span approx. 96-feet.	9,258
103737	Flow Change Location	River-mile 268.7 – tributary flows into Musselshell River.	9,258
105916	Headgate location	Headgate D19 – concrete structure not included in hydraulic model.	–
105916	Diversion location	Diversion D20 – concrete construction, total span approx. 65-feet.	6,925
111151	Diversion location	Diversion D21 – concrete construction, total span approx. 65-feet.	6,925
116889	Diversion location	Diversion D22 – rock construction, total span of approx. 81-feet.	6,925
122094	Winnecook Lane	Structure B40 – clear span steel truss structure with wood deck, total span approx. 105-feet.	6,925
145431	Private Road	Structure B41 – two span steel and wood structure with wood deck, total span approx. 108-feet.	6,925
149125	Diversion location	Diversion D23 – rock construction, total span of approx. 106-feet.	6,925
160584	Diversion location	Diversion D24 – rock construction, total span of approx. 105-feet.	6,925
161024	Flow Change Location	Effective Zone A Tie-In of American Fork – confluence with Musselshell River.	6,925
166931	Tierney Loop Road	Structure B42 – three span steel structure with concrete deck, total span approx. 149-feet	5,848
167527	Diversion location	Diversion D24A – rock construction, total span of approx. 54-feet.	5,848
176075	Diversion location	Diversion D25 – rock construction, total span of approx. 93-feet.	5,848
181893*	Private Road	Structure D43 – clear span wood structure, total span approx. 63-feet.	5,848
195296	Upstream Limit Reach 3	End of model reach – near Musselshell River station mile 37.	5,848

* Bridge structure not included in hydraulic model due to parallel alignment to flood flows and limited hydraulic backwater conditions.

Table 8. Key Features along Reach 9 Profile Baseline

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
195296	Downstream Limit of Study	Beginning of model reach – near Musselshell River station mile 37.0.	5,848
196779	Red Bridge Road	Structure B44 – clear span steel structure and wood deck, total span approx. 164-feet.	5,848
199966	Diversion location	Diversion D26 – rock construction, total span of approx. 95-feet.	5,848
209174	Flow Change Location	Flow junction – confluence of Harlow Overflow Channel and Musselshell River.	5,848
212531	Flow Change Location	Lateral weir – inflow from Harlow Overflow Channel.	5,574
212976	U.S. Highway 191	Structure B45 – two span steel structure and wood deck, total span approx. 173-feet.	5,530
218526	Klock Road	Structure B46 – four span steel structure and wood deck, total span approx. 106-feet.	5,530
226366	Abandoned Railroad Grade	Structure B47 – two span steel structure and wood deck, total span approx. 134-feet.	5,530
226389	Lateral Weir	Outflow - overtopping to Harlowton Overflow Channel.	5,530
226421	Diversion location	Diversion D26A – concrete construction, total span of approx. 126-feet.	5,530
226468	Lateral Weir	Outflow - overtopping to Harlowton Overflow Channel.	5,530
226516	Flow Change Location	Lateral weir – outflow to Harlow Overflow Channel.	5,530
226816	Lateral Weir	Outflow - overtopping to Harlowton Overflow Channel.	5,804
227374	Lateral Weir	Outflow - overtopping to Harlowton Overflow Channel.	5,804
227918	Lateral Weir	Outflow - overtopping to Harlowton Overflow Channel.	5,804
228203	Flow Change Location	Milton Creek – confluence with Musselshell River.	5,804
228402	Muir Lane	Structure B48 – three span wood structure and deck.	5,586
230790	Diversion location	Diversion D27 – rock construction, total span of approx. 77-feet.	5,586
239663	Upstream Limit of Study	End of model reach – near Musselshell River station mile 45.4.	5,586

Table 9. Key Features along Harlowton Overflow Split Flow Profile Baseline

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
0	Downstream Limit of Study	Beginning of model reach – junction to Musselshell River station mile 39.6.	274
1028	Abandon Railroad Grade	Structure HOC1 – 42-inch diameter CSP, 24-inch diameter CSP, and outlets twin 48-inch diameter RCP culvert crossings.	274
1202	Railroad Pedestrian Path	Structure HOC2 – multiple opening single span wood structure and wood deck, total span approx. 51-feet with twin 48-inch diameter RCP culverts.	274
1260	Culvert Crossing	Inlet location of twin 48-inch diameter RCP culverts.	274
1682	Rodeo Drive	Structure HOC3 – twin 4.33’ x 6.06’ CSPA culvert crossing.	274
2899	Fish Pond	Structure HOC4 – multiple opening single span concrete structure and wood deck with 24-inch diameter CSP culvert.	274
3565	B Avenue NW	Structure HOC5 – 3.58’ x 6’ CSPA and 2.75’ x 4.43’ CSPA culverts crossing.	274
4980	U.S. Highway 191	Structure HOC7 – 84-inch diameter CSP culvert crossing.	274
6390	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
7270	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
8170	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
9020	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
9061	Klock Road	Structure HOC9A and HOC9B – multiple opening 3.92’ x 6.02’ CSPA and 24-inch dimeter CSP culvert crossing.	274
9200	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
9800	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
10400	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
10700	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
10920	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
10973	Field Crossing	Structure HOC10 – 48-inch diameter CSP culvert crossing.	274
11015	Lateral Weir	Outflow - overtopping of abandoned railroad grade to Musselshell River.	274
11192	Field Crossing	Structure HOC 11 – 24-inch diameter CSP culvert crossing.	274
14675	Upstream Limit of Study	End of model reach – near Musselshell River station mile 43.0.	274

Table 10. Key Features along Antelope Creek Profile Baseline

River Station (feet)	Reach	Feature	Description	1% AC Discharge (cfs)
0	Antelope DS	Downstream Limit of Study	Beginning of model reach – confluence to Musselshell River station mile 38.2.	7,705
580		Flow Junction 1	Junction 1 – beginning of split flow along abandoned railroad grade.	7,705
1361	Antelope MID	Flow Junction 2	Junction 2 – convergence of Antelope Creek overflow split flow with Antelope Creek primary channel.	21,490
1804	Antelope US	Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	14,767
2100		Lateral Weir	Overtopping – 566-foot long lateral weir.	18,807
2258		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	18,807
2350		Lateral Weir	Overtopping – 239-foot long lateral weir.	19,607
2485		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	19,607
2600		Lateral Weir	Overtopping – 239-foot long lateral weir.	20,317
2775		Lateral Weir	Overtopping – 239-foot long lateral weir.	20,317
2899		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	20,317
3000		Lateral Weir	Overtopping – 249-foot long lateral weir.	20,420
3200		Lateral Weir	Overtopping – 337-foot long lateral weir.	20,420
3750		Lateral Weir	Overtopping – 104-foot long lateral weir.	20,420
4000		Lateral Weir	Overtopping – 213-foot long lateral weir.	20,420
4175		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	20,420
4300		Lateral Weir	Overtopping – 559-foot long lateral weir.	20,622
4501		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	20,622
4700		Lateral Weir	Overtopping – 405-foot long lateral weir.	20,769
4970		Flow Change Location	Outflow – overtopping site topography to Antelope Overflow.	20,769
5100		Lateral Weir	Overtopping – 612-foot long lateral weir.	21,490
5394		U.S. Highway 12	Structure AC4 – four span steel structure and concrete deck, total span approx. 204-feet.	21,490
13306		Flow Change Location	Alkali Creek – confluence with Antelope Creek.	21,490
20787		Upstream Limit of Study	End of model reach – 3.2 river-miles north of Harlowton.	18,800

Table 11. Key Features along Antelope Overflow Profile Baseline

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
0	Downstream Limit of Study	Beginning of model reach – Junction 2, convergence of Antelope Creek overflow split flow with Antelope Creek primary channel.	6,723
626	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	6,723
1001	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	2,683
1316	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	1,883
2608	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	1,173
3427	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	1,070
3696	Flow Change Location	Inflow – from overtopping site topography along Antelope Creek.	868
4074	Upstream limit of study	End of model reach – near U.S. Highway 12.	721

Table 12. Key Features along Abandoned Railroad Grade Split Profile Baseline

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
1000	Downstream Limit of Study	Beginning of model reach – Red Bridge road.	3,962
1050	Lateral Weir	Overtopping – 148-foot long lateral weir.	4,422
1136	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River	4,422
1300	Lateral Weir	Overtopping – 373-foot long lateral weir.	6,893
1505	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River.	6,893
1800	Lateral Weir	Overtopping – 496-foot long lateral weir.	9,503
2001	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River.	9,503
2200	Lateral Weir	Overtopping – 493-foot long lateral weir.	11,375
2497	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River.	11,375
2700	Lateral Weir	Overtopping – 475-foot long lateral weir.	12,509
2982	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River.	12,509
3250	Lateral Weir	Overtopping – 503-foot long lateral weir.	12,884
3700	Lateral Weir	Overtopping – 494-foot long lateral weir.	12,884
3978	Flow Change Location	Outflow - overtopping of abandoned railroad grade to Musselshell River.	12,884
4200	Lateral Weir	Overtopping – 526-foot long lateral weir.	13,785
4778	Flow Junction	End of model reach –Junction 1 split flow along abandoned railroad grade.	13,785

4.4 Boundary Conditions

To perform the hydraulic analysis, HEC-RAS requires boundary condition input data at the first downstream cross section of the model reach. Per FEMA Guidelines and Specifications, Appendix C (FEMA, 2009), the downstream boundary condition in a one-dimensional, steady flow, step-backwater model should be taken from a previously established water-surface elevation, if available. The boundary condition established water-surface elevation for Wheatland County, MT Reach 3 was taken from the upstream Musselshell River model reach of Golden Valley County, MT as part of the Mapping Activity Statement (MAS 2015-02) for the Musselshell Watershed Project, Phase II. The normal depth energy slopes of 0.002349 ft/ft (0.23%) is representative of the boundary condition flood profile slope for Reach 10. This boundary conditions was determined for the river approximately 1,700 feet downstream of the Reach 10 study limits.

A summary of the boundary condition established for each model segment for Wheatland County, MT is provided in Table 13.

Table 13. Boundary Condition Summary

Segment	Watershed	Boundary Condition Source
Reach 3	Musselshell River	WSELs Musselshell River Reach 2
Reach 9		WSELs Musselshell River Reach 3
Reach 4	Antelope Creek	WSELs Antelope Creek Reach 10
Reach 10		Normal Depth Slope = 0.002349 ft/ft

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. End points for all cross sections were established as required 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.

The LiDAR elevation data for the limited detail study Reach 3 of the Musselshell River did not include bathymetry below the water surface. However, the LiDAR data represents the water surface elevation of the river at the time the data was obtained. A rectangular low-flow channel was inserted in the model 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 +/- 0.5 feet of the observed LiDAR elevation.

The detailed study Reaches 9 and 10 include stream channel bathymetry survey 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

A field reconnaissance and hydraulic structure assessment for the Musselshell River limited detail study Reach 3 was performed by Pioneer Technical Services, Inc. in 2015 (Pioneer, 2015a). The geometries of hydraulic structures were modeled with the data obtained from the structures assessment. Thirty bridge and twenty diversion structures exist within the study limits. The structures range from abandoned railroad bridges to structures on county and private roadways. Diversion structures deliver water to irrigation districts or private water user associations. One bridge crossing remains from the historic Milwaukee Road Railroad which was decommissioned in the 1970's.

The field survey for hydraulic structures for the Musselshell River detail study Reach 9 was completed by Morrison-Maierle, Inc. in 2015. The survey included hydraulic structures located along the Harlowton Overflow Channel.

The geometry for the hydraulic structures were modeled with the data obtained from the structure assessment and field survey. The expansion and contraction coefficients of the two upstream cross sections along with the one downstream cross sections at the bridge constrictions were increased from the natural channel value of 0.1 and 0.3, to 0.3 and 0.5, 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 configuration. The high flow methods consist of either the Energy (Standard Step) or Pressure/Weir flow. The Energy method is the standard step calculation method and is utilized when the bridge low chord has freeboard and/or if the road approaching the bridge is lower and the bridge is perched above the approach road. The Pressure/Weir flow method is the high flow method that is used when flood waters impact and/or overtop the bridge structure.

The low flow methods include either the Energy, Momentum or Yarnell methodologies. The energy method is utilized if the bridge is a clear span structure with no piers. The Momentum Balance and Yarnell equation methods are used if the structure is constructed with mid-span piers. The Momentum and Yarnell methods are low flow methods to account for the hydraulic losses due to water moving around the piers. The momentum method requires an input for the Drag Coefficient (CD), and the Yarnell equation using a K Coefficient based on the pier shape.

Most of the pier shapes for the bridge structures consist of circular piers, twin-cylinder piers with or without connecting diaphragms, elongated piers with semi-circular ends, square or triangular nose, and ten pile trestle bents. The CD and K coefficients used for the different pier shapes are summarized in Table 14.

Table 14. Pier CD and K Coefficients

No.	Pier Shape	Acronym	C_D	K
1	Circular Piers	CP	1.20	1.05
2	Cylinder Piers with Connecting Diaphragm	CPWD	1.33	0.95
3	Cylinder Piers without Connecting Diaphragm	CPWOD	1.60	1.05
4	Elongated Piers with Semi-Circular Ends	EPSCE	1.33	0.90
5	Square Nose	SQNS	2.00	1.25
6	Triangular Nose with 90° Angle	TN90	1.33	1.05
7	Ten Pile Trestle Bent	TPTB	1.20	2.50

A summary of the bridge structures and hydraulic model settings for each structure are summarized in Tables 15 and 16, respectively. A summary of the culvert crossings on the Harlowton Overflow Channel are listed in Table 17. Photographs 1 thru 5 are of representative highway, county road and abandoned railroad bridge structures. Photographs of all the modeled bridge structures and culvert crossings are provided in Appendix C.

Photograph 1: Shawmut Road Bridge B37 with Triangular Nose with 90° Angle Piers.

Photograph 2: MT Highway 191 Bridge B45 with Triangular Nose with 90° Angle Piers.

Photograph 3: Red Bridge Road Clear Span Bridge B44 with No Piers.

Photograph 4: Abandoned Railroad Bridge B47 with Triangular Nose with 90° Angle Pier.

Photograph 5: Muir Road Bridge B48 with Ten Pile Trestle Bent Pier.

Table 15. Summary of Bridge Structures

ID No.	Roadway	River Reach	River Station	Spans	Total Span (feet)	Deck Width (feet)	Deck Thickness (feet)	Pier Width (feet)	Appendix C Photo Pages
B35	Private Road	3	21723	1	83	12	3.6	–	1, 2, 3
B36	OK Bar Road		25737	1	91	15	2.7	–	4, 5, 6
B37	Shawmut Road		53373	2	132	22	3.3	2	7, 8, 9
B38	Private Road		70744	1	81	16	3.2	–	10, 11, 12
B39	Private Road		80127	2	84	16.2	2	1	13, 14, 15
B40	Winne-Cook Lane		122094	1	105	19.5	1.9	–	16, 17, 18
B41	Private Road		145433	2	108	16	1.5	4	19, 20, 21
B42	Tierney Loop Road		166934	3	149	28	3	2.5	22, 23, 24
B43*	Private Road		181893	1	63	14	1.7	–	25, 26, 27
B44	Red Bridge Road	9	196779	1	110	28.4	5.2	–	28, 29, 30
B45	U.S. Highway 191		212976	2	173	45.8	5	3	31, 32, 33
B46	Klock Road		218526	4	106	13	2.3	1	34, 35, 36
B47	Abandoned Railroad Grade		226366	2	128	10	4	6	37, 38, 39
B48	Muir Lane		228402	3	91	16	1.8	1	40, 41, 42
HOC2**	Railroad Pedestrian Path	HOC	1202	1	50	10	1.4	–	47, 48, 49, 50
HOC4**	Fish Pond Crossing		2899	1	3.7	7.5	0.5	–	54, 55, 56, 57
AC2	Logan Street SE	10	2868	2	37	18	2.7	1.7	76, 77, 78
AC4	U.S. Highway 12		5394	4	204	33	3.6	3.5	79, 80, 81

* Bridge structure not included in hydraulic model due to parallel alignment to flood flows and limited hydraulic backwater conditions.
** HOC – Harlowton Overflow Channel

Table 16. Summary of Bridge Model Settings

ID No.	Roadway	River Reach	River Station	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
B35	Private Road	3	21723	0.3	0.5	Energy	Pressure/Weir
B36	OK Bar Road		25737	0.3	0.5	Energy	Pressure/Weir
B37	Shawmut Road		53373	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
B38	Private Road		70744	0.3	0.5	Energy	Pressure/Weir
B39	Private Road		80127	0.3	0.5	Energy, Momentum, Yarnell	Energy
B40	Winnecook Lane		122094	0.3	0.5	Energy	Pressure/Weir
B41	Private Road		145433	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
B42	Tierney Loop Road		166934	0.3	0.5	Energy, Momentum, Yarnell	Energy
B43*	Private Road		181893	Not modeled*			
B44	Red Bridge Road	9	196779	0.3	0.5	Energy	Energy
B45	U.S. Highway 191 N		212976	0.3	0.5	Energy, Momentum, Yarnell	Energy
B46	Klock Road		218526	0.3	0.5	Energy, Momentum, Yarnell	Energy
B47	Abandoned Railroad Grade		226366	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
B48	Muir Lane		228402	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
HOC2**	Railroad Pedestrian Path	HOC	1202	0.3	0.5	Energy, Momentum	Pressure/Weir
HOC4**	Fish Pond Crossing		2899	0.3	0.5	Energy	Pressure/Weir
AC2	Logan Street SE	10	2868	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
AC4	U.S. Highway 12		5394	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir

* Bridge structure not included in hydraulic model due to parallel alignment to flood flows and limited hydraulic backwater conditions.
** HOC – Harlowton Overflow Channel

Table 17. Summary of Culvert Crossings

ID No.	Roadway	River Reach	River Station	Culvert Length (feet)	Culvert Type	Culvert Shape	Culvert Size (feet)	Appendix C Photo Pages
HOC1	Abandoned Railroad Grade	Harlowton Overflow Channel	1028	39	RCP	Twin Round	4	43, 44, 45, 46
				39	CSP	Round	3.5	
				39	CSP	Round	2	
–	Twin 48” Dia. RCP		1120	132	RCP	Twin Round	4	–
HOC2	Railroad Pedestrian Path		1202	30	RCP	Twin Round	4	47, 48, 49, 50
–	Twin 48” Dia. RCP		1260	67	RCP	Twin Round	4	–
HOC3	Rodeo Drive		1682	34	CSPA	Twin Arch	4.3 x 6.1	51, 52, 53
HOC4	Fish Pond Crossing		2899	23	CSP	Round	2	54, 55, 56, 57
HOC5	B Avenue NW		3565	77	CSPA	Arch	3.6 x 5.9	58, 59, 60
				77	CSPA	Arch	2.8 x 4.4	
HOC7	U.S. Highway 191		4980	195	CSP	Round	7	61, 62, 63
HOC9A	Klock Road		9061	33	CSPA	Arch	3.9 x 6.0	64, 65, 66
HOC9B	Klock Road			21	CSP	Round	2	67, 68, 69
HOC10	Private Field Crossing		10973	25	CSP	Round	4	70, 71, 72
HOC11	Private Field Crossing		11192	21	CSP	Round	2	73, 74, 75

The study reach includes eleven diversion structures used to create a backwater condition and two headgate structures with the purpose of diverting Musselshell River flow into adjacent irrigation canals. The diversion structures were modeled with the placement of one cross section at the location that represents the crest of the diversion and the second cross section downstream where the river channel returns to a normal depth and natural channel cross section. Table 18 is a summary of the diversion and headgate structures located along the Musselshell River in Wheatland County, MT. Photographs 6 and 7 are examples of concrete and rock diversions. Photographs of all the modeled diversion structures are provided in Appendix C.

Table 18. Summary of Diversion Structures

ID No.	River Reach	River Station	Type	Material	Condition	Span (feet)	Appendix C Photo Pages
D17 *	3		Headgate	Concrete	–	0	82, 83
D18			Diversion	Concrete	Good	96	84, 85
D19 *			Headgate	Concrete	–	0	–
D20 **			Diversion	Rock	Poor	0	86, 87
D21			Diversion	Concrete	Fair	65	88, 89
D22			Diversion	Rock	Good	81	90, 91
D23			Diversion	Rock	Good	106	92, 93
D24			Diversion	Rock	Good	105	94, 95
D24A			Diversion	Rock	Good	54	96, 97
D25			Diversion	Rock	Good	93	98, 99
D26	9		Diversion	Rock	Good	95	100, 101
D26A			Diversion	Concrete	Good	126	102, 103
D27			Diversion	Rock	Good	77	104, 105

* Headgate bank structure not included in hydraulic model.
** Diversion structure no longer exists.

Photograph 6: Diversion D18 Concrete Structure.

Photograph 7: Diversion D25 Rock Structure.

4.7 Manning's 'n' Values

Manning's 'n' values are roughness coefficients representing the frictional resistance acting on water 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' values 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 cross-sections in the model.

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. Higher Manning's 'n' values of up to 0.23 were necessary due to critical depths calculated with the model due to large flows, steep terrain, and terrain variability. 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 19.

Table 19: Manning's 'n' Values

Roughness Area Land Class Type	Manning's 'n' Value	Description
Main Channel *	0.039 – 0.230	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 – 0.080	Heavy willow and cottonwood growth
Medium Dense Trees	0.080 – 0.150	Stands of timber, few down trees

* Manning's 'n' value set lower or higher at some cross sections to produce higher friction losses required to bring flow regime above critical depth.

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. This conditions provide limited or non-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.

The areas of non-conveyance included the following:

- Backwater and ponded areas.
- Flow constriction or expansion.
- Areas isolated by non-accredited levees, railroad embankments or elevated roads.
- High topography either upstream or downstream that eliminates flow in a lower area.

Isolated depression areas in locations of Reach 3 of the Musselshell River and just upstream of Logan Street in Reach 10 of Antelope Creek were classified as blocked areas since there would be non-conveyance in the downstream direction.

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 in a stream wise to lateral direction using a 1:1 (upstream) and a 4:1 (downstream) 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).

4.9 Model Calibration

The model calibration for Reaches 3 and 9 of the Musselshell River was completed by comparing model output with aerial photography taken by the Montana Department of Transportation (MDT) during the high water event which occurred in on May 2011. The peak flow rate of 5,520 cfs was recorded at USGS gage 06120500 Musselshell River at Harlowton, MT on May 25, 2011. A comparison of the 1% annual-chance water surface elevations (WSE's) from the HEC-RAS model were directly 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 3 model ranged from minimum of 0.0-feet to a maximum of 1.0-feet. The differences in Reach 9 model, ranged from minimum of 0.2-feet to a maximum of 0.9-feet.

The calibration for Reaches 4 and 10 of Antelope Creek was completed with historic flooding records obtained by the USGS during the June 1950 flood of record. The records from the USGS 1950 survey included:

- Cross sections at the U.S. Highway 12 bridge face and at an upstream approach section.
- High water profiles along both the left and right bank from above the approach section to below the structure.
- A plan view sketch of the surveyed points.
- Photographs of the bridge structure.

A HEC-RAS hydraulic model was created for calibration that matched the post 1950 ground conditions based on the USGS records. The model was developed as a means to calibrate the Reaches 4 and 10 of the Antelope Creek model. The mixed flow regime option in HEC-RAS is required for the modeling of Reaches 4 and 10, due to the steep channel gradient and significant magnitude of the Antelope Creek flood flows. Segments of the model go into a supercritical flow regime where critical depth flow occurs due to the extreme hydraulic conditions of Antelope Creek.

By utilizing the HEC-RAS mixed flow regime option, the differences in the 1950 flood event measurements by the USGS to the HEC-RAS model ranged from minimum of 0.1-feet at the U.S. Highway 12 Bridge to 0.9 to1.5-feet at the upstream approach cross section.

Based on the differences in Tables 20, 21, and 22, the HEC-RAS modeling is reasonably calibrated for the purposes of the Wheatland County floodplain study by the comparison to water surfaces elevations and depths from a known high water event.

Table 20. Musselshell River Reach 3 Model Calibration

River Station	Approx. WSE 5/26/2011 Aerial Photo (feet)	Modeled WSE (feet)	Difference (feet)
4324	3746.5	3746.6	0.1
11523	3758.0	3757.7	0.3
50015	3842.0	3842.2	0.2
51022	3845.0	3844.0	1.0
55329	3853.0	3853.4	0.4
93314	3925.0	3925.0	0.0
96340	3932.8	3932.6	0.1
97573	3934.0	3934.7	0.7
98592	3939.0	3938.8	0.2
130315	4005.5	4005.5	0.0
132828	4011.0	4010.9	0.1
139316	4022.0	4022.1	0.1
140207	4023.0	4023.2	0.2
141390	4025.3	4024.8	0.5
145214	4032.8	4033.1	0.3
183143	4109.0	4109.2	0.2
190430	4119.0	4119.4	0.4
193709	4124.0	4124.1	0.1
194664	4127.0	4127.6	0.6

Table 21. Musselshell Reach 9 Model Calibration

River Station	Approx. WSE 5/26/2011 Aerial Photo (feet)	Modeled WSE (feet)	Difference (feet)
195296	4,128	4,128.8	0.8
195945	4,131	4,130.6	0.6
197464	4,138	4,138.2	0.2
200092	4,143	4,143.9	0.9
207579	4,160	4,159.5	0.5
211011	4,169	4,168.8	0.2
216374	4,186	4,185.5	0.5
224628	4,205	4,205.4	0.4
236748	4,238	4,238.3	0.3
239663	4,244	4,244.2	0.2

Table 22. Antelope Creek Reaches 4 and 10 Model Calibration

Location	1950 Flood Depth (feet)	Modeled Depth (feet)	Difference (feet)
U.S. Hwy 12 Bridge	16.4	16.3	0.1
Upstream Cross Section	17.7	18.6 – 19.2	0.9 – 1.5

4.10 Split Flow Analysis

As discussed in Section 1.0 of the report and shown on Figure 2, the Harlowton Overflow Channel is a spit flow conveyance of the Musselshell River floodplain. Antelope Creek has a two split flow segments, one within the town of Harlowton and the second along the abandoned railroad grade. Junctions and lateral weirs were defined to model the flow split and the secondary flow path that would be created. Utilizing the flow optimization option within HEC-RAS, the discharge split across the junction and lateral weirs was calculated ensuring that conservation of mass was balanced across the system while also balancing the energy equation. Lateral weirs were specified as a broad crested weir and utilized a weir coefficient ranging from 0.5 to 2.0. In general, lateral weir coefficients should be lower than typical values used for inline weirs. The lower weir coefficients value is due to the energy/momentum loss associated with flow lines turning from their downstream orientation to a lateral direction out of the river/reach (RAS Solution 2013). The discharge determined over each weir was calculated using the flow optimization option within HEC-RAS.

4.10.1 Harlowton Overflow Channel

The HEC-RAS lateral weir option was used to determine the flows that would be discharged to the Harlowton Overflow Channel. With the development of the Musselshell River Reach 9 hydraulic model and review of the initial results, locations were identified in which discharge overflowed the left bank of the channel or via the diversion structure D26A. The

resultant overflow, as shown on Figure 2, would be directed to the Harlowton Overflow Channel upstream of the abandoned railroad bridge structure B47.

Lateral weirs along the abandoned railroad embankment were specified as a broad crested weir and utilized a weir coefficient of 1.8 and returned flows back to the Musselshell River channel. The resultant peak annual chance discharges for the Harlowton Overflow Channel are listed in Table 23 for the lateral weir locations shown on Figures 5 and 6.

4.10.2 Antelope Creek

With the development of the hydraulic model and review of the initial results, it was determined that Reach 10 of Antelope Creek has two split flow segments. The first split, as shown on Figure 2, is within the town of Harlowton and is produced by the overtopping of site topography to the west for approximately 3,340-feet of channel distance before rejoining with the Antelope Creek channel upstream the confluence of the Musselshell River. The second split would occur north of the abandoned railroad grade with the overtopping of the east bank and flows would be conveyed away from the primary channel to the east along the abandoned railroad grade to Red Bridge road.

The HEC-RAS optimization option was used at flow Junction 1 to determine the flow rates that would be conveyed along the abandoned railroad grade to Red Bridge road. Lateral weirs along the abandoned railroad embankment were specified as a broad crested weir and utilized a weir coefficient of 1.8 and discharge flows to the Musselshell River channel. The resultant peak annual chance discharges for the Antelope Creek railroad split are listed in Table 24 for the lateral weir locations shown on Figure 7.

Table 23. Reach 9 Split Flow Peak Discharges

Musselshell River Watershed Project - Phase II
Mapping Activity Statement: No. 2015-02
Reach 9 Split Flow Data Summary Map
Plan: Reach 9 MultipleProfile

Recurrance Interval		Musselshell Reach 9 River Station																		
		239663	228203	227632	227116	226516	226421	226398	221123	220617	220101	219489	219064	218658	218498	216930	215816	214141	213078	212531
Flow Rate (cfs)	10% AC	2522	2,595	2,595	2,595	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,527	2,542
	4% AC	3617	3,742	3,742	3,742	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,608	3,634
	2% AC	4552	4,722	4,722	4,722	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,530	4,564
	1% AC	5586	5,804	5,804	5,804	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,530	5,574
	0.2% AC	8407	8,747	8,709	8,504	7,916	7,938	7,940	7,941	7,948	7,965	7,981	8,002	8,022	8,042	8,074	8,096	8,132	8,195	8,264

Recurrance Interval		Harlowton Overflow Channel River Station													
		14675	14406	10995	10890	10650	10186	9981	9614	9213	9087	8304	7491	6549	5083
Flow Rate (cfs)	10% AC	68	68	68	68	68	68	68	68	68	68	68	68	68	68
	4% AC	134	134	134	134	134	134	134	134	134	134	134	134	134	134
	2% AC	192	192	192	192	192	192	192	192	192	192	192	192	192	192
	1% AC	274	274	274	274	274	274	274	274	274	274	274	274	274	274
	0.2% AC	830	806	806	805	798	781	765	744	724	704	672	650	614	551

Lateral Weir Flow Data Summary Table

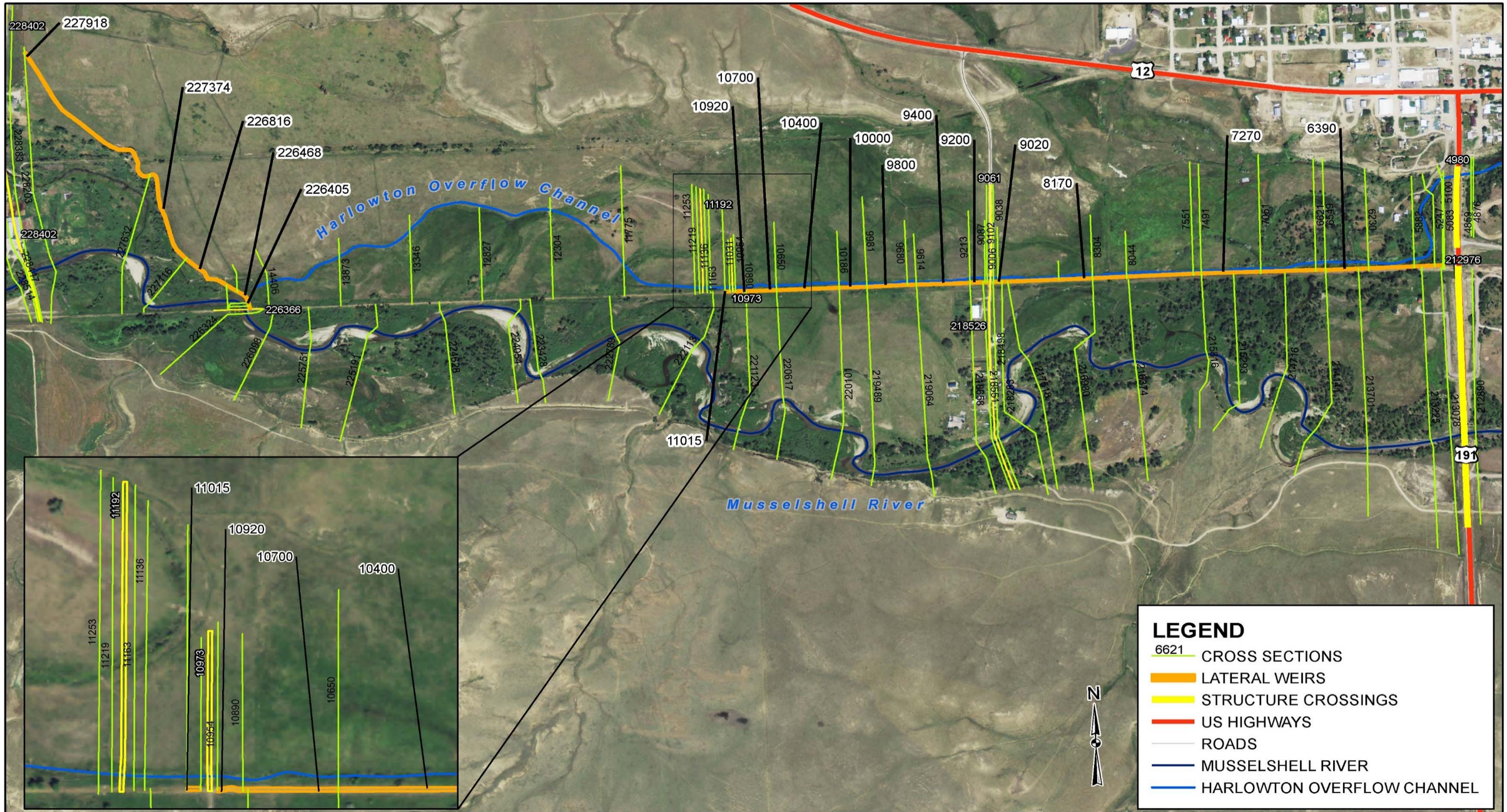
Recurrance Interval		Musselshell Reach 9 River Station					Harlowton Overflow Channel River Station											
		227918	227374	226816	226468	226405	11015	10920	10700	10400	10000	9800	9400	9200	9020	8170	7270	6390
Flow Rate (cfs)	10% AC	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4% AC	0	0	134	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2% AC	0	0	192	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1% AC	0	0	274	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.2% AC	38	205	588	-22	-2	0	1	7	17	16	21	20	20	32	22	36	63

Optimization Editor Data Format

River	Reach	River Station	50% AC	10% AC	4% AC	2% AC	1% AC	0.2% AC
HOC	HOC	11015	0	0	0	0	0	0
HOC	HOC	10920	0	0	0	0	0	1
HOC	HOC	10700	0	0	0	0	0	7
HOC	HOC	10400	0	0	0	0	0	17
HOC	HOC	10000	0	0	0	0	0	16
HOC	HOC	9800	0	0	0	0	0	21
HOC	HOC	9400	0	0	0	0	0	20
HOC	HOC	9200	0	0	0	0	0	20
HOC	HOC	9020	0	0	0	0	0	32
HOC	HOC	8170	0	0	0	0	0	22
HOC	HOC	7270	0	0	0	0	0	36
HOC	HOC	6390	0	0	0	0	0	63
Musselshell	R9B	227918	0	0	0	0	0	38
Musselshell	R9B	227374	0	0	0	0	0	205
Musselshell	R9B	226816	1	68	134	192	274	588
Musselshell	R9B	226468	0	0	0	0	0	-22
Musselshell	R9B	226405	0	0	0	0	0	-2

Junction 3 Calibration

Recurrance Interval	MSLSHEL XS209865	HARLOTON XS1004	Difference
10% AC	4164.93	4164.85	0.1
4% AC	4165.42	4165.29	0.1
2% AC	4165.74	4165.57	0.2
1% AC	4166.04	4165.84	0.2
0.2% AC	4166.7	4166.47	0.2



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APPR. BY: MAF
DATE: 06/07/16

Harlowton Overflow Channel MT

Split Flow Profile Baseline

PROJECT NO. 1447.041

FIG. 5

0 175 350 Feet

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Harlowton Overflow Channel MT

Split Flow Profile Baseline

PROJECT NO. 1447.041

FIG. 6

Table 24. Reach 10 Split Flow Peak Discharges

Musselshell River Watershed Project - Phase II
Mapping Activity Statement: No. 2015-02
Reach 10 Split Flow Data Summary Map
Plan: Reach 10 MultipleProfile

Recurrance Interval		Antelope Creek Upstream River Station													AntelopeCr-MID RS	AntelopeCr-DS RS
		20787	13306	4970	4501	4175	3887	3388	3132	2899	2716	2486	2257	1804	1361	580
Flow Rate (cfs)	10% AC	1290	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,520	1,435	1,520	879
	4% AC	4230	4,920	4,920	4,920	4,920	4,920	4,920	4,920	4,920	4,920	4,920	4,920	4,055	4,920	2,012
	2% AC	9230	10,640	10,484	10,484	10,484	10,484	10,484	10,484	10,484	10,484	10,415	10,230	8,135	10,640	3,778
	1% AC	18800	21,490	20,769	20,622	20,420	20,420	20,420	20,420	20,317	20,317	19,607	18,807	14,767	21,490	7,705
	0.2% AC	81310	91,550	84,480	78,360	71,200	69,270	68,323	66,117	63,477	63,227	59,407	55,972	46,157	91,550	45,798

Recurrance Interval		Antelope Creek Overflow Rver Station											Railroad Split River Station								
		4074	3696	3427	3216	3140	2894	2608	1701	1316	1001	626	4506	3978	3485	2982	2497	2001	1505	1136	1000
Flow Rate (cfs)	10% AC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	85.1	641	641	641	641	641	641	641	581	576
	4% AC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	865.1	2,908	2,907	2,907	2,907	2,907	2,769	2,106	1,509	1,414
	2% AC	156	156	156	156	156	156	156	156	225	410	2,505	6,862	6,721	6,721	6,721	6,705	6,155	4,156	2,749	2,489
	1% AC	721	868	1,070	1,070	1,070	1,070	1,173	1,173	1,883	2,683	6,723	13,785	12,884	12,884	12,509	11,375	9,503	6,893	4,422	3,962
	0.2% AC	7,070	13,190	20,350	22,280	23,227	25,433	28,073	28,323	32,143	35,578	45,393	45,752	37,226	32,170	26,710	21,427	16,347	11,419	7,563	6,776

Lateral Weir Flow Data Summary Table

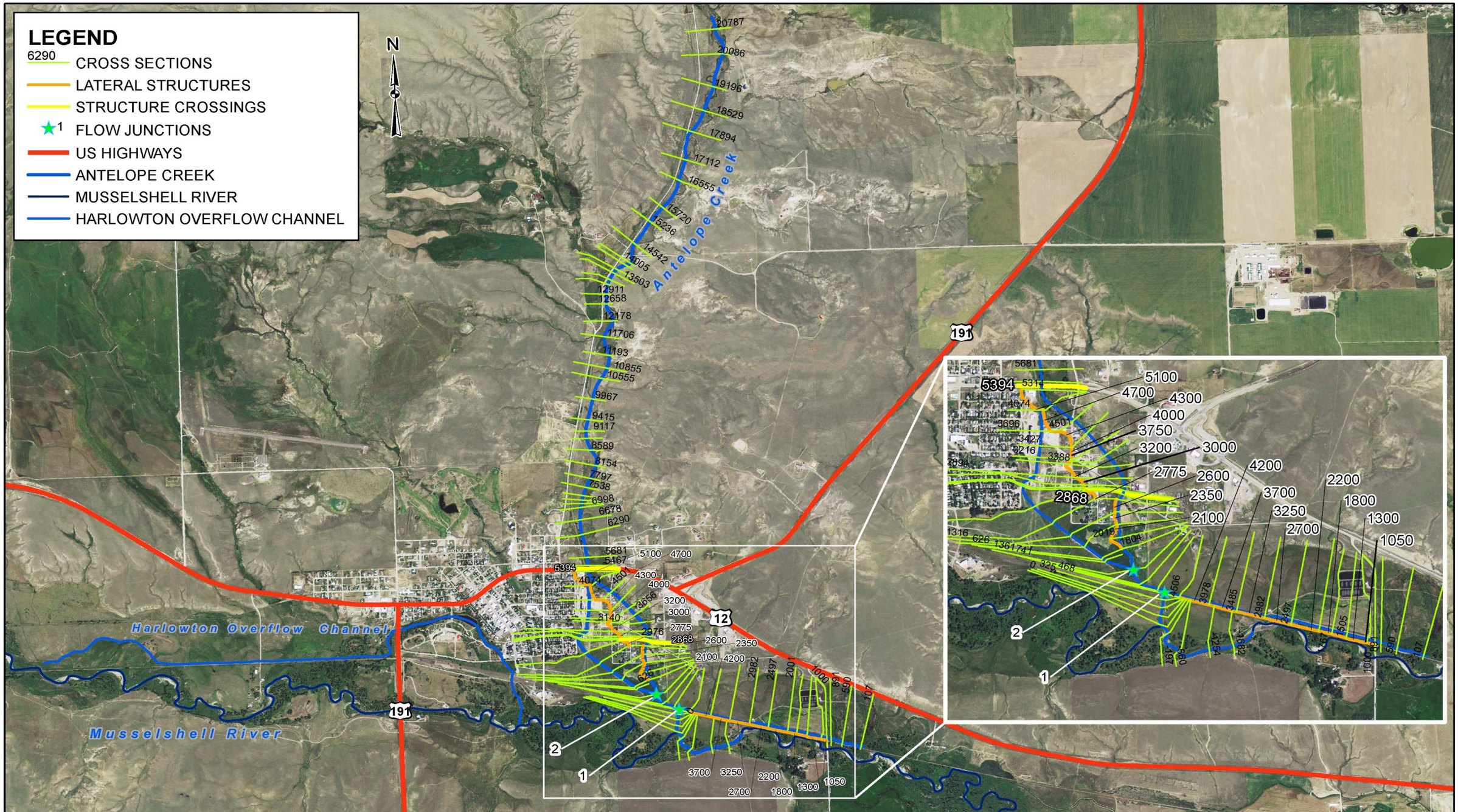
Recurrance Interval		Antelope Creek River Station											Railroad Split River Station							
		5100	4700	4300	4000	3750	3200	3000	2775	2600	2350	2100	4200	3700	3250	2700	2200	1800	1300	1050
Flow Rate (cfs)	10% AC	0.1	0.0	0	0	0	0	0	0	0	0	85	0.0	0	0	0	0	0	60	5
	4% AC	0.1	0.0	0	0	0	0	0	0	0	0	865	1.0	0	0	0	138	663	597	95
	2% AC	156	0.0	0	0	0	0	0	0	69	185	2095	141	0	0	16	550	1999	1407	260
	1% AC	721	147	202	0	0	0	103	0	710	800	4040	901	0	375	1134	1872	2610	2471	460
	0.2% AC	7070	6120	7160	1930	947	2206	2640	250	3820	3435	9815	8526	5056	5460	5283	5080	4928	3856	787

Lateral Weir Optimization Editor Data Format

River	Reach	River Station	10% AC	4% AC	2% AC	1% AC	0.2% AC
AC	AC-US	5100	0	0	156	721	7070
AC	AC-US	4700	0	0	0	147	6120
AC	AC-US	4300	0	0	0	202	7160
AC	AC-US	4000	0	0	0	0	1930
AC	AC-US	3750	0	0	0	0	947
AC	AC-US	3200	0	0	0	0	2206
AC	AC-US	3000	0	0	0	103	2640
AC	AC-US	2775	0	0	0	0	250
AC	AC-US	2600	0	0	69	710	3820
AC	AC-US	2350	0	0	185	800	3435
AC	AC-US	2100	85	865	2095	4040	9815
RR Split	RR Split	4200	0	1	141	901	8526
RR Split	RR Split	3700	0	0	0	0	5056
RR Split	RR Split	3250	0	0	0	375	5460
RR Split	RR Split	2700	0	0	16	1134	5283
RR Split	RR Split	2200	0	138	550	1872	5080
RR Split	RR Split	1800	0	663	1999	2610	4928
RR Split	RR Split	1300	60	597	1407	2471	3856
RR Split	RR Split	1050	5	95	260	460	787

Junction Optimization

J2
641.1
2907.7
6862.3
13785.1
45752.3



0 1,150 2,300 Feet

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Antelope Creek MT

Split Flow Profile Baseline

PROJECT NO. 1447.041

FIG. 7

4.11 Floodways

Floodways were computed for detailed study Reach 9 of the Musselshell River and Reach 10 of Antelope Creek 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).

It is not technically possible to have a full 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. The floodway modeling may produce a surcharge at an upstream 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 because of the effect that a greater encroachment at these locations would have on adjacent cross sections.

Determination of whether separate regulatory floodways were to be completed for the split flow reaches was verified in accordance with FEMA Guidelines and Specifications, Appendix C (FEMA, 2009). This protocol includes calculating the water-surface elevations for the total flow in the main channel and comparing the water-surface elevations with the reduced flow rate due to divergence to the split flow reaches. If the difference in water-surface elevations is greater than the 0.5 foot maximum regulatory surcharge, then a separate regulatory floodway is to be delineated for the split flow channels of the main stream. This was completed on the Harlowton Overflow Channel and the differences in WSE's was on the order of 0.1 to 0.3 feet. The Antelope Creek Overflow difference in WSE's was greater than 0.5 feet. Therefore, the floodways for the split flow reaches of Reach 9 of the Musselshell River were not determined and only the identified 1% and 0.2% annual chance floodplain delineations are included on the hydraulic work maps. The floodway for Reach 10 of Antelope Creek was determined and is included on the hydraulic work maps.

4.12 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 Wheatland County, Montana reach of the Musselshell River and Antelope Creek 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 products for end users that are described in the following sections.

5.1 Hydraulic 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 structures under existing conditions are presented on the work maps. Zone AE delineation is the floodplain delineated for Reaches 3 and 9 of the Musselshell River and Reaches 4 and 10 of Antelope Creek. A portion of the Antelope Creek Overflow downstream of Logan Street SE has been delineated Zone AO to account for flows overtopping the primary channel and sheet-flowing to the overflow channel. The Antelope Creek floodplain has been delineated in accordance to the modeling as discussed in Section 4.0 of the report.

Typically, islands that were determined to be higher than the adjacent 1% annual-chance water surface profile and less than one-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 flood event backwater elevations and the corresponding profile baseline station is included in Table 25 below.

Table 25. Backwater Elevation Summary

River Station	River Reach	1% AC	0.2% AC	County
14855	3	3763.3	-	Wheatland
17603	↓	3766.3	3768.5	Wheatland
17263		3766.3	3768.5	Wheatland
19269		-	3768.5	Wheatland
20376		3770.5	3771.4	Wheatland
21251		3771.8	-	Wheatland
232654	9	4230.0	-	Wheatland
235738		4236.0	4237.6	Wheatland
3490	HOC	4172.4	4173.1	Wheatland
7051		4178.3	-	Wheatland

The floodplain and floodway delineations at residential structure locations are based on local topographic grading and associated Base Flood Elevations (BFE's).

5.2 Map Tie-In Locations

There is one map tie-in location for the updated Zone AE floodplain of the Musselshell River. This is the confluence of the American Creek at river station 161024. This tributary to the Musselshell River has an effective Zone A floodplain. The effective floodplain has been copied onto the work map since no modeling or updated mapping was completed for American Creek. The proposed tie-in transition to the digitized effective floodplain mapping is shown on the hydraulic work map 10 of 16 (Appendix A).

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, and better represent current conditions in the area. The sections below describe and present select output illustrating these Changes Since Last FIRM (CSLF).

5.4 One-Percent Annual Chance (SFHA) Boundary

A very useful set of output from the proposed floodplain mapping for Wheatland County along the Musselshell River are a series of work maps that visually represent areas of the SFHA that have changed under the proposed hydraulic analysis and mapping. This information can be used by community officials and Wheatland County staff to assess the implications of the changes, aid in outreach and education, provide information for planning and mitigation activities, communicate updated flood risk to residents, and other uses. The CSLF work maps for the one-percent annual chance boundary are provided in Appendix G.

5.5 Letters of Map Change

There are no effective Letters of Map Change (LOMC) for the Musselshell River and Antelope Creek in Wheatland County, MT.

5.6 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.

5.7 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 3 Musselshell River
- Reach 4 Antelope Creek
- Reach 9 Musselshell River
- Reach 10 Antelope Creek

Appendix B – Profiles

- Reach 3 Musselshell River
- Reach 4 Antelope Creek
- Reach 9 Musselshell River
- Reach 10 Antelope Creek

Appendix C – Structure Photographs

Appendix D – Floodway Data Tables

- Reach 9 Musselshell River
- Reach 10 Antelope Creek

Appendix E – cHECk-RAS Checklists

- Reach 3 Musselshell River
- Reach 4 Antelope Creek
- Reach 9 Musselshell River
- Reach 10 Antelope Creek

Appendix F – QA/QC Checklists

- Reach 3 Musselshell River
- Reach 4 Antelope Creek
- Reach 9 Musselshell River
- Reach 10 Antelope Creek

Appendix G – CSLF