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Musselshell River Floodplain Study – Phase 1

Musselshell River Hydrologic Analysis

Montana DNRC

May 1, 2015

Pioneer Technical Services, Inc. 106 Pronghorn Trail, Bozeman Montana 59718

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Phase 1 Musselshell River Floodplain Study

Musselshell River Hydrologic Analysis

Prepared for:

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May 1, 2015

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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EXECUTIVE SUMMARY

Flood flow frequency calculations were conducted for a 325-mile reach of the mainstem Musselshell River. The study reach extends from the confluence of the north and south forks of the Musselshell River near Martinsdale, to the intersection of the Musselshell River with the Charles M. Russell Wildlife Refuge Area. Information gathered from this analysis will be used for future floodplain studies and mapping projects.

The Musselshell River is located east of the Continental Divide in central Montana and originates in the Castle, Little Belt, and Crazy Mountains. The study watershed basin from the headwaters to the boundary of the Charles M. Russell Wildlife Refuge Area is approximately 8,651 square miles. The basin terrain varies from a high alpine environment in its headwaters to a prairie landscape in the eastern reaches. 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 farming and ranching operations.

The primary cause of flooding on the Musselshell River is spring snowmelt and runoff from intense rainfall events. There are historical records from several U.S. Geological Survey (USGS) stream gages on the river that date back to 1909, documenting basin flood history. In 2011 and 2014, significant flooding occurred in the Musselshell River basin, significantly exceeding previous peak floods of record in some areas.

Previous flood studies on the Musselshell River are limited and most of the mainstem Musselshell River has no flood hazard mapping. The most relevant earlier flood studies were the City of Harlowton in Wheatland County 1981 Flood Insurance Study (FIS) (FEMA, 1981a) and the Town of Lavina in Golden County 1981 FIS (FEMA, 1981b). The USGS Report *Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998*, (Parrett and Johnson, 2004) was also an important study, which included flood frequency analysis for the Musselshell River.

Flood flow frequency analysis was conducted to develop peak flow discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance events. Peak flow estimates were calculated at 49 mainstem locations (flow nodes) within the watershed (8 gaged sites and 41 ungaged sites). Estimates at the gaged sites were conducted using Bulletin #17B methodologies. At the ungaged sites, peak flow estimates were calculated using the Two Station Logarithmic Interpolation method and the Drainage Area Transfer method. These methods conform to standard engineering practice.

Flood flow frequency results from this study were compared with flood flow frequency estimates from the previous studies. In the upper Musselshell River watershed, flood frequency estimates from this study compared well with previous studies. In the middle and lower reaches of the Musselshell River, the flood flow frequency estimates from this study produced significantly higher peak discharge estimates compared with earlier studies. These significant differences in

the middle and lower Musselshell watershed reaches can be attributed to the large floods which occurred in 2011 and 2014.

In the upper Musselshell basin, the 2011 and 2014 floods were not as large and consequently did not significantly alter 2014 flood frequency estimates compared with previous studies.

The hydrologic analysis documented in this report conforms to FEMA standards for detailed/enhanced level studies, and the recommended flows of this analysis are deemed reliable and suitable for future floodplain studies and hydraulic analyses.

1 INTRODUCTION

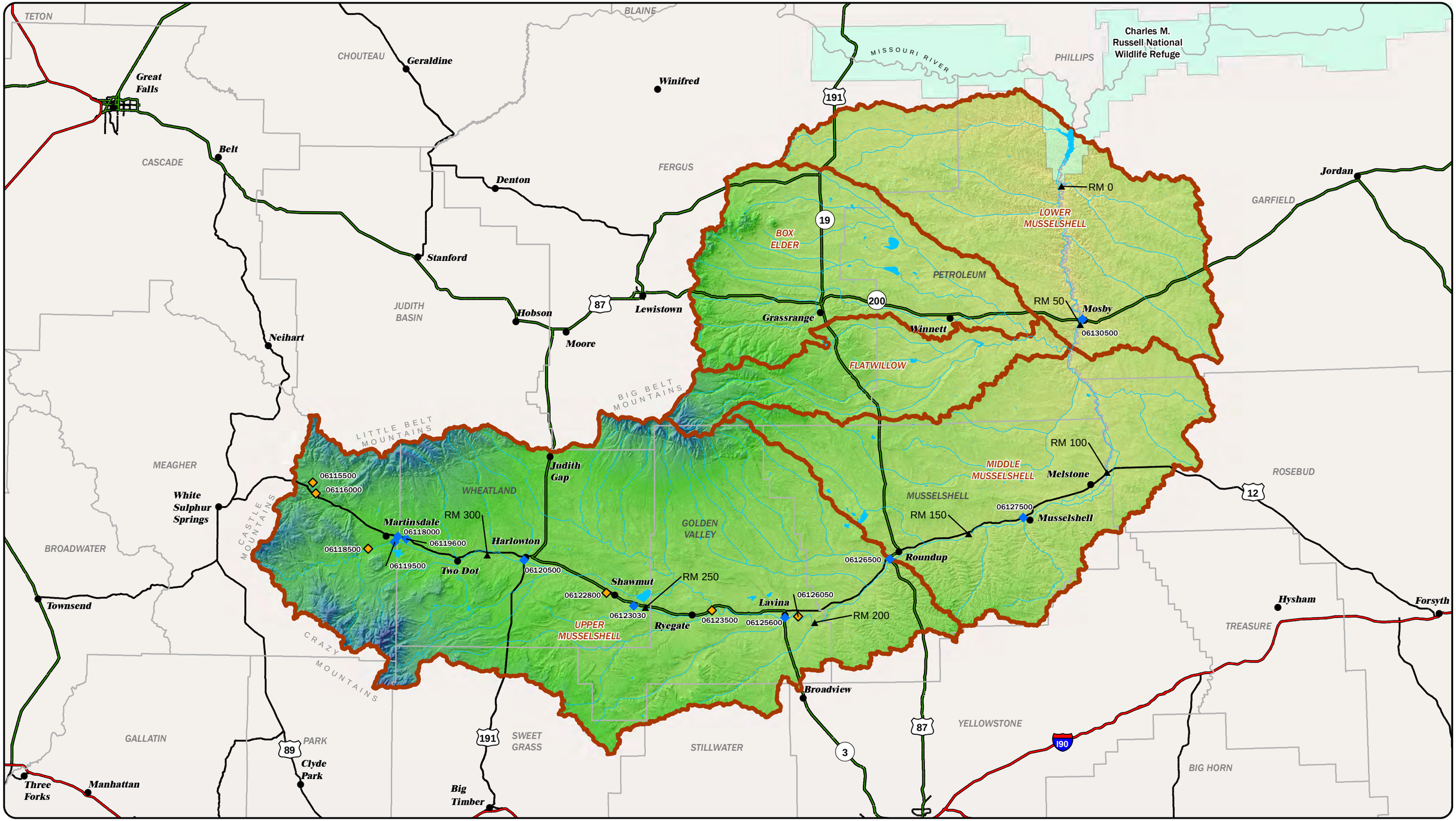
As part of the Musselshell River Floodplain Study – Phase 1 activities, the Montana Department of Natural Resources and Conservation (DNRC) contracted Pioneer Technical Services, Inc.(Pioneer) to complete a comprehensive, basin-wide, peak flow hydrologic analysis for the mainstem Musselshell River. This study encompasses the entire Musselshell River watershed, up to the Charles M. Russell Wildlife Refuge Area Boundary, which is approximately 8,651 square miles. The study reach for the peak flood discharges is focused on the 335-mile mainstem Musselshell River and does not include tributaries. Information gathered from this analysis will be the basis for both detailed/enhanced level and limited detail level hydraulic analyses and floodplain mapping, to be performed under subsequent phases. Figure 1 shows the project study reach and the river's watershed.

1.1 Background Information

The Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program (NFIP). As part of this program, FEMA supports flood hazard studies and prepares flood hazard maps and related documents. Most of the mainstem Musselshell River is sparsely populated with a predominantly rural environment. The existing floodplain mapping for the mainstem Musselshell River includes either Approximate Zone A, Limited Detail, or is unmapped. These existing floodplain mapping studies typically date back to the late 1970s and early 1980s.

Approximate Zone A flood maps are developed using approximate methodologies and are not based on detailed hydraulic analysis. This level of flood mapping is often used in rural areas with low populations. Base Flood Elevations (BFEs) or flood depths are not identified in Approximate Zone A mapping (a BFE is the computed elevation to which floodwater is estimated to rise during the base flood). As a result, areas designated with Zone A flood mapping are difficult for local communities to manage and administer.

Detailed and Limited Detail mapping are similar in that both use standard hydrologic and hydraulic modeling methods to estimate BFEs and flood inundation areas. Both require the same topographic accuracy. However, Limited Detail mapping does not include a floodway delineation, may not include a 500-year floodplain delineation, and may allow some flexibility in the acquisition and modeling of bathymetric and structure survey data.



LEGEND

USGS MUSSELSHELL RIVER GAGE
- ACTIVE
- INACTIVE

- TOWN
- RIVER MILE
- HUC 8 BOUNDARIES (MUSSELSHELL RIVER WATERSHED AREA)

N

DISPLAYED AS:
PROJECTION/ZONE: MSP
DATUM: NAD 83
UNITS: INTERNATIONAL FEET
SOURCE: PIONEER/DNRC/USGS/NRIS

0 7.5 15 30
Miles

FIGURE 1

PIONEER TECHNICAL SERVICES, INC.

MUSSELSHELL RIVER STUDY AREA

DATE: 4/10/2015

Path: P:\DNRC\Musselshell\GIS\Project\HydraulicStudy\MslshlFP-GI-Hydra-001-14.mxd

In 2013, the City of Roundup and Musselshell County requested assistance from the Montana DNRC to update their floodplain mapping. The DNRC, in partnership with FEMA, the Musselshell River communities, and other stakeholders, initiated work to produce new floodplain studies along select reaches of the river. This first phase of the Musselshell River Floodplain Study will provide the groundwork for scoping and completing floodplain mapping projects along the mainstem Musselshell River. This phase of the project consists of the following activities:

1. Structure and bathymetric survey for a 10-mile reach near Roundup, Montana (Pioneer, 2015a).
2. Field reconnaissance and hydraulic structure assessment (Pioneer, 2015b).
3. Hydrologic analysis.

This report documents the methodology and results of the hydrologic analysis (Activity 3) completed along the mainstem Musselshell River. The hydrologic analysis includes calculation of peak discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance events at key flow change locations (such as significant tributary confluences, stream gages, and population centers) along the study reach. Per directions from FEMA (DNRC, 2015), the "1-percent plus" frequency analysis was not required as part of this study. This hydrologic analysis conforms to FEMA standards for detailed/enhanced level studies (FEMA, 2014).

As part of this hydrologic analysis, the DNRC partnered with the USGS, under a non-formal agreement, to perform updated flood frequency analysis of all the stream gages along the mainstem Musselshell River through Water Year 2014. The USGS flood frequency analysis for the gaged locations was used to develop peak discharge estimates at the selected ungaged flow change locations.

In 2012, a 0.7 meter Light Detection and Ranging (LiDAR) high resolution topographic data set was developed for an approximately 296-river-mile corridor along the mainstem Musselshell River and extended into Fort Peck Reservoir for the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The LiDAR begins approximately 4.5 miles downstream from Harlowton. This LiDAR data set along with the 3 Musselshell River activities referenced above is available to support Detailed and Limited Detail mapping within the mainstem Musselshell River.

1.2 Basin 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 and flows to the east and then north for approximately 335 miles to its confluence with the Missouri River and the Fort Peck Reservoir (Figure 1). The entire Musselshell watershed area encompasses approximately 9,471 square miles. The study watershed basin area from the headwaters to the boundary of the Charles M. Russell Wildlife Refuge Area boundary is

approximately 8,651 square miles. Approximately 820 square miles of watershed area lies between the Charles M. Russell Wildlife Refuge area boundary and the Musselshell River confluence with the Fort Peck Reservoir.

The Musselshell River basin elevations range from approximately 9,000 feet in the Crazy Mountains to approximately 2,000 feet at the river's mouth. 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.

From its headwaters east to the town of Harlowton, the climate is cool and wet and supports cold water fisheries. East of Harlowton the basin becomes warmer and more arid and the fishery is dominated by warm water aquatic species.

Land use in the Musselshell River basin is primarily agricultural with irrigated 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; the Martinsdale Reservoir near Martinsdale; and the Deadman's Basin Reservoir between Shawmut and Ryegate. The Martinsdale Reservoir and the Deadman's Reservoir do not provide any flood protection due to their limited feeder canal capacity. The Bair Reservoir is located in the headwaters of the North Fork Musselshell River and does not provide any flood protection for the mainstem Musselshell due to its limited capacity. During the summer and fall, reaches of the Musselshell are often dewatered due to irrigation operations.

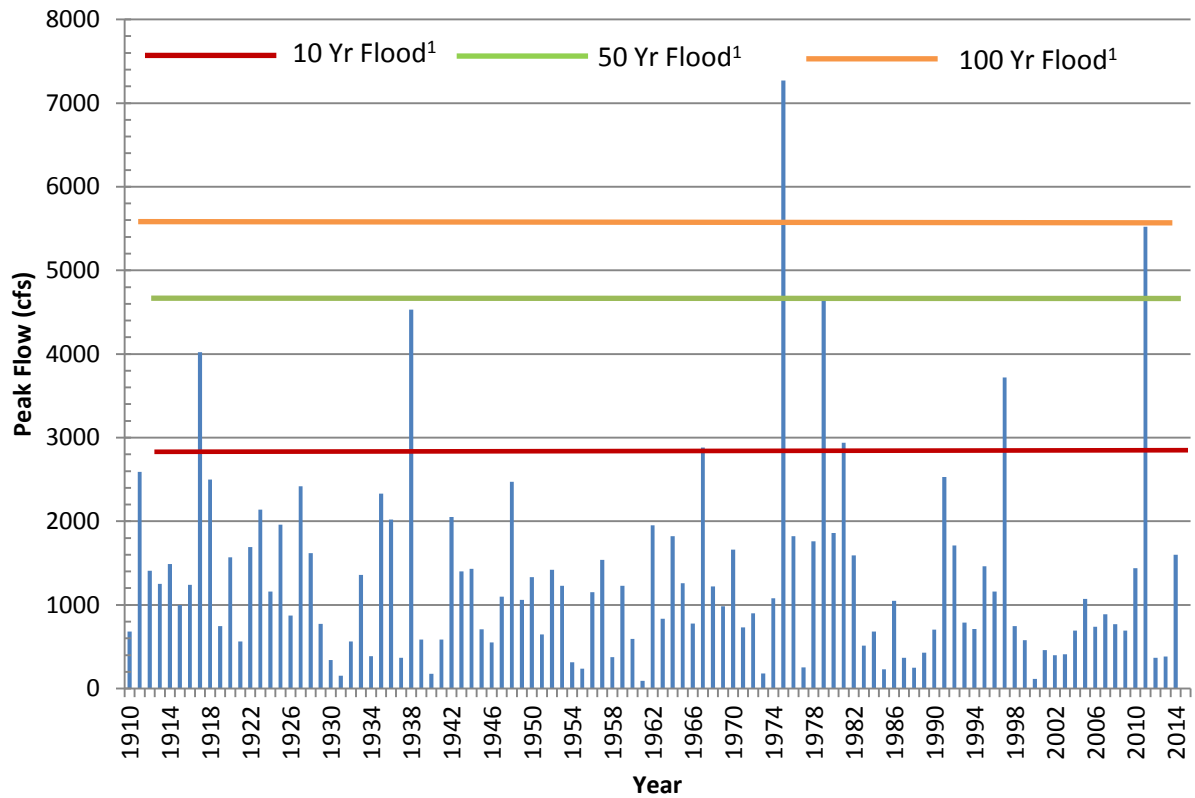
In 1908 the Milwaukee Railroad within the Musselshell River Basin was completed, extending from Melstone upstream through Harlowton and up the South Fork Musselshell towards Ringling. In 1980 this track was authorized for abandonment (Applied Geomorphology and RATT, 2012). When the railroad was constructed, the Musselshell River was significantly altered (straightened and shortened) to accommodate the railroad right of way. The railroad construction isolated portions of the historic river channel and floodplain from the active channel. Approximately 35 miles of removed channel length was estimated to have resulted from the railroad construction upstream of Melstone (Applied Geomorphology and RATT, 2012). As a result of the channel straightening associated with the railroad construction, the Musselshell River above Melstone has become entrenched and the historic floodplain is no longer accessible by floodwaters in many areas (Applied Geomorphology and RATT, 2012).

The Musselshell River is an alluvial river, with erodible streambanks, that actively migrates across its floodplain. In the upper part of the watershed the valley edges are fairly erosion resistant due to the sandstone outcrops. Where Bearpaw shale exists in the lower reaches, the river banks and valley margins are prone to erosion and mass failure. (Applied Geomorphology and RATT, 2012).

1.3 Flood History

The primary cause of flooding on the Musselshell is spring snowmelt and runoff from intense rainfall events. There are historical records from several USGS stream gages on the river that document flooding history. The USGS stream gages at Harlowton, Roundup, and Mosby are representative of the mainstem Musselshell flood history for the upper reach (Harlowton), the middle reach (Roundup), and the Lower Reach (Mosby). The Harlowton USGS Gage (06120500) has the longest, continuous flow record (1909-2014). The annual peak flow record for the Harlowton gage is shown in Figure 2. Peak flow recurrence intervals shown in Figure 2 are based on previously published flood frequency analysis through Water Year 1998 (Water Resources Investigations Report [WRIR] 03-4308) (Parrett and Johnson, 2004).

Figure 2 Musselshell River at Harlowton

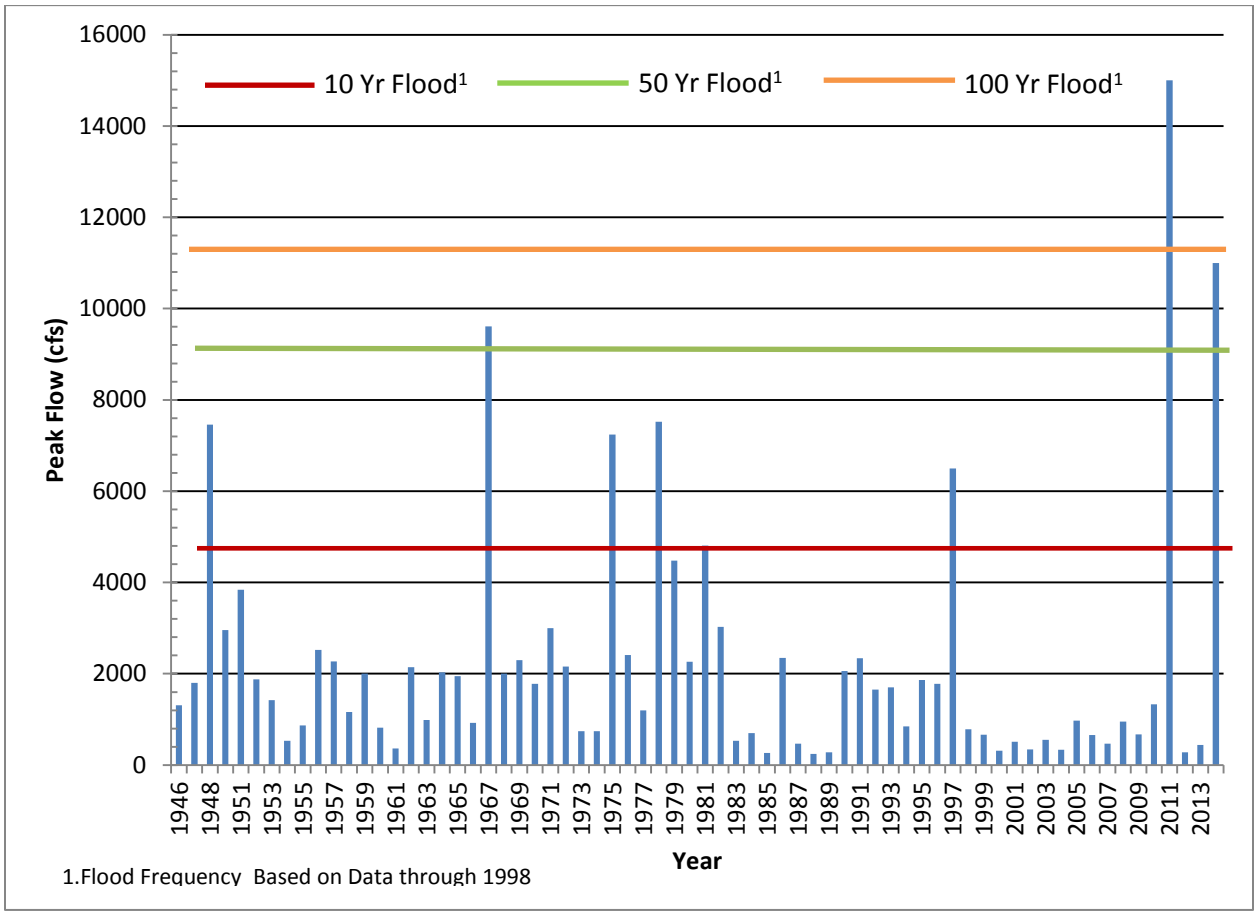


1. Flood Frequency Values Based on Data through 1998

Figure 2 shows that the peak flood of record at Harlowton occurred in 1975 with a flow of 7,720 cubic feet per second (cfs), exceeding the 1% chance annual flow of 5,560 cfs. The second highest flood on record occurred in 2011 with a flow of 5,520 cfs. In the 106-year period of record at the Harlowton gage, the 10-year flow has been exceeded 8 times.

Figure 3 shows the peak flow record from 1946 to 2014 (68 years) for the Musselshell River gage near Roundup (USGS 0612650). Peak flow recurrence intervals shown in Figure 3 are based on previously published flood frequency analysis from WRIR 03-4308.

Figure 3 Musselshell River near Roundup



The flood of record at Roundup occurred in 2011 with a flow of 15,000 cfs exceeding the 100-year flood by over 30%. The annual peak flow has exceeded the 10-year flood 7 times over the last 68 years. In the 35 years between 1979 and 2014, the 10-year flow was only exceeded 3 times: 1997, 2011, and 2014. Figure 4 shows flooding at the Highway 87 Bridge crossing near Roundup during the 2011 flood.

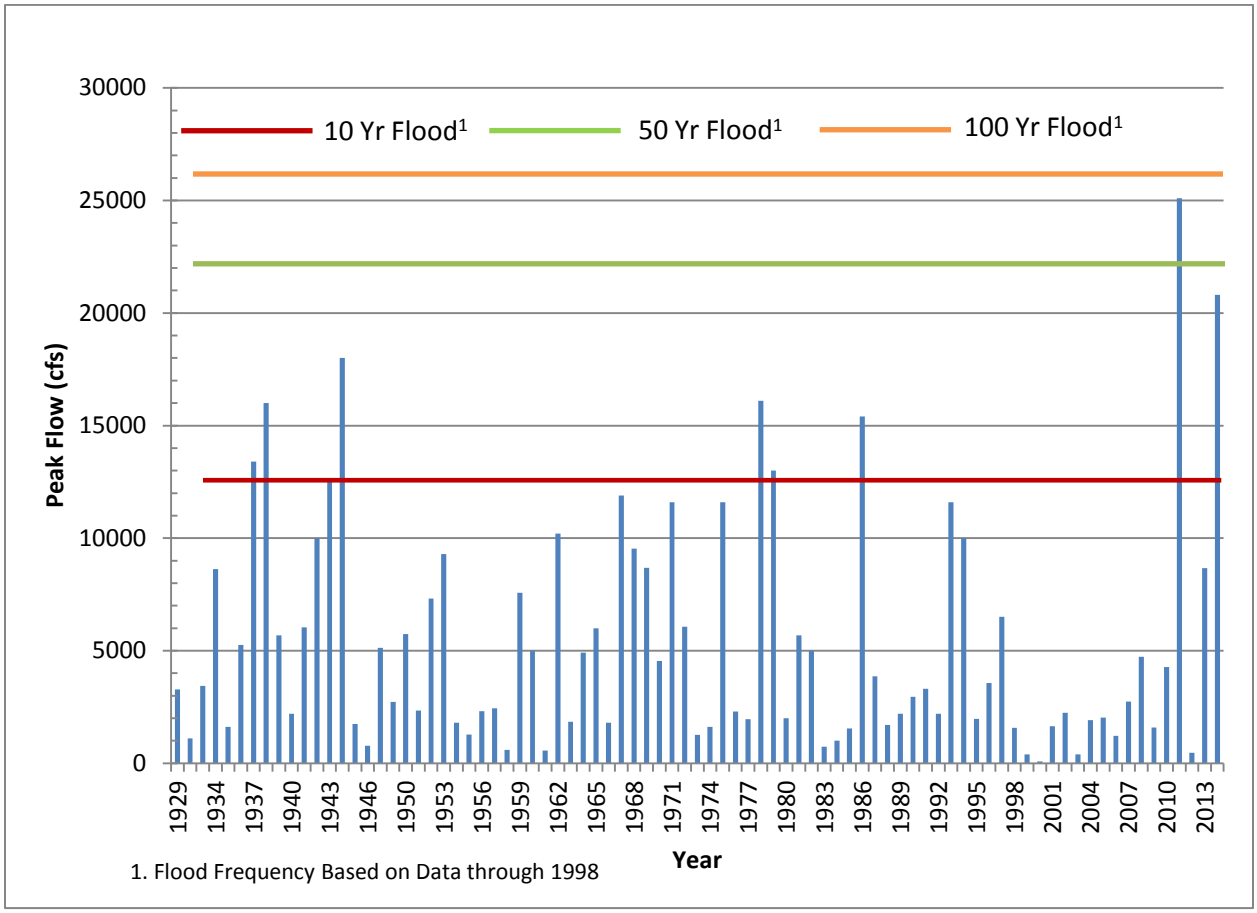
Figure 4 2011 Flooding Near Roundup

Photo by Kestral Aerial Services, Inc.

Figure 5 shows the annual peak flow record for the Musselshell River gage at Mosby (USGS 06130500). Peak flow recurrence intervals shown in Figure 5 are based on previously published flood frequency analysis from WRIR 03-4308 .

The Musselshell River gage at Mosby has 83 years of flow record (1929-2014, not continuous). During that time, the 10-year flow has been exceeded 8 times. The Musselshell flood of record at Mosby occurred in 2011 with a flow of 25,100 cfs. Prior to 2011, the second highest flood on record was 18,000 cfs in 1943. The 2011 flood was almost 40% greater than the 1943 flood and was the result of an episodic rain-on-snow event. In 2014 the Mosby area experienced the second highest flood on record with a flow of 20,800 cfs. In the Musselshell River basin, annual peak flows are typically associated with spring snowmelt or rain-on-snow events. At the Mosby gage, 87% of annual peak flows occur between February and June. The 2014 flood was unique in that it occurred in August from an episodic rain event.

Figure 5 Musselshell River at Mosby



Of all the floods that occurred during the documented flow measurement periods, the 2011 flood was the most significant resulting in dramatic changes to the Musselshell River and causing extensive damage to infrastructure and property within the river corridor. The flood was long lasting, with major flooding persisting over three weeks in places and causing extensive bank erosion and numerous avulsions (Applied Geomorphology and RATT, 2012). Figure 6 shows 2011 flooding near Mosby.

As evidenced by the 2011 flood, the Musselshell River is capable of producing large-scale flooding with significant impacts to the river corridor, public infrastructure, and private property.

Figure 6 2011 Musselshell River Flood near Mosby

Photo by Kestral Aerial Services, Inc.

2 PAST STUDIES AND EXISTING FLOOD DATA

Past flood studies for the mainstem of the Musselshell River are limited. Studies relevant to this hydrologic study are those that include peak flow frequency analyses. Within the mainstem Musselshell River basin, FEMA FIS exist for portions of Wheatland and Golden Valley counties. Musselshell County is all Approximate Zone A floodplain mapping, so it does not have an FIS report. Rosebud County does not have any portion of the Musselshell River floodplain mapped. Garfield and Petroleum County do not participate in the NFIP. Table 1 shows a summary of the mainstem Musselshell River Floodplain Mapping.

Table 1 Mainstem Musselshell River Floodplain Mapping Summary

County	Map Panel Summary					Musselshell River			
	Community	# of FIRM Panels	# of FBFM Panels	FIRM Panel Effective Date	FIS Date	Approx. A (mi)	Limited Detail (mi)	Unmapped (mi)	Total (mi)
Wheatland	Wheatland Co.	7	3	9/16/1981	3/16/1981	34.9	5.6	38.8	79.3
	Harlowton, City of	1	3	9/16/1981					
Golden Valley	Golden Valley Co.	4		9/16/1981	3/16/1981	13.4	5.7	32.4	51.5
	Lavina, Town of	1		9/16/1981					
	Ryegate, Town of	1		7/20/1982					
Musselshell	Musselshell Co.	*4		*3/1/2001	N/A	60.7	0	55.3	116.0
	Roundup, City of	1		3/18/1986					

Source: DNRC 2015

* FHBMS dated 5/29/1979 updated to FIRMs by letter

FIRM: Flood Insurance Rate Map

FBFM: Flood Boundary Floodway Map

FHBM: Flood Hazard Boundary Map

FIS: Flood Insurance Study

mi: Miles measured along channel alignment

In addition to the two FEMA FISs, USGS WRIR 03-4308 documents the flood frequency analysis on several gages along the mainstem Musselshell River.

In response to the 2011 flood, the Musselshell Watershed Coalition (MWC) organized a River Assessment Triage Team (RATT) to investigate and document the impacts of the 2011 flood and to identify measures to support local economies and sustainable river corridor practices. The RATT Report (Applied Geomorphology and RATT, 2012) does not include any quantitative hydrologic analysis but does provide relevant information relating to the 2011 flood extent and impacts to the river corridor, infrastructure, and property. These studies and investigations are discussed in more detail in the following sections.

2.1 City of Harlowton and Wheatland County Flood Insurance Study

The City of Harlowton and Wheatland County FIS (Harlowton FIS) was issued on March 16, 1981 (FEMA, 1981a). As part of the FIS, the mainstem Musselshell River was studied using limited detail and approximate methods. The hydrologic and hydraulic analysis was completed by Morrison-Maierle, Inc. in November 1979. The study area included the incorporated areas of the City of Harlowton and the unincorporated areas of Wheatland County. The FIS identified several major floods in the Harlowton area with flows of 4,020 cfs in May 1917; 4,530 cfs in June 1938; 2,880 cfs in June 1967; and 7,270 cfs in June 1975. The 1975 flood remains the flood of record in the Harlowton area.

Hydrologic analyses were carried out using industry standard methods. The Musselshell River peak flow analysis was conducted using systematic data from the USGS Gage 06120500 at Harlowton. At the time of the study, this gage had recorded 70 years of data. Table 2 summarizes the estimated peak discharges from the Harlowton FIS.

Table 2 Harlowton FIS Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs)			
		10-Year	50-Year	100-Year	500-Year
Musselshell River at USGS Gage 06120500	1,125	2,820	N/A	5,740	N/A

The Harlowton FIS profiles only display the 10-year and 100-year flow profiles.

2.2 Town of Lavina and Golden Valley County Flood Insurance Study

The FEMA FIS for the town of Lavina and Golden Valley County (Lavina FIS) was issued on March 16, 1981 (FEMA, 1981b). The hydrologic and hydraulic analyses were completed by Morrison-Maierle, Inc., in November 1979. The study area included Lavina and the unincorporated areas of Golden Valley County. This FIS studied the mainstem Musselshell by limited detail and approximate methods.

At the time of the FIS, Golden Valley had experienced two large floods. The June 16, 1967, flood had a peak flow of 9,500 cfs as recorded at the USGS Gage 06123500 near Ryegate. This flood was caused by rainfall and the flood crest was sustained for several days causing considerable damage to land and structures. The second large flood was on June 21, 1975, and had a peak flow of 8,550 cfs, resulting in considerable damage to the inundated areas. This flood was caused by rain and snowmelt in the upper watershed areas.

Hydrologic analyses were conducted using industry standard methods to estimate the peak discharge-frequency relationships for selected recurrence intervals. Lavina lies between Ryegate and Roundup; therefore, the flood frequency analysis was performed using annual peak flow data from USGS Gage Station 06123500 near Ryegate and USGS Gage Station 06126500 near Roundup. At the time of the FIS, each gage had recorded 31 years of data.

A peak flow flood frequency analysis was conducted on the systematic data from each gage. Results of the analysis indicated that flood peaks did not change significantly between the two stations, and a slight decrease is observed between Ryegate and Roundup. The Lavina FIS attributes this slight decrease in peak flows to large overbank storage. Consequently, the 100-year peak flow at the Ryegate gage was applied to Lavina directly without employing any transfer methodologies. Table 3 summarizes the peak discharges from the Lavina FIS.

Table 3 Lavina FIS Peak Flow Summary

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharge for Recurrence Interval (years) (cfs)			
		10-Year	50-Year	100-Year	500-Year
Musselshell River at Gage No. 061235 Near the Town of Ryegate	1,979	4,370	N/A	12,700	N/A
At Highway 3	2,975	4,370	N/A	12,700	N/A
Musselshell River At Gage No. 061265 Near the City of Roundup	4,023	4,990	N/A	11,900	N/A

Comparison of the Harlowton FIS peak flows with the Lavina FIS peak flows indicate that the 100-year peak flow estimate increases 120% between the Harlowton gage and the Ryegate gage, with only a 76% increase in drainage area. This steep increase is observed in subsequent flood frequency analyses, including the WRIR 03-4308 analyses and this study (presented in subsequent sections), indicating it spans multiple periods of record. The area between Harlowton and Ryegate is a transitional reach between the Upper Yellowstone-Central Mountain and East-Central Plains Hydrologic Regions as shown in WRIR 03-4308, Plate 1. This boundary represents a shift from the Western Montana climatic regions, which receive their moisture from

the Pacific Ocean, to the Eastern Montana climatic regions, which can receive moisture from the Pacific Ocean and the Gulf of Mexico (Parrett and Johnson, 2004). The reasons for this sharp increase are complex but it is likely related to spatial variability in precipitation intensity and changes in basin characteristics such as soil types and vegetation.

2.3 Water Resources Investigations Report 03-4308

The USGS WRIR 03-4308 developed annual peak discharges with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years (*T*-year floods) for 660 gaged sites in Montana and in adjacent areas of Idaho, Wyoming, and Canada, based on data through Water Year 1998. The flood-frequency information was used in regression analyses to develop equations relating *T*-year floods to various basin and climatic characteristics, active-channel width, and bankfull width. The equations can be used to estimate flood frequency at ungaged sites. Flood-frequency data typically were determined by fitting a log-Pearson Type III probability distribution using methods described by the Interagency Advisory Committee on Water Data (IACWD), Bulletin #17B (IACWD, 1982). Table 4 provides the WRIR 03-4308 peak discharge summary for the USGS gages on the Musselshell River. Table 4 shows that 100-year peak flows attenuate from Ryegate to Musselshell and then nearly double at Mosby. The attenuation between Ryegate, Roundup, and Musselshell can be partly attributed to floodplain storage and may also be influenced by non-congruent periods of records. The large peak flow increase between Musselshell and Mosby is due to the inflow of several major tributaries such as Flatwillow Creek and Box Elder Creek as shown on Figure 1.

Table 4 WRIR 03-4308 Musselshell River Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	Peak discharge, for Recurrence Interval (years). (cfs)				
				10	25	50	100	500
06119600	Musselshell River near Martinsdale	N/A	N/A	N/A	N/A	N/A	N/A	N/A
06120500	Musselshell River at Harlowton	1,125	90	2,810	3,860	4,700	5,560	7,690
06123030	Musselshell River above Mud Creek, near Shawmut	N/A	N/A	N/A	N/A	N/A	N/A	N/A
06123500	Musselshell River near Ryegate	1,979	33	4,740	7,350	9,720	12,500	20,600
06126050	Musselshell River near Lavina	N/A	N/A	N/A	N/A	N/A	N/A	N/A
06126500	Musselshell River near Roundup	4,023	52	4,850	7,090	9,030	11,200	17,100
06127500	Musselshell River at Musselshell	4,568	53	4,480	6,700	8,660	10,900	17,100
06130500	Musselshell River at Mosby	7,846	67	12,700	18,200	22,300	26,200	34,900

Based on systematic data through 1998

2.4 River Assessment Triage Team (RATT) Report

Activities for the RATT Report occurred in late 2011 and 2012. While no quantitative flood frequency analysis was performed as part of this investigation, the RATT report provides a systematic interpretation of the mainstem Musselshell River and the 2011 flood impacts. The RATT study evaluated the river corridor as the aggregate of the interrelated components (the system) including hydrology, geology, fluvial geomorphology, fisheries, ecology, land use, infrastructure, and economics. A summary of the report findings is as follows (Applied Geomorphology and RATT, 2012):

- The 2011 Musselshell River flood was record breaking in terms of both the magnitude of the event and the length of time that flood stage was exceeded.
- The flood caused 59 avulsions, which abandoned almost 37 miles of channel.
- Avulsions created just over 9 miles of new channel.
- The river was shortened by 8% between Fort Peck Reservoir and Martinsdale.
- The most severe shortening was in the lowermost 89 miles of river, below Flatwillow Creek.
- In places, the river migrated several hundreds of feet during the flood, causing massive erosion, and sediment delivery downstream.
- A total of 31 breaches through the railroad embankment were mapped using post-flood air photos.
- Several diversion structures were flanked or abandoned.
- Dozens of irrigation pumps were abandoned.
- Floodplain sediment deposition was several feet thick in some areas, commonly in agricultural fields.
- Vast carpets of cottonwood and willow seedlings were established by the flood.
- Effective rehabilitation strategies can address both short-term needs as well as the longer-term processes of system recovery.

2.5 Additional Previous Studies

Additional related previous studies conducted along the Musselshell River involve fisheries management and water management:

- *The Musselshell River Streambank Physical Features Inventory*, Water Quality Bureau, and Department of Health and Environmental Services (Pedersen, 1980).
- *South Central Montana Fisheries Investigation, Musselshell River Study, Job Progress Report (*Marcuson and Cardinal, 1981).
- *South Central Montana Fisheries Investigation, Musselshell River Study, Job Progress Reports* completed by Wade Fredenberg (Fredenberg, 1983, 1984, 1985, 1986, 1987).

- *An Evaluation of the trout population in three sections of the Musselshell River near Deadman's Basin Reservoir* completed by Montana Department of Fish, Wildlife and Parks (Vaughn and Fredenberg, 1984).
- *Musselshell River Basin Water Management Study* completed by U.S. Bureau of Reclamation (U.S. BOR, 1998).
- *Musselshell River Drainage* completed by Montana Fish, Wildlife and Parks in 2012 (FWP, 2012).

2.6 Additional Flood Data

At Roundup, on March 10, 2014, the Musselshell River experienced the 2014 peak flow. At USGS Gage 06126500, the peak flow measurement was recorded at 11,000 cfs with 13.24 feet of river stage (3.24 feet over flood stage) (Billings Gazette, 2014). The DNRC contracted with Great West Engineering to conduct a high water mark survey in Roundup following the March 10, 2014, flood. This survey data is available from DNRC.

3 Hydrologic Analyses and Results

The purpose of the hydrologic analyses conducted as part of this project is to develop peak flow discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance events at key flow change locations (such as at significant tributaries confluences, stream gages, and population centers) along the study reach. The analysis is organized into two sections:

1. USGS Stream Gage Analysis.
2. Ungaged Flow Node Analysis.

Throughout the study reach, 49 locations (flow nodes) were identified as having significant changes in streamflow or being at a critical location. Out of the 49 flow nodes, 6 are located at active USGS stream gage sites, 2 are located at discontinued USGS stream gage sites, and 41 are located between or downstream of stream gages (ungaged sites). The river stationing used in this report is based on the RATT Report alignment (RATT alignment). The RATT alignment begins approximately 8 river miles downstream of the Charles M. Russell Wildlife Refuge Area intersection with the mainstem Musselshell River. The alignment origin used in this study begins at the mainstem Musselshell River intersection with the Charles M. Russell Wildlife Refuge Area boundary. The upstream end of this study reach ends at the confluence of the north and south forks of the Musselshell River (River Mile 327.5). The most upstream flow node is located at the Martinsdale gaging station (USGS Station 06119600) approximately 2 miles downstream (River Mile 325.5) from the confluence of the north and south fork Musselshell River.

3.1 USGS Stream Gage Analysis

The USGS has historically maintained 15 stream gages along the Musselshell River, including along the North Fork and South Fork of the Musselshell River. The oldest records date back to 1908 at USGS Gaging station 06118000 on the North Fork of the Musselshell River near

Martinsdale and 06119500 on the South Fork of the Musselshell River near Martinsdale, with both periods of record ending in 1914. Currently, there are 9 (of the 15) USGS gaging stations being maintained on the mainstem and north and south forks of the Musselshell River. Figure 1 shows the study reach and the locations of the USGS gaging stations used in the hydrologic analysis. The Harlowton gage has the longest congruent period of record extending from 1909 to 2014 (106 years). Table 5 lists a summary of all the USGS stream gages (active and inactive) along the mainstem Musselshell River and the North Fork and South Fork Musselshell River.

The USGS is in the process of updating the regional regression equations used to estimate flood frequency at ungaged sites in Montana using stream gage data through 2011 (the current set of regression equations is based on flow data through 1998). As part of this effort, the USGS is conducting flood frequency analysis on the mainstem Musselshell River. In conjunction with the Musselshelll hydrologic analysis and the regression equation update, the USGS collaborated with DNRC to conduct a flood frequency analysis for the mainstem Musselshell River using gage data through 2014. This longer period of record should produce more accurate peak discharge estimates than those based on a shorter period of record. Using peak flow data through 2014 provides added value because it captures a significant flood event, which occurred in August 2014, producing the second highest flood on record at the Mosby gage.

At the time of the USGS analysis, some of the 2014 peak flow measurements were considered provisional (preliminary) and were subject to revisions following the USGS flow data review process. Despite this potential for future revisions, the value of the longer period of record and inclusion of the significant 2014 flood events in the data set was considered more important than potential revisions to the 2014 peak flow measurements. Results of the USGS flood frequency analysis based on data through 2014 have been employed in this hydrologic analysis.

This section summarizes the Musselshell River flood frequency work conducted by the USGS. A detailed description and supporting information for the USGS flood frequency analysis is provided in Appendix A. The flood frequency analyses were performed following Bulletin #17B methods (IACWD, 1982). Systematic flood frequency calculations were completed for 11 of the 15 gages (Appendix A, Table B.2) shown in Table 5, using data through 2014. Systematic flood frequency analysis was not completed for 4 of the gages shown in Table 5 either due to insufficient periods of record (06118000 and 06125600) or because the gage data was combined with other gages (06119500 and 06122800). Figure 7 plots the systematic flood frequency results as a function of drainage area.

Table 5 Musselshell River USGS Gage Summary

Station number	Station name	Drainage[1] Area (square miles)	Period of Systematic Record[2]	Number of Annual Peaks[2]	River Station (miles)
06115500*	North Fork Musselshell River near Delpine	37.3	1941-1979	39	N/A
06116000*	North Fork Musselshell River at Delpine	47.3	1909-1911, 1922-1932	14	N/A
06118000	North Fork Musselshell River near Martinsdale	248	1908-1914	7	N/A
06118500*	South Fork Musselshell River above Martinsdale	268	1942-1979	38	N/A
06119500	South Fork Musselshell River near Martinsdale	280	1908-1914, 1930, 1932	9	N/A
06119600	Musselshell River near Martinsdale	537	2003-2014	12	325.5
06120500	Musselshell River at Harlowton	1,108	1909-2014	106	289.0
06122800*	Musselshell River near Shawmut	1,484	1986-1997	12	262.3
06123030	Musselshell River above Mud Creek, near Shawmut	1,518	1998-2014	17	253.8
06123500*	Musselshell River near Ryegate	1,957	1947-1979	33	231.6
06125600	Musselshell River above Big Coulee Creek at Lavina	2,691	2012-2014	2	211.0
06126050*	Musselshell River near Lavina	2,947	1992-2011	20	205.7
06126500	Musselshell River near Roundup	3,998	1946-1948, 1950-2014	68	175.1
06127500	Musselshell River at Musselshell	4,534	1929-1930, 1932, 1946-1979, 1983-2014	68	133.8
06130500	Musselshell River at Mosby	7,784	1929, 1931-1932, 1934-1946, 1948-2014	83	48.4

1. Source: National Watershed Information System (NWIS)
2. Data from USGS flood frequency analysis (Appendix A, Table B.1)

* Denotes inactive gage location

Figure 7 USGS Flood Frequency Estimates Systematic Record through 2014

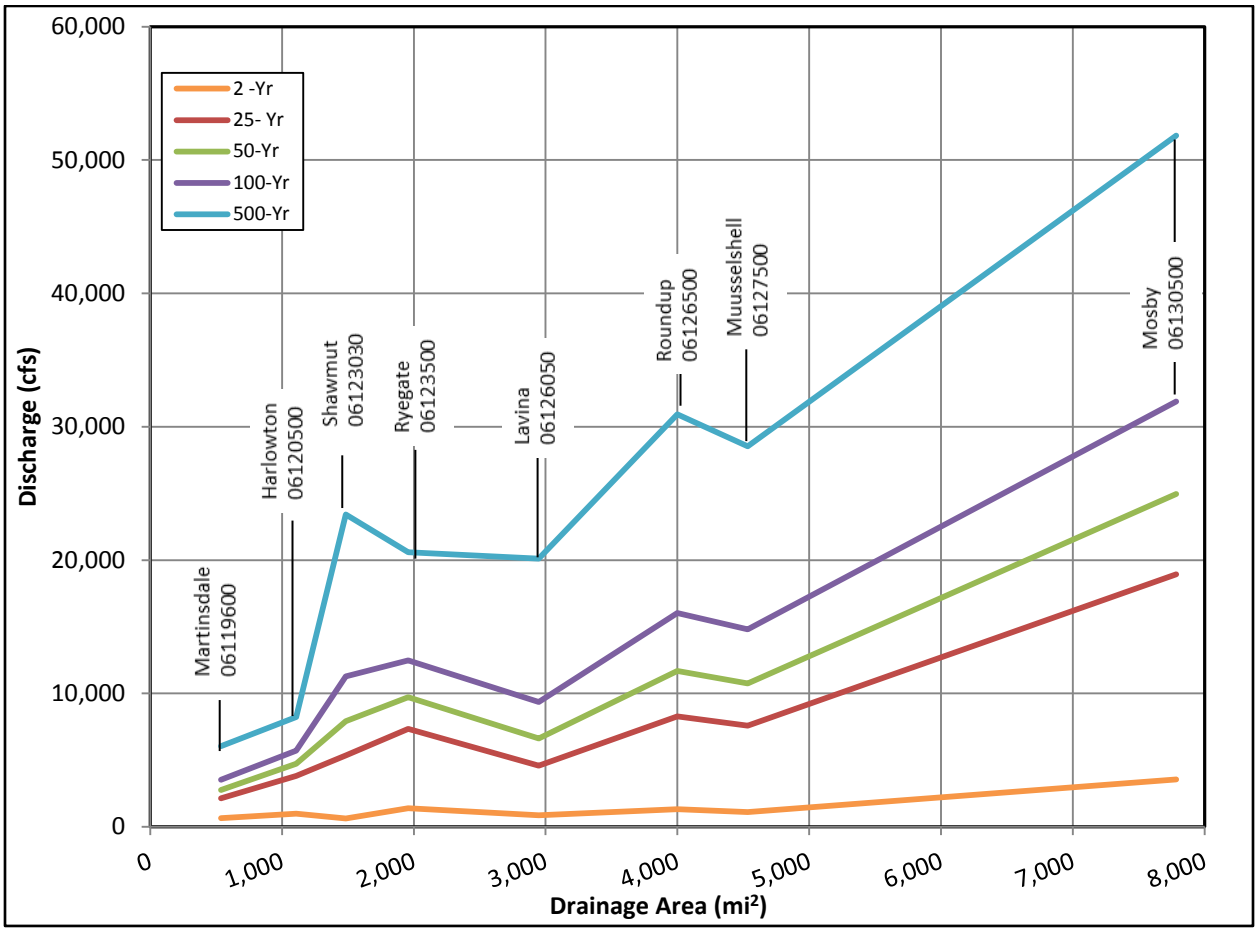


Figure 7 indicates peak discharges do not consistently increase with increasing drainage area, as typically expected. These inconsistences can be related to non-congruent periods of record or variability in flood storage. To address the non-congruent periods of record, the MOVE.1 (Maintenance Of Variance Extension, Type 1) and the drainage area transfer methods were used to extend the historical gage records. The MOVE.1 method correlates streamflow at a short-term gaging station with a longer term index gaging station using a base 10 logarithmic transformation. The Move.1 method can be used for record extension when a linear relationship exists between the logarithms of the same-year peak discharges at the target station and a nearby index station. Drainage area transfer methods correlate the streamflow at a short-term gaging station with the longer-term index station using the drainage area ratio of the two sites as described in USGS WRIR 03-4308. A base period of 1941-2014 was selected for the record extension, as the mainstem gages generally have a better continuity of record during that time period and all the gages have some degree of regulation beginning in 1941. Regulation occurs in a basin when flood flows are altered by reservoir operations or other water resource control structures (such as diversion dams). In this flood frequency analysis, gages were defined as regulated when greater than 20% of the basin lies upstream from reservoirs. The primary

dams/reservoirs within the Musselshell basin are the Bair Dam (1939), Martinsdale Reservoir (1939), and Deadman's Basin Reservoir (1941). As discussed previously in Section 1.2, none of these reservoirs provide significant flood flow attenuation.

Annual peak estimates from the MOVE.1 analysis were generally reasonable and consistent with recorded upstream and downstream peaks. However, the MOVE.1 method severely overestimated the largest peaks in some cases. For these cases the drainage area adjustment method was used instead of MOVE.1. For the gages used in the Musselshell River Basin, 20 peaks were estimated using the drainage area ratio rather than the MOVE.1 estimate.

Table 6 summarizes the Musselshell River gage analysis flood frequency estimates using the extended record. Figure 8 plots the extended record analysis results and shows that the flood frequency estimates generally increased with increasing drainage areas. These results indicate that much of the attenuation observed in the systematic flood frequency estimates (Figure 7) was associated with non-congruent periods of records rather than significant floodplain storage. In some cases, the flood frequency estimates for the shorter return frequency events (i.e., the 2-Year event) did not increase with increasing drainage areas. Systematic peak flow data from corresponding periods were inspected and it was determined that in many cases the lesser peaks tended to attenuate in the downstream direction, thereby validating that the peak flow flood frequency estimates for the shorter return frequency events may not increase with increasing drainage areas.

Flood frequency peak flow estimates using the extended record data set establishes a congruent period of record for the mainstem Musselshell River stream gages. Using the extended record data set eliminates much of the downstream attenuation observed in the systematic record flood frequency analysis and will minimize the error potential associated with non-congruent periods of record.

For these reasons, flood flow frequency estimates using the 2014 extended record data set, were selected to represent the annual chance flood potential at the Musselshell River gaged locations.

Table 7 compares flood frequency estimates between the 1998 WRIR 03-4308 analysis and this study's 2014 extended record analysis. The WRIR 03-4308 flood frequency estimates are a systematic analysis based on the entire period of record. The 2014 flood frequency analysis is based on the congruent period of record 1941 to 2014; therefore, some differences between the 1998 and 2014 peak flow estimates can be attributed to the different period of records used in the analysis.

In general, differences between the 1998\2014 flood frequency estimates tend to increase in the downstream direction and with increasing return intervals. In the upper watershed, represented by the Harlowton gage (06120500), 1998\2014 flood frequency estimates are similar with the greatest difference observed at the 500-year return interval. In the period between 1998, and 2014, the Harlowton gage has only experienced 1 significant flood event (2011). With the

exception of the 2011 flood, annual peak flows at the Harlowton gage between 1998 and 2014 did not depart significantly from the historical norm (see Figure 2) resulting in minor differences between the 1998 and 2014 flood frequency estimates.

Further downstream, as observed in the Roundup (06126500) and Mosby (06130500) gages, the flood frequency estimate differences are greater between the 1998 and 2014 analyses and become significant at the higher return intervals. At the Roundup gage, the 2014, 100-year peak flow estimate is 31% greater than the 1998 estimate. At the Mosby gage, the 2014, 100-year peak flow estimate is 21% greater than the 1998 estimate. These significant increases can be attributed to the large flood events in 2011 and 2014 that impacted the middle and lower watershed reaches. At both the Roundup gage and the Mosby gage, 2011 produced the peak flow of record exceeding the previous records by 56% and 39% respectively; 2014 produced the second highest peak flow of record. Within the middle and lower watershed reaches, the 2011 and 2014 peak flow magnitudes, relative to the previous periods of record, were large enough to significantly increase the 100-year recurrence interval flow estimates.

Table 6 Gage Flood Frequency Estimates Using Extended Record

Station Number	Station name	Analysis Period of Record	Peak discharge, (cfs), for indicated exceedance probability (%)								
			66.67	50	20	10	4	2	1	0.5	0.2
			Peak discharge (cfs), for indicated return interval (years)								
			1.5	2	5	10	25	50	100	200	500
06119600	Musselshell River near Martinsdale	1941-2014	667	890	1,583	2,151	2,994	3,717	4,522	5,417	6,753
06120500	Musselshell River at Harlowton	1941-2014	638	919	1,836	2,610	3,768	4,756	5,848	7,050	8,816
06123030	Musselshell River above Mud Creek, near Shawmut	1941-2014	489	826	2,173	3,495	5,673	7,665	9,968	12,590	16,580
06123500	Musselshell River near Ryegate	1941-2014	839	1,236	2,662	3,991	6,167	8,184	10,570	13,370	17,790
06126050	Musselshell River near Lavina	1941-2014	936	1,373	2,990	4,561	7,241	9,824	12,980	16,820	23,130
06126500	Musselshell River near Roundup	1941-2014	898	1,340	3,045	4,773	7,831	10,880	14,700	19,460	27,520
06127500	Musselshell River at Musselshell	1941-2014	781	1,229	3,035	4,909	8,252	11,580	15,750	20,900	29,540
06130500	Musselshell River at Mosby	1941-2014	2,226	3,445	7,904	12,060	18,750	24,810	31,820	39,850	52,170

Figure 8 USGS Flood Frequency Estimates Extended Record (1941-2014)

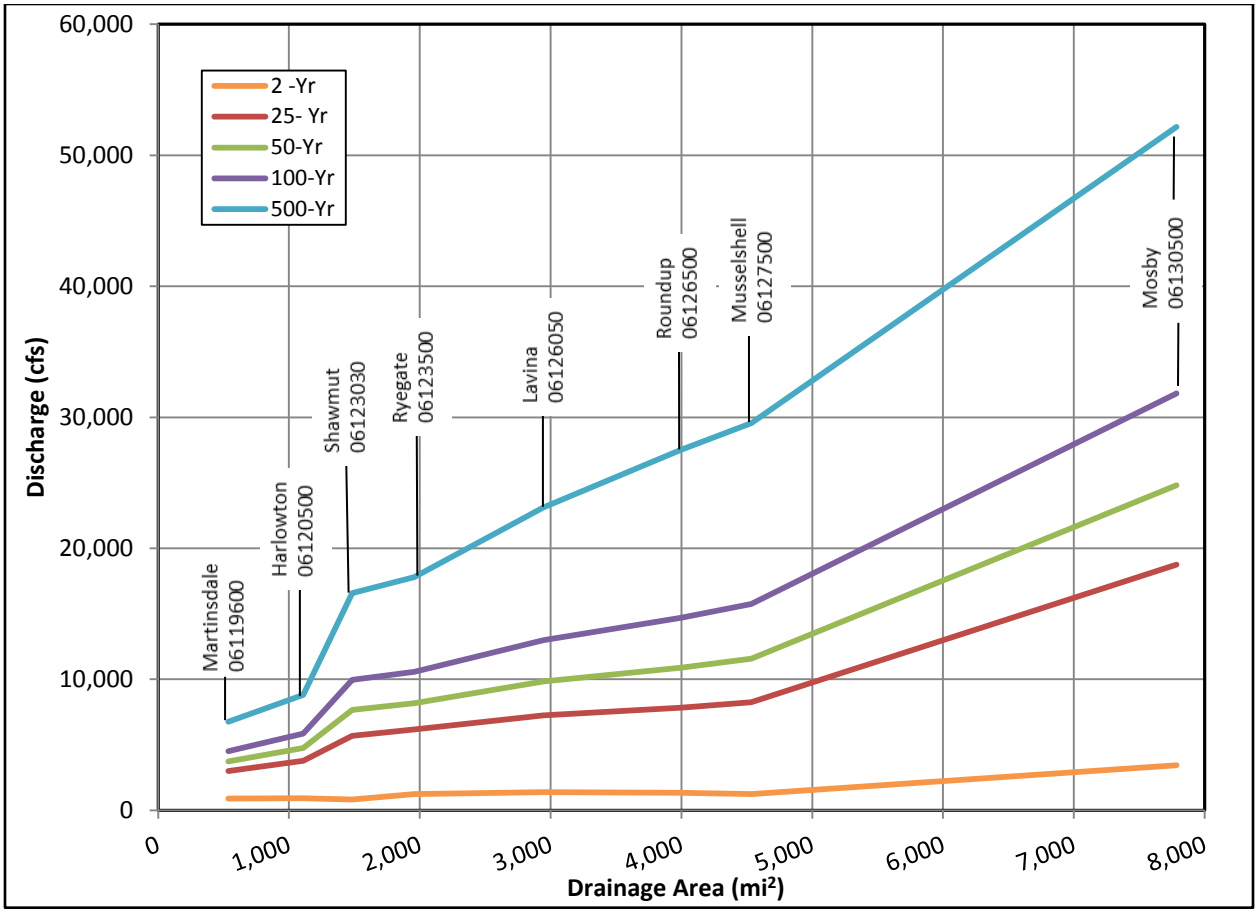


Table 7 USGS Flood Frequency Estimate Comparison 1998 and 2014

Station Number	Station Name	Peak Discharge, for Return Interval (years) (cfs)													
		5		10		25		50		100		200		500	
		1998	2014	1998	2014	1998	2014	1998	2014	1998	2014	1998	2014	1998	2014
06119600	Musselshell River near Martinsdale	N/A	1,583	N/A	2,151	N/A	2,994	N/A	3,717	N/A	4,522	N/A	5,417	N/A	6,753
06120500	Musselshell River at Harlowton	2,040	1,836	2,810	2,610	3,860	3,768	4,700	4,756	5,560	5,848	6,460	7,050	7,690	8,816
06123030	Musselshell River above Mud Creek, near Shawmut	N/A	2,173	N/A	3,495	N/A	5,673	N/A	7,665	N/A	9,968	N/A	12,590	N/A	16,580
06123500	Musselshell River near Ryegate	3,130	2,662	4,740	3,991	7,350	6,167	9,720	8,184	12,500	10,570	15,700	13,370	20,600	17,790
06126050	Musselshell River near Lavina	N/A	2,990	N/A	4,561	N/A	7,241	N/A	9,824	N/A	12,980	N/A	16,820	N/A	23,130
06126500	Musselshell River near Roundup	3,370	3,045	4,850	4,773	7,090	7,831	9,030	10,880	11,200	14,700	13,600	19,460	17,100	27,520
06127500	Musselshell River at Musselshell	3,060	3,035	4,480	4,909	6,700	8,252	8,660	11,580	10,900	15,750	13,400	20,900	17,100	29,540
06130500	Musselshell River at Mosby	8,670	7,904	12,700	12,060	18,200	18,750	22,300	24,810	26,200	31,820	30,100	39,850	34,900	52,170

Table 8 compares the results of the Harlowton FIS study peak flow estimates with the peak estimates from the USGS flood frequency estimates using the extended gage records through 2014. Review of Table 8 indicates the FIS and USGS 2014 peak flow estimates are similar (less than 10% difference) for both the 10-year recurrence interval and the 100-year recurrence interval.

Table 8 Harlowton FIS Flood Frequency Estimate Comparison

Flooding Source and Location	Peak Discharges (cfs)								
	Drainage Area[1] Square Miles	10-Year		50-Year		100-Year		500-Year	
		FIS	2014	FIS	2014	FIS	2014	FIS	2014
Musselshell River at Harlowton USGS Gage 06120500	1,108	2,820	2,610	N/A	4,756	5,740	5,848	N/A	8,816

1. Source: National Watershed Information System (NWIS)

Table 9 compares the Lavina 1981 FIS peak flow estimates with the USGS flood frequency estimates using extended gage records through 2014. Results shown in Table 9 for the Ryegate gage (06123500) indicate 2014 peak flow estimates are less than the 1981 FIS peak flows estimates (9% less for the 10-year recurrence interval and 17% less for the 100 year-recurrence interval.). These differences can be related to the period of record used in the FIS study (1947-1979) and the extended period of record used in the 2014 analysis (1941-2014). Comparison of the Lavina gage FIS values with the USGS 2014 extended record values indicates similar values for the 10-year recurrence interval and the 100-year recurrence interval (less than 5% difference). For the Roundup gage, the 10-year recurrence interval values are similar; however, the 100-year recurrence interval 2014 estimate is significantly higher (23.5% greater).

Table 9 Lavina FIS Flood Frequency Comparison

Flooding Source and Location	Peak Discharges (cfs)								
	Drainage Area[1] Square Miles	10-Year		50-Year		100-Year		500-Year	
		FIS	2014	FIS	2014	FIS	2014	FIS	2014
Musselshell River near the Town of Ryegate Gage No. 06123500	1,957	4,370	3,991	N/A	8,184	12,700	10,570	N/A	17,790
Musselshell River near Lavina Gage No. 06126050 (At Highway 3)	2,947	4,370	4,561	N/A	9,824	12,700	12,980	N/A	23,130
Musselshell River near the Town of Roundup At Gage No. 061265	3,998	4,990	4,773	N/A	10,880	11,900	14,700	N/A	27,520

1. Source: National Watershed Information System (NWIS)

3.2 Flow Change Node Locations

Future flood studies will use hydraulic models that are composed of geometric data and streamflow data. To accurately model the Musselshell River, the locations of major tributary confluences and other flow change locations must be identified. The results of this hydrologic analysis will be used as the streamflow data input at the tributary confluences within the hydraulic model. A detailed review of the study area was performed to identify all potential flow change locations (flow nodes) within the mainstem Musselshell River. At each flow node, a drainage basin area was delineated and streamflow values were calculated for the various recurrence interval floods. Generally, the hydraulic models simulate flood events using steady-state conditions, and, therefore, the peak flow rate calculated at a flow node is projected to the next upstream flow node. This method was followed for the hydrologic analysis calculations. Flow nodes were assigned immediately upstream of major tributaries; this method of locating the flow nodes was employed so that the additional flow resulting from the tributary confluence is accurately reflected to the reach downstream of the confluence.

To identify significant flow change locations (flow nodes), hydrologic Unit Code (HUC) 12-digit watershed boundaries were used to initially locate the flow nodes. The HUC 12-digit watershed boundaries represent the smallest USGS-delineated watershed areas available in geographic information system (GIS) format. Using ArcGIS (Esri's GIS mapping software), flow nodes were located just upstream of the HUC 12 boundary intersection with the Musselshell River mainstem.

This study uses the nearest Geographic Naming Information System (GNIS) hydrographic feature name for the ungaged flow node names. In some cases these features (typically tributary streams) flow into the mainstem Musselshell just downstream of the flow node. For hydrographic features that do not have a GNIS name, the river mile where the node is located is used as the node name.

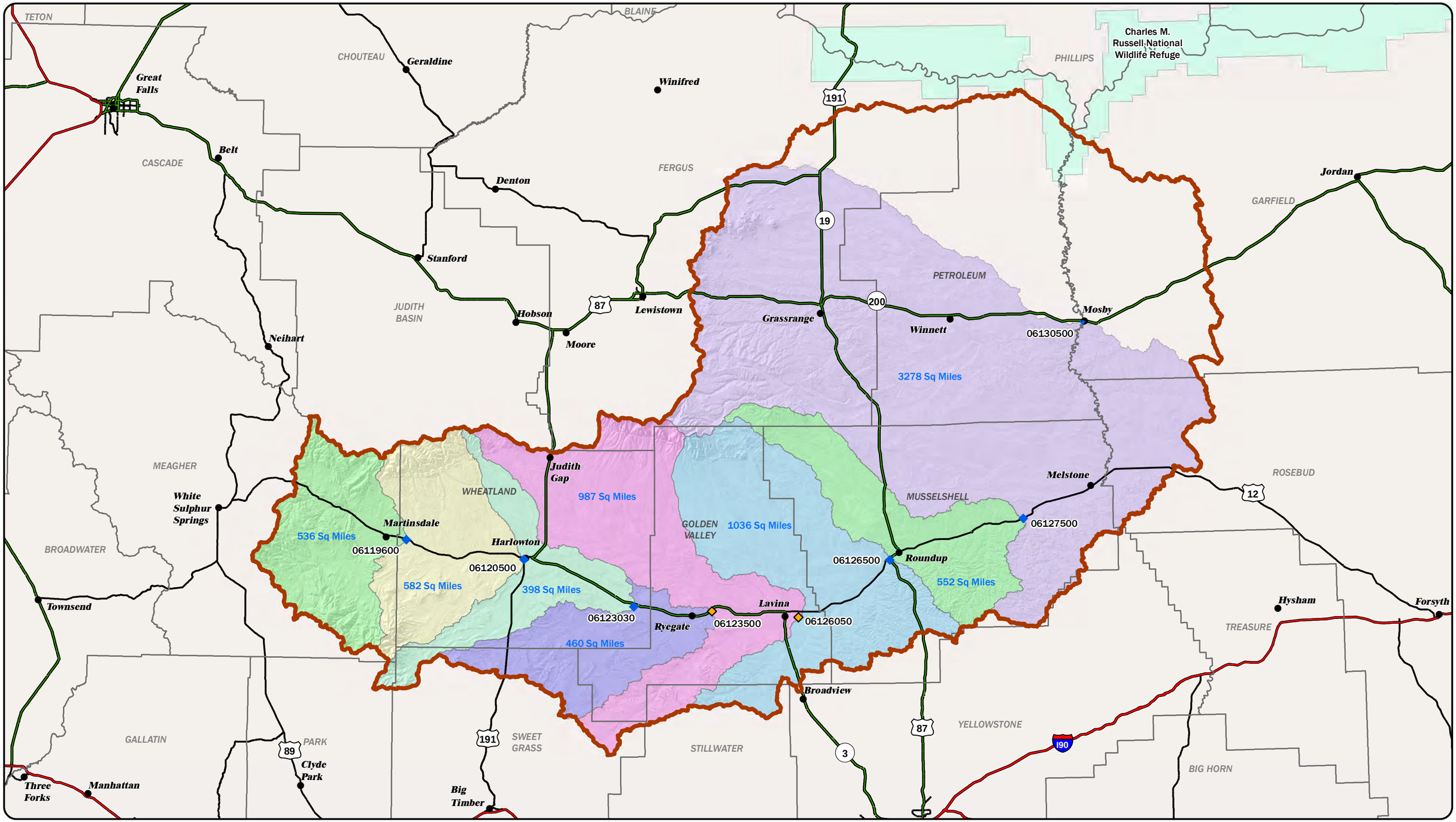
To avoid excessive flow changes between HUC 12 boundary nodes, additional flow nodes were located immediately downstream of towns, near the mid-point of reaches with significant length, or where intermediate tributaries within the HUC 12 boundaries intersected the mainstem. Two flow nodes were added downstream of towns, one at Lavina and one at Roundup. A total of 8 flow nodes were added as intermediate nodes between the HUC 12 boundaries. These town nodes and intermediate nodes are identified in Table 11.

After the initial flow node locations were established, a raster digital elevation model (DEM) data set of the entire Musselshell River watershed area was constructed by integrating USGS 10-meter resolution DEM tiles. Individual watershed areas for each flow node were then calculated using the Flow Accumulation tool in ArcGIS.

As an accuracy check, the USGS gaging station watershed areas calculated in ArcGIS, were compared to the USGS National Watershed Information System (NWIS) (http://waterdata.usgs.gov/nwis) published gaging station areas. Figure 9 shows the USGS gaging stations analyzed and the correlating GIS model-generated watershed areas along the study area. Table 10 shows the results of this comparison. Based on the 8 gaging stations analyzed, the project GIS model calculates watershed areas that are within 1% of the USGS NWIS published areas (Appendix A).

The USGS NWIS watershed area data are GIS-calculated watershed areas using the National Hydrography Dataset Plus Version2 (NHDPlusV2) that integrates the National Elevation Dataset (NED) and the Watershed Boundary Dataset. The NHDPlusV2 NED uses 30-meter resolution DEMs. Using a higher resolution DEM should result in a higher accuracy of the drainage area measurement; therefore, the watershed values based on the 10-meter DEMs were used in this analysis.

A total of 49 flow nodes were identified throughout the study reach, including 8 gaged locations and 41 ungaged locations. Table 11 is a summary of all flow nodes and the associated watershed areas. Figure 10 maps the flow node locations and corresponding watershed areas from Table 11.



LEGEND

- USGS GAGING STATION - ACTIVE
- USGS GAGING STATION - INACTIVE
- MUSSELSHELL RIVER WATERSHED

USGS STATION NUMBER

- 06119600
- 06120500
- 06123030
- 06123500
- 06126050
- 06126500
- 06127500
- 06130500

N

DISPLAYED AS:
PROJECTION/ZONE: MSP
DATUM: NAD 83
UNITS: INTERNATIONAL FEET
SOURCE: PIONEER/DNRC/USGS/NRIS

0 7.5 15 30
Miles

FIGURE 9

PIONEER TECHNICAL SERVICES, INC.

MUSSELSHELL RIVER USGS WATERSHEDS

DATE: 4/10/2015

Path: P:\DNRC\Musselshell\GIS\Project\HydraulicStudy\MslshlFP-GI-Hydra-002-14.mxd

Table 10 USGS and GIS Model Watershed Comparison

Station Number	Station Name	USGS Published Drainage Area[1] (mi^2)	GIS Calculated Cumulative Basin Areas[2] (mi^2)	Percent Change	Relative Accuracy of Areas
06119600	Musselshell River near Martinsdale, MT	537	536	0.14%	99.9%
06120500	Musselshell River at Harlowton, MT	1,108	1,118	0.88%	99.1%
06123030	Musselshell River above Mud Creek near Shawmut, MT	1,518	1,515	0.17%	99.8%
06123500	Musselshell River near Ryegate, MT	1,957	1,975	0.92%	99.1%
06126050	Musselshell River near Lavina, MT	2,947	2948	0.00%	100%
06126500	Musselshell River near Roundup, MT	3,998	3,998	0.00%	100.0%
06127500	Musselshell River at Musselshell, MT	4,534	4,550	0.36%	99.6%
06130500	Musselshell River at Mosby, MT	7,784	7,828	0.56%	99.4%

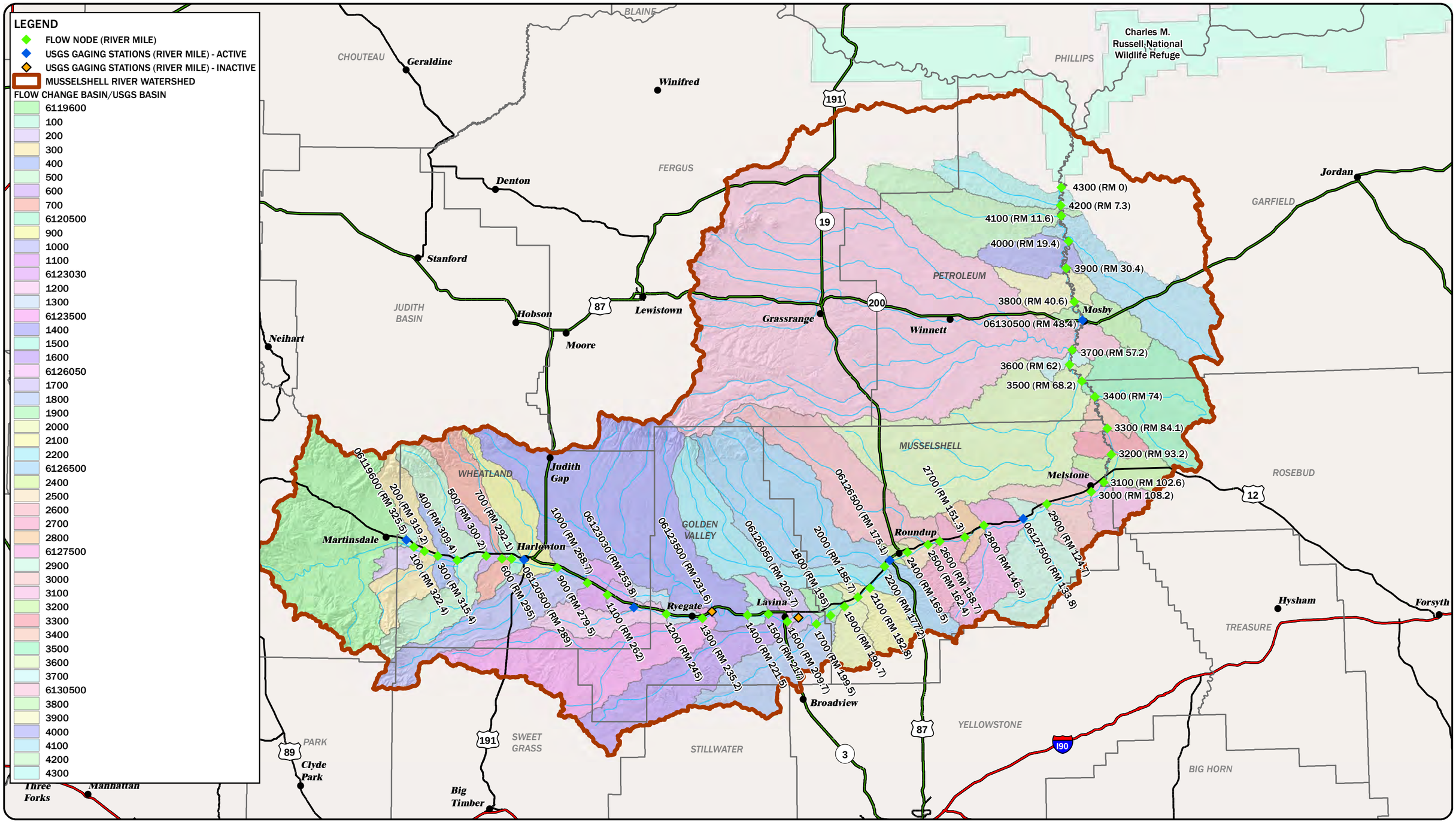
1. Source: National Watershed Information System (NWIS)
2. Cumulative basin areas (watershed areas) used for hydrological analysis.

Table 11 Flow Node and USGS Gage Station Information Used in Hydrologic Analyses

Node/USGS Station ID	Location Description	County	River Station[2] (mi)	GIS Incremental Basin Area (mi^2)	GIS Cumulative Basin Area (mi^2)
06119600	**Musselshell River near Martinsdale, MT**	**Wheatland**	**325.5**	**536**	**536**
100	River Mile 322.4[1]	Wheatland	322.4	7	544
200	Daisy Dean Creek	Wheatland	319.2	27	570
300	Little Elk Creek	Wheatland	315.4	131	701
400	Alkali Creek	Wheatland	309.4	36	737
500	Mexican John Creek	Wheatland	300.2	210	948
600	Mud Creek	Wheatland	295.0	33	981
700	Milton Creek[1]	Wheatland	292.1	113	1,094
06120500	**Musselshell River at Harlowton, MT**	**Wheatland**	**289.0**	**24**	**1,118**
900	American Fork	Wheatland	279.5	113	1,231
1000	River Mile 268.7	Wheatland	268.7	222	1,453
1100	River Mile 262[1]	Wheatland	262.0	42	1,495
06123030	**Musselshell River above Mud Creek, near Shawmut**	**Wheatland**	**253.8**	**21**	**1,515**
1200	River Mile 245[1]	Golden Valley	245.0	80	1,596
1300	Fish Creek	Golden Valley	235.2	29	1,624
06123500	**Musselshell River near Ryegate**	**Golden Valley**	**231.6**	**351**	**1,975**
1400	Ninemile Creek	Golden Valley	221.5	688	2,663
1500	Fivemile Creek	Golden Valley	217.0	22	2,684
1600	Big Coulee Creek	Golden Valley	209.7	245	2,929
06126050	**Musselshell River near Lavina**	**Golden Valley**	**205.7**	**19**	**2,948**
1700	Painted Robe Creek	Golden Valley	199.5	25	2,973
1800	River Mile 195[1]	Musselshell	195.0	165	3,138
1900	Dean Creek	Musselshell	190.7	28	3,167
2000	Goulding Creek[1]	Musselshell	185.7	67	3,233
2100	Currant Creek	Musselshell	182.8	75	3,308
2200	Horsethief Creek	Musselshell	177.2	235	3,543
06126500	**Musselshell River near Roundup**	**Musselshell**	**175.1**	**455**	**3,998**
2400	N-F Ditch[1]	Musselshell	169.5	10	4,008
2500	Willow Creek	Musselshell	162.4	21	4,028

Node/USGS Station ID	Location Description	County	River Station[2] (mi)	GIS Incremental Basin Area (mi^2)	GIS Cumulative Basin Area (mi^2)
2600	Parrot Creek	Musselshell	158.7	276	4,304
2700	Krueger Spendiff Ditch[1]	Musselshell	151.3	79	4,384
2800	Fattig Creek	Musselshell	146.3	31	4,415
06127500	**Musselshell River at Musselshell**	**Musselshell**	**133.8**	**136**	**4,550**
2900	Chandler Ditch	Musselshell	124.7	175	4,725
3000	Lost Horse Creek	Musselshell	108.2	91	4,816
3100	Horse Creek	Petroleum/Garfield	102.6	71	4,887
3200	River Mile 93.2	Petroleum/Garfield	93.2	71	4,958
3300	River Mile 84.1	Petroleum/Garfield	84.1	45	5,003
3400	Rattlesnake Creek	Petroleum/Garfield	74.0	33	5,036
3500	North Willow Creek	Petroleum/Garfield	68.2	262	5,298
3600	River Mile 62[1]	Petroleum/Garfield	62.0	610	5,908
3700	Flatwillow Creek	Petroleum/Garfield	57.2	22	5,931
06130500	**Musselshell River at Mosby**	**Petroleum/Garfield**	**48.4**	**1898**	**7,828**
3800	Cat Creek	Petroleum/Garfield	40.6	68	7,896
3900	Cottonwood Creek	Petroleum/Garfield	30.4	81	7,976
4000	Calf Creek	Petroleum/Garfield	19.4	84	8,060
4100	Blood Creek	Petroleum/Garfield	11.6	245	8,305
4200	Dovetail Creek	Petroleum/Garfield	7.3	243	8,549
4300	Lodgepole Creek	Petroleum/Garfield	0	101	8,650

1. Denotes an additional flow node change downstream of a town reach or intermediate tributary not associated with HUD-12 boundary
2. River miles start at the boundary of the Charles M. Russell Wildlife Refuge Area (mi: miles)



DISPLAYED AS:
PROJECTION/ZONE: MSP
DATUM: NAD 83
UNITS: INTERNATIONAL FEET
SOURCE: PIONEER/DNRC/USGS/ESRI

0 7.5 15 30
Miles

FIGURE 10

PIONEER TECHNICAL SERVICES, INC.

DELINEATED SUBBASIN AREAS AND FLOW NODE LOCATIONS

DATE: 4/10/2015

Path: P:\DNRC\Musselshell\GIS\Project\HydraulicStudy\MslshlFP-GI-Hydra-003-14.mxd

3.3 Gage Transfer to Ungaged Sites

To calculate peak flood discharge estimates at the ungaged flow nodes, methods described in USGS WRIR 03-4308 were considered. These methods included estimating flood frequency using regional flood-frequency relations (regression analysis) and estimating flood frequency on gaged streams by translating gaged data to ungaged locations (drainage area gage transfer and logarithmic interpolation between two gaged sites).

Based on the hydrologic regions defined in WRIR 03-4308, the Musselshell River flows through the Upper Yellowstone-Central Mountain Region and the East-Central Plains Region. The boundary between these two regions crosses the mainstem Musselshell River near the town of Ryegate. Downstream of Ryegate the Musselshell lies within the East-Central Plains Region. Upstream of Ryegate the Musselshell is within the Upper Yellowstone-Central Mountain Region. Most of the mainstem Musselshell River flow nodes within the East-Central Plains Region have watershed areas that exceed the maximum watershed area used to develop the regional regression equations. The WRIR 03-4308 report indicates that using the regional regression equations outside the range of the values used to develop the regional regression equations can lead to erroneous estimates and is not recommended; therefore, the regional regression equations were determined not applicable to ungaged sites within the East-Central Plains Region.

The Musselshell River flow nodes within the Upper Yellowstone-Central Mountain Region have watershed areas that are within the limits of the watershed area values used to develop the regional regression equations and therefore regression equations are considered an appropriate estimation method. Numerous USGS gaging stations are located on the mainstem Musselshell and all the ungaged flow nodes within the Upper Yellowstone-Central Mountain Region are located between two gaging stations. It is assumed that using the gaging station data will provide more accurate results than the regression equations. Based on the limitations of the regional regression equations and the availability of gaged sites upstream and downstream of ungaged flow node locations, it was decided that regional regression equations would not be used to estimate peak flow values at ungaged sites within the Upper Yellowstone-Central Mountain region.

Peak flow frequency estimates at ungagged flow nodes were calculated using the drainage area gage transfer method and the two site logarithmic interpolation method.

3.3.1 Two Site Logarithmic Interpolation Method

The log interpolation method presented in WRIR 03-4308 was used for analysis on ungaged sites between two gaged sites. In this method, the logarithm of the flood-frequency discharge estimates at the ungaged site is linearly interpolated based on discharge estimates and drainage basin areas of the upstream and downstream gaged sites. This method is presented in the equation below from WRIR 03-4308:

$$\log Q_{T,U} = \log \mathrm{Q}_{T,G1} + \frac{\log \mathrm{Q}_{T,G2} - \log \mathrm{Q}_{T,G1}}{\log \mathrm{DA}_{G2} - \log \mathrm{DA}_{G1}} (\log \mathrm{DA}_U - \log \mathrm{DA}_{G1})$$

where

log	is the base 10 logarithm
$Q_{T,U}$	is the *T*-year flood at the ungaged site, in cfs
$Q_{T,G1}$	is the *T*-year flood at the upstream gaged site, in cfs
$Q_{T,G2}$	is the *T*-year flood at the downstream gaged site, in cfs
DA_{G2}	is the drainage area at the downstream gaged site, in square miles
DA_{G1}	is the drainage area at the upstream gaged site, in square miles
DA_U	is the drainage area at the ungaged site, in square miles

Table 12 shows the calculation results. Figure 11 plots the relationship between the calculated discharge estimates and correlating drainage area. Results indicate estimated flows increase with increasing drainage area as expected and are consistent with the gage site estimates.

Table 12 Log Interpolation of 2014 Extended Period of Record Gage Results to Ungaged Flow Nodes

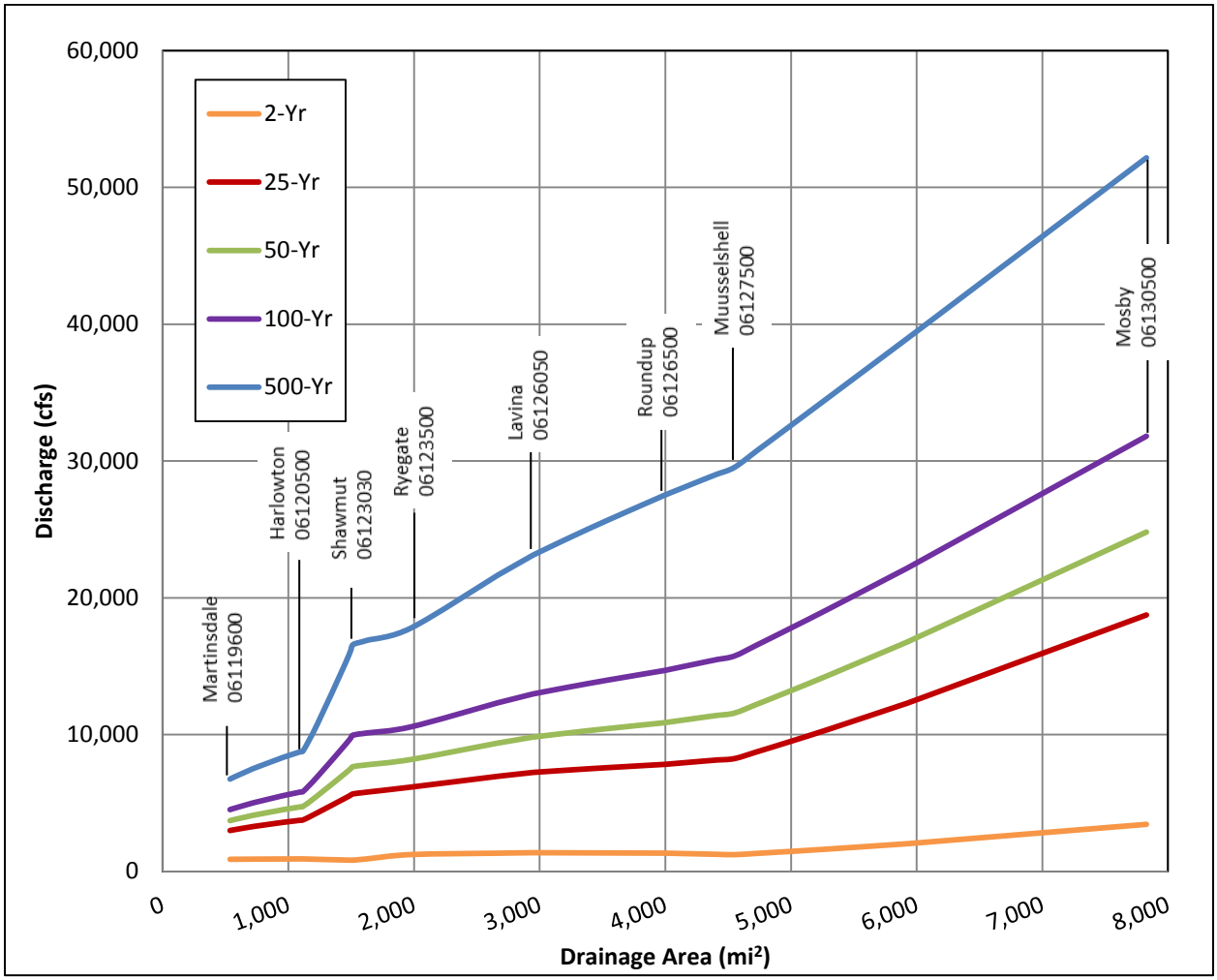
Node/USGS Station ID	Location Description	Log Interpolation of Gaged Analysis					
		Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
06119600	**Musselshell River near Martinsdale, MT**	**890**	**2,151**	**2,994**	**3,717**	**4,522**	**6,753**
100	River Mile 322.4[1]	890	2,159	3,007	3,734	4,543	6,786
200	Daisy Dean Creek	892	2,186	3,052	3,794	4,620	6,905
300	Little Elk Creek	900	2,309	3,256	4,067	4,968	7,444
400	Alkali Creek	902	2,339	3,308	4,136	5,055	7,580
500	Mexican John Creek	912	2,499	3,578	4,500	5,520	8,304
600	Mud Creek	913	2,522	3,617	4,552	5,586	8,407
700	Milton Creek[1]	918	2,595	3,742	4,722	5,804	8,747
06120500	**Musselshell River at Harlowton, MT**	**919**	**2,610**	**3,768**	**4,756**	**5,848**	**8,816**
900	American Fork	888	2,863	4,290	5,533	6,925	10,770
1000	River Mile 268.7	838	3,356	5,360	7,174	9,258	15,190
1100	River Mile 262[1]	830	3,449	5,568	7,500	9,729	16,110
06123030	**Musselshell River above Mud Creek, near Shawmut**	**826**	**3,495**	**5,673**	**7,665**	**9,968**	**16,580**
1200	River Mile 245[1]	893	3,586	5,766	7,763	10,082	16,809
1300	Fish Creek	918	3,619	5,799	7,798	10,122	16,889
06123500	**Musselshell River near Ryegate**	**1,236**	**3,991**	**6,167**	**8,184**	**10,570**	**17,790**
1400	Ninemile Creek	1,337	4,409	6,951	9,378	12,319	21,636
1500	Fivemile Creek	1,340	4,421	6,974	9,413	12,371	21,751
1600	Big Coulee Creek	1,371	4,551	7,222	9,795	12,937	23,032
06126050	**Musselshell River near Lavina**	**1,373**	**4,561**	**7,241**	**9,824**	**12,980**	**23,130**

Node/USGS Station ID	Location Description	Log Interpolation of Gaged Analysis					
		Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
1700	Painted Robe Creek	1,372	4,567	7,257	9,852	13,025	23,242
1800	River Mile 195[1]	1,366	4,604	7,358	10,032	13,315	23,969
1900	Dean Creek	1,365	4,610	7,375	10,062	13,364	24,092
2000	Goulding Creek[1]	1,363	4,624	7,415	10,132	13,478	24,379
2100	Currant Creek	1,360	4,640	7,459	10,210	13,605	24,700
2200	Horsethief Creek	1,353	4,688	7,591	10,448	13,991	25,685
06126500	**Musselshell River near Roundup**	**1,340**	**4,773**	**7,831**	**10,880**	**14,700**	**27,520**
2400	N-F Ditch	1,338	4,776	7,839	10,893	14,720	27,558
2500	Willow Creek	1,333	4,781	7,855	10,920	14,760	27,635
2600	Parrot Creek	1,276	4,850	8,068	11,274	15,290	28,654
2700	Krueger Spendiff Ditch[1]	1,260	4,869	8,128	11,374	15,440	28,943
2800	Fattig Creek	1,254	4,877	8,152	11,412	15,498	29,055
06127500	**Musselshell River at Musselshell**	**1,229**	**4,909**	**8,252**	**11,580**	**15,750**	**29,540**
2900	Chandler Ditch	1,320	5,225	8,736	12,209	16,538	30,730
3000	Lost Horse Creek	1,369	5,394	8,993	12,542	16,954	31,354
3100	Horse Creek	1,407	5,525	9,193	12,801	17,277	31,835
3200	River Mile 93.2	1,446	5,658	9,395	13,062	17,601	32,318
3300	River Mile 84.1	1,472	5,744	9,525	13,229	17,810	32,627
3400	Rattlesnake Creek	1,490	5,807	9,620	13,352	17,962	32,853
3500	North Willow Creek	1,641	6,316	10,387	14,338	19,183	34,648
3600	River Mile 62[1]	2,019	7,567	12,251	16,712	22,096	38,844
3700	Flatwillow Creek	2,033	7,614	12,320	16,800	22,203	38,997
06130500	**Musselshell River at Mosby***	**3,445**	**12,060**	**18,750**	**24,810**	**31,820**	**52,170**

* Sites downstream of USGS Gaging Station 06130500 were not included in the log linear interpolation method calculations.

1. Denotes an additional flow node downstream of a town or intermediate tributary not associated with HUD-12 boundary

Figure 11 Musselshell River Log Interpolation Gage Analysis Results



3.3.2 Drainage Area Gage Transfer Method

Ungaged flow nodes located downstream of the Musselshell River USGS Gaging Station 06130500 at Mosby do not lie between two gaged stations, therefore, the interpolation method cannot be employed. Estimating flood-frequency discharges for the ungaged flow nodes downstream of USGS Gaging Station 06130500 requires using the drainage area gage transfer method. This method, presented in WRIR 03-4308, uses a drainage area ratio of the ungaged flow node to the gaged station to transfer flow estimates from the gaged site to the ungaged site as shown below in the following equation (Parrett and Johnson, 2004):

$$Q_{T,U} = Q_{T,G}\left(\frac{\mathrm{DA}_U}{\mathrm{DA}_G}\right)^{\exp_T}$$

where

$Q_{T,U}$ is the *T*-year flood at the ungaged site, in cfs

$Q_{T,G}$ is the *T*-year flood at the gaged site, in cfs

DA_G is the drainage area at the gaged site, in square miles

DA_U is the drainage area at the ungaged site, in square miles

$\exp_T$ is the regression coefficient for a simple OLS regression relating to the log of the *T*-year flood to log of drainage area within each region

Limitations for this method include a recommended drainage area ratio between 0.5 and 1.5. All flow node drainage area ratios were verified to be within the recommended range. The drainage area transfer method provides an estimation method for the Musselshell River, where using the regression equations is not applicable (based on the flow node drainage areas in relation to the range of drainage area sizes used to develop the regression equations). Additional gage transfer methods using either the active channel width or the bankfull widths have been developed, but due to the variability of the Musselshell River channel dimensions and geomorphic instability, those methods were determined unsuitable for flood frequency estimation.

As previously discussed, the Musselshell River is located partially in the Upper Yellowstone-Central Mountain Region and partially in the East-Central Plains Region. Regression coefficients shown in the equation above vary based on hydrologic region and the flood recurrence interval. The applicable regression coefficients provided in Table 13 were used in these calculations. The drainage area transfer method results are shown in Table 14, and Figure 12 shows the plot for the calculated peak discharges and correlating drainage areas. Appendix B provides the flood frequency calculations at the ungaged flow nodes. Appendix C provides the digital calculation files. Results indicate peak flow estimates increase with increasing drainage area as expected.

Table 13 Drainage Area Gage Transfer Regression Coefficients

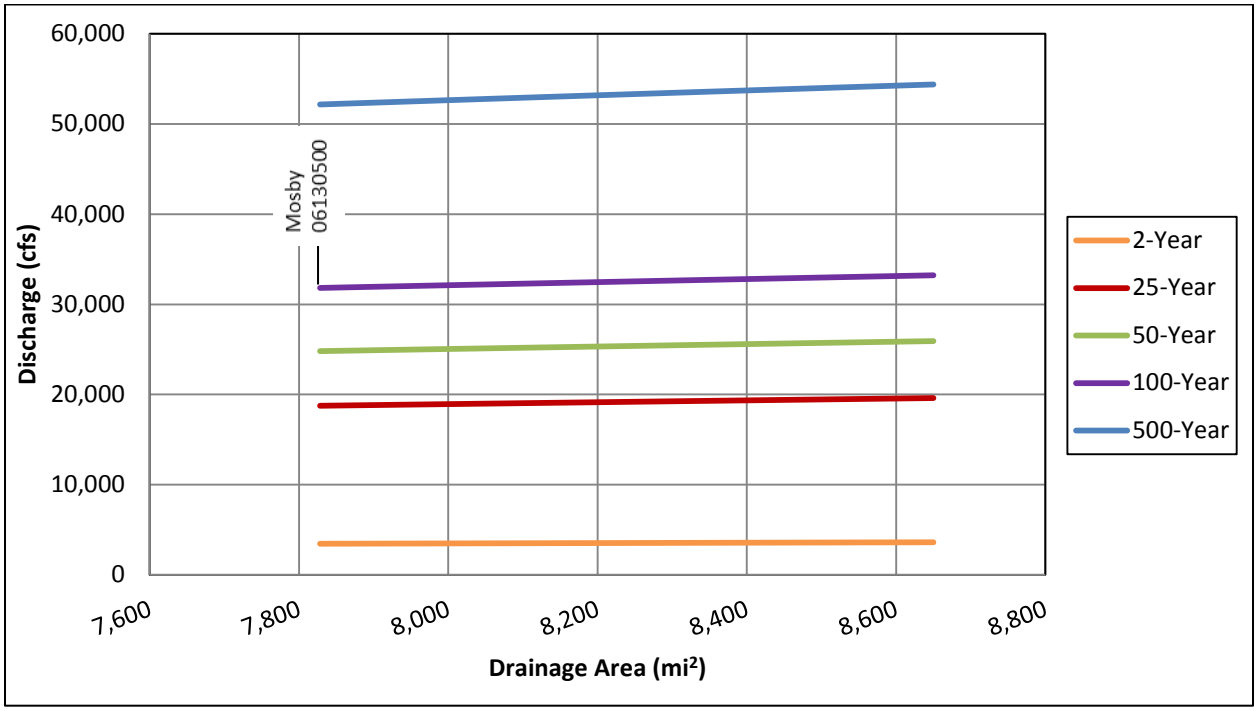
T-year flood	Regression Coefficient Relating T-year flood to Drainage Area for Indicated Region	
	Upper Yellowstone-Central Mountain Region	East-Central Plains Region
Q_2	0.877	0.464
Q_{10}	0.712	0.454
Q_{25}	0.656	0.446
Q_{50}	0.618	0.439
Q_{100}	0.587	0.432
Q_{500}	0.523	0.417

Source: WRIR 03-4308

Table 14 Drainage Area Gage Transfer Method Results for Flow Node Locations Downstream of USGS Gage 06130500 at Mosby

Node/USGS Station ID	Location Description	Drainage Area Gage Transfer					
		Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
06130500	**Musselshell River at Mosby**	**3,445**	**12,060**	**18,750**	**24,810**	**31,820**	**52,170**
3800	Cat Creek	3,459	12,107	18,822	24,904	31,938	52,357
3900	Cottonwood Creek	3,475	12,163	18,908	25,015	32,079	52,580
4000	Calf Creek	3,492	12,221	18,996	25,130	32,224	52,809
4100	Blood Creek	3,541	12,388	19,251	25,463	32,644	53,473
4200	Dovetail Creek	3,589	12,552	19,501	25,788	33,053	54,121
4300	Lodgepole Creek	3,608	12,619	19,604	25,922	33,222	54,388

Figure 12 Musselshell River Drainage Area Gage Transfer Results



4 SUMMARY/DISCUSSION

A peak discharge frequency analysis was conducted for the entire 335 mile stretch of the mainstem Musselshell River, from the confluence of the North and South Fork Musselshell rivers near Martinsdale, downstream to the intersection with the Charles M. Russell National Wildlife Refuge. Information gathered from this analysis will be used as the basis for future hydraulic analyses and floodplain mapping studies.

Previous flood studies on the Musselshell River are limited and most of the mainstem Musselshell River has no flood hazard mapping. The most relevant earlier flood studies were the City of Harlowton in Wheatland County FIS (FEMA, 1981a) and the Town of Lavina in Golden County FIS (FEMA, 1981b). Both of these studies were conducted in 1981. The USGS WRIR 03-4308, published in 2004 was also an important study which included flood frequency analysis for multiple Musselshell River gaging stations. The results of these previous studies were compared with the results of this study.

Flood frequency estimates for both gaged and ungaged sites were conducted. Peak flow estimates were calculated at 49 mainstem locations (flow nodes) within the watershed (8 gaged sites and 41 ungaged sites).

At the gaged sites, flood frequency estimates were conducted using two different gage record data sets; a systematic data set through 2014 and an extended record data set, 1941-2014. The flood flow frequency estimates were calculated using Bulletin #17B methodologies. Regional regression methods were considered but not used. In the middle to lower Musselshell watershed, drainage areas exceeded the regional regression application limits. In the upper watershed, the gage analysis was selected over the regional regression methods due to the higher confidence associated with flood frequency estimates that are based on measured stream flows.

The systematic record data set had variable and discontinuous periods of record between the stream gages and produced results where flood discharge did not always increase with increasing drainage area. To address these non-congruent periods of record, data transfer methods were used to extend the historical gage records and create an extended record data set.

Flood flow frequency results from this study were compared with flood flow frequency estimates from the previous studies. In the upper Musselshell River watershed, flood frequency estimates from this study compared well with previous studies. In the middle and lower reaches of the Musselshell River, the flood flow frequency estimates from this study produced significantly higher peak discharge estimates at the 1% and 0.2% annual chance flood potential. In the middle and lower watershed reaches, the significant differences in peak flow estimates between this study and previous studies can be attributed to the large floods, which occurred in 2011 and 2014. At the Roundup Gage (06126500) and the Mosby Gage (06130500), the 2011 flood was the peak flow of record and was significantly larger than the previous floods of record. The 2014 floods (one in March at Roundup and one in August at Mosby) produced the second highest peak flow of record at both the Roundup Gage and the Mosby gage. These 2014 floods were also significantly higher than the pre-2011 floods of record. As a result, the 1% and 0.2% annual chance flood potential are significantly higher than previous studies.

In the upper Musselshell basin, the 2011 and 2014 floods were not as large and consequently did not significantly alter 2014 flood frequency estimates compared with previous studies.

The flood flow frequency estimates based on the gage extended record data set were determined to provide the most accurate peak flow estimates for the basin, due to the long congruent period of record, which minimized errors associated with non-congruent periods of gage records.

Flood flow frequency estimates were also conducted at 41 ungaged locations. The ungaged sites (flow nodes) were located at major tributaries, population centers, and at intermediate locations in longer reaches.

Three methods were considered for estimating peak flood discharges at ungaged flow nodes: 1) Regional Regression; 2) Two Station Logarithmic Interpolation method; and 3) the Drainage Area gage transfer method.

The regional regression method was not selected for the reasons discussed previously.

The Two Station Logarithmic Interpolation method was used on 35 ungaged flow nodes between USGS Gaging Station 06119600 near Martinsdale and USGS Gaging Station 06130500 at Mosby.

The drainage area gage transfer method was used on the 6 flow nodes located downstream of USGS Gaging Station 06130500 at Mosby. This method was required for the furthest downstream flow nodes because they were not located between two USGS gaging stations. A summary of the resulting, recommended discharge rates from both methods are shown in Table 15. Figure 13 shows the recommended 1% annual discharge for each flow node location.

The hydrologic analysis results provided in Table 15 represent the recommended discharges at each flow node location throughout the study reach. The methods used for hydrological analysis are industry accepted methods (Bulletin #17B and WRIR 03-4308) based on the Musselshell River's basin characteristics. This hydrologic analysis conforms to FEMA standards for detailed/enhanced level studies, and the recommended flows of this analysis are deemed reliable and suitable for future floodplain studies and hydraulic analyses.

Table 15 Flood Discharge Estimates from the Log Interpolation Method and Drainage Area Transfer Method

Node/USGS Station ID	Location Description	Peak Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
06119600	**Musselshell River near Martinsdale, MT**	**890**	**2,151**	**2,994**	**3,717**	**4,522**	**6,753**
100	River Mile 322.4[1]	890	2,159	3,007	3,734	4,543	6,786
200	Daisy Dean Creek	892	2,186	3,052	3,794	4,620	6,905
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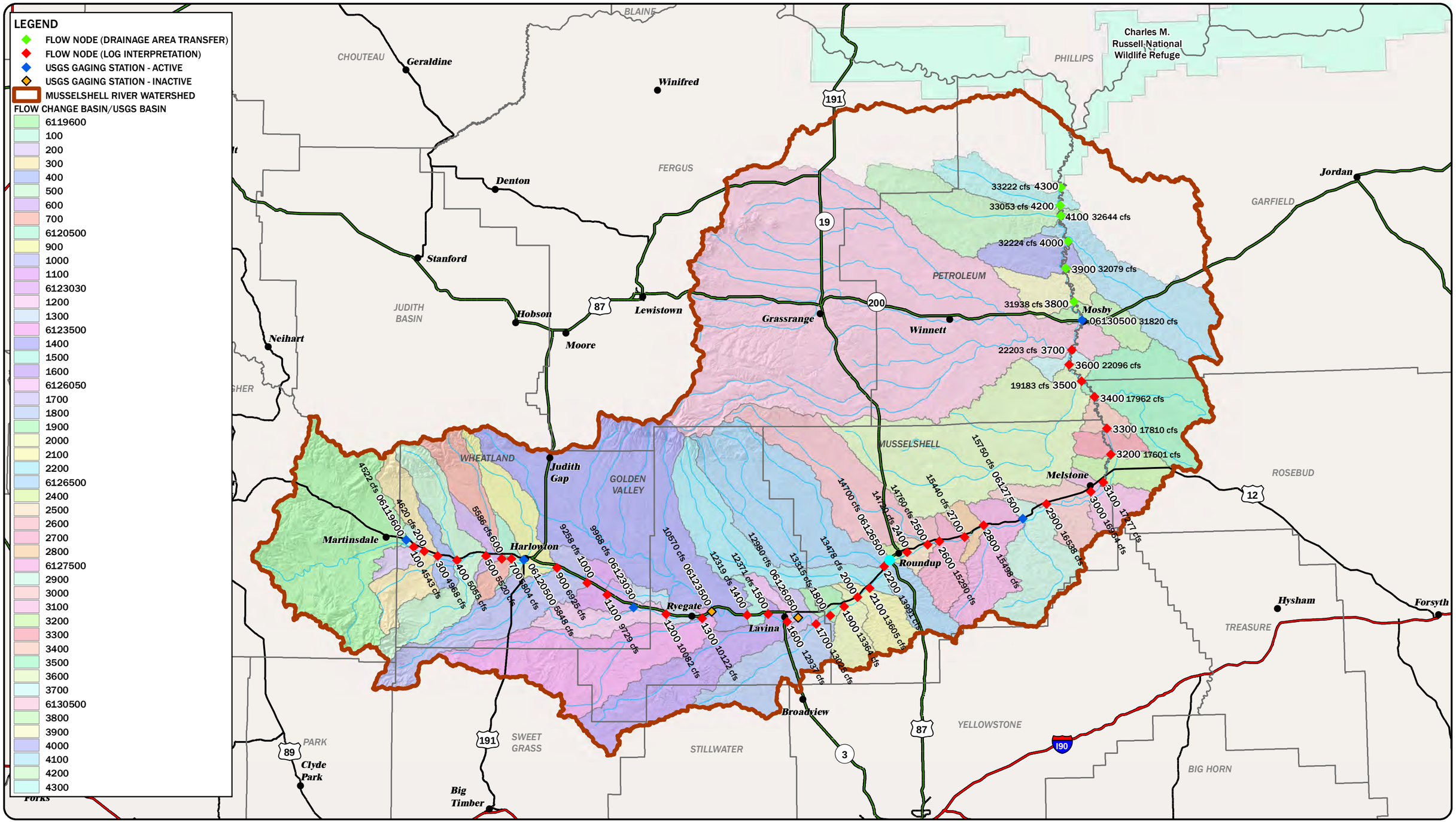
400	Alkali Creek	902	2,339	3,308	4,136	5,055	7,580
500	Mexican John Creek	912	2,499	3,578	4,500	5,520	8,304
600	Mud Creek	913	2,522	3,617	4,552	5,586	8,407
700	Milton Creek[1]	918	2,595	3,742	4,722	5,804	8,747
06120500	**Musselshell River at Harlowton, MT**	**919**	**2,610**	**3,768**	**4,756**	**5,848**	**8,816**
900	American Fork	888	2,863	4,290	5,533	6,925	10,770
1000	River Mile 268.7	838	3,356	5,360	7,174	9,258	15,190
1100	River Mile 262[1]	830	3,449	5,568	7,500	9,729	16,110
06123030	**Musselshell River above Mud Creek, near Shawmut**	**826**	**3,495**	**5,673**	**7,665**	**9,968**	**16,580**
1200	River Mile 245[1]	893	3,586	5,766	7,763	10,082	16,809
1300	Fish Creek	918	3,619	5,799	7,798	10,122	16,889
06123500	**Musselshell River near Ryegate**	**1,236**	**3,991**	**6,167**	**8,184**	**10,570**	**17,790**
1400	Ninemile Creek	1,337	4,409	6,951	9,378	12,319	21,636
1500	Fivemile Creek	1,340	4,421	6,974	9,413	12,371	21,751
1600	Big Coulee Creek	1,371	4,551	7,222	9,795	12,937	23,032
06126050	**Musselshell River near Lavina**	**1,373**	**4,561**	**7,241**	**9,824**	**12,980**	**23,130**
1700	Painted Robe Creek	1,372	4,567	7,257	9,852	13,025	23,242
1800	River Mile 195[1]	1,366	4,604	7,358	10,032	13,315	23,969

Node/USGS Station ID	Location Description	Peak Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
1900	Dean Creek	1,365	4,610	7,375	10,062	13,364	24,092
2000	Goulding Creek[1]	1,363	4,624	7,415	10,132	13,478	24,379
2100	Currant Creek	1,360	4,640	7,459	10,210	13,605	24,700
2200	Horsethief Creek	1,353	4,688	7,591	10,448	13,991	25,685
06126500	**Musselshell River near Roundup**	**1,340**	**4,773**	**7,831**	**10,880**	**14,700**	**27,520**
2400	N-F Ditch	1,338	4,776	7,839	10,893	14,720	27,558
2500	Willow Creek	1,333	4,781	7,855	10,920	14,760	27,635
2600	Parrot Creek	1,276	4,850	8,068	11,274	15,290	28,654
2700	Krueger Spendiff Ditch[1]	1,260	4,869	8,128	11,374	15,440	28,943
2800	Fattig Creek	1,254	4,877	8,152	11,412	15,498	29,055
06127500	**Musselshell River at Musselshell**	**1,229**	**4,909**	**8,252**	**11,580**	**15,750**	**29,540**
2900	Chandler Ditch	1,320	5,225	8,736	12,209	16,538	30,730
3000	Lost Horse Creek	1,369	5,394	8,993	12,542	16,954	31,354
3100	Horse Creek	1,407	5,525	9,193	12,801	17,277	31,835
3200	River Mile 93.2	1,446	5,658	9,395	13,062	17,601	32,318
3300	River Mile 84.1	1,472	5,744	9,525	13,229	17,810	32,627
3400	Rattlesnake Creek	1,490	5,807	9,620	13,352	17,962	32,853
3500	North Willow Creek	1,641	6,316	10,387	14,338	19,183	34,648
3600	River Mile 62[1]	2,019	7,567	12,251	16,712	22,096	38,844
3700	Flatwillow Creek	2,033	7,614	12,320	16,800	22,203	38,997
06130500	**Musselshell River at Mosby**	**3,445**	**12,060**	**18,750**	**24,810**	**31,820**	**52,170**
3800	Cat Creek	3,459	12,107	18,822	24,904	31,938	52,357
3900	Cottonwood Creek	3,475	12,163	18,908	25,015	32,079	52,580
4000	Calf Creek	3,492	12,221	18,996	25,130	32,224	52,809

Node/USGS Station ID	Location Description	Peak Discharge (cfs)					
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year
4100	Blood Creek	3,541	12,388	19,251	25,463	32,644	53,473
4200	Dovetail Creek	3,589	12,552	19,501	25,788	33,053	54,121
4300	Lodgepole Creek	3,608	12,619	19,604	25,922	33,222	54,388

1. **Denotes an additional flow node change downstream of a town or intermediate tributary not associated with HUD-12 boundary**



DISPLAYED AS:
PROJECTION/ZONE: MSP
DATUM: NAD 83
UNITS: INTERNATIONAL FEET
SOURCE: PIONEER/DNRC/USGS/ESRI

0 7.5 15 30
Miles

FIGURE 13

PIONEER TECHNICAL SERVICES, INC.

RECOMMENDED 1-PERCENT ANNUAL DISCHARGE FOR EACH LOCATION

DATE: 4/30/2015

Path: P:\DNRC\Musselshell\GIS\Project\HydraulicStudy\MslshlFP-GI-Hydra-004-14.mxd

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Appendix A: USGS Flood Frequency Analysis

Flood frequency analyses for the Musselshell River Basin

The Musselshell River Basin is located in central Montana and flows easterly until it reaches Melstone, MT before turning north and flowing into Fort Peck Reservoir. The headwaters of the Musselshell River include the North Fork and South Fork of the Musselshell River which receives contributions from the Little Belt Mountains, Castle Mounts, and Crazy Mountains. Three gages have been operated on the North Fork Musselshell River and two gages have been operated on the South Fork Musselshell River. The main stem Musselshell River has been gaged at nine different locations (table B1). Drainage areas for the main stem gages vary from 538 square miles at Martinsdale to 7,846 square miles at Mosby.

Streamflow regulation to some degree exists for all of the main stem sites on the Musselshell River. As of 2011 the percent of the basin regulated by reservoirs ranges from 13.8 to 24.7 for the nine main stem gages (table B1). For the purpose of this flood frequency study, gages were defined as regulated when greater than 20 percent of the basin lays upstream from reservoirs. Within the Musselshell River Basin, four gages are considered regulated based on this definition. Dates of regulation for the main stem sites range from 1956 to 1978. *(The rest of this paragraph involves further discussion on regulation. We have yet to determine how to address regulated sites which are considered regulated by the cumulative effect of multiple dams)* The 20-percent rule for determining regulation will result in some streamgages being classified as regulated due to the cumulative effect of multiple small reservoirs. For example, Musselshell River at Harlowton (06120500) and Musselshell River at Mosby (06130500) are classified as regulated; however, the peak streamflows at these gaged locations are not regulated by a large reservoir designed for flood-control purposes. Large reservoirs designed for flood control typically reduce the peak magnitude and is evident in pre- and post-regulation analyses for streamgages below the reservoir. The effect of multiple smaller reservoirs on streamflow peaks can vary substantially based on many parameters such as the size and duration of the flood event as well as management of the reservoir. Thus a flood frequency analyses for the pre-regulation, post-regulation, and entire period of record will be performed for each streamgage which is considered regulated due to the cumulative effect of multiple small reservoirs

Flood frequency analyses were performed following Bulletin 17B (reference) for ten gages in the Musselshell River basin having ten or more systematic peak streamflows (table B2). Systematic records for regulated gages were divided into pre- and post-regulation periods and flood frequency analyses were performed on both periods when ten or more years of record was available for that period. Gages having less than 5 percent difference in drainage areas were evaluated for combining systematic records and performing one flood frequency analysis. Within the main stem Musselshell River Basin the systematic record for two gages (06122800 Musselshell River near Shawmut and 06123030 Musselshell River above Mud Creek, near Shawmut) were combined and used to develop a single flood frequency analysis (table B2). The South Fork Musselshell River above Martinsdale and the South Fork Musselshell River near Martinsdale were also combined.

Flood frequency analyses using the systematic peak streamflows on the Musselshell River Basin resulted in peak discharge estimates which do not consistently increase with increasing drainage areas (table B2), as is generally expected. These inconsistencies are generally related to non-congruent periods of record. Record extension methods such as MOVE.1, MOVE.2, 2-station analysis, and drainage area adjustment, may be used to develop congruent periods of record. Record extension is complicated in the Musselshell River Basin due to the effects of regulation. Nearly all gages have some regulation whereas only four gages are considered regulated by the 20-percent rule. Additionally complicating the record extension is regulation dates for gages in the Musselshell River Basin range from 1938-1978. A base period of 1941-2011 was selected for the record extension as the main stem gages generally have better continuity of record and all of the gages have some degree of regulation beginning in 1941. The MOVE.1 method was used to perform the initial record extension. The MOVE.1 method is used to estimate streamflows when the relation between the logarithms of the same-year peak discharges at the target station and a nearby index station is linear. Estimated peak streamflows from the MOVE.1 analysis generally resulted in strong correlations between the target and index stations (correlation coefficients ranged from 0.62-0.99, table B3). Annual peak estimates from the MOVE.1 were generally reasonable and consistent with known upstream and downstream peaks. However, the MOVE.1 method severely overestimated the largest peaks in some cases. Thus the ten largest peaks for each gage were inspected and a drainage area adjustment was used instead of the MOVE.1 estimate only when a systematic peak was recorded at the nearest upstream and nearest downstream gage. For the gages in the Musselshell River Basin a total of 20 peaks were estimated using the drainage area ratio rather than the MOVE.1 estimate.

Flood frequency estimates were calculated for eight gages using data from the systematic record and record extension methods for the base period 1941-2011 (table B4). The flood frequency estimates generally increased with increasing drainage areas. In some cases, the flood frequency estimates for the higher annual exceedance probabilities (AEP) did not increase with increasing drainage areas. Systematic peak flow data from congruent periods were inspected and determined that in many cases the lesser peaks tend to attenuate in the downstream direction, thereby validating that flood frequency estimates for the higher AEPs may not increase in with increasing drainage areas.

The 2014 peaks were obtained from the unit-values available on NWIS and are currently still considered unapproved and are subject to revision when the 2014 data is reviewed by the Billings Field Office.

Tables B.1 through B.4 based on data through water year 2014. The 2014 peaks are considered prelimenary and are subject to revision.	
B.1	Gage number, location, drainage area, and summary of regulation information.
B.2	Flood frequency analyses on the systematic record for each gage. Some gages are combined with others having similar drainage areas. Multiple analyses are presented for gages considered regulated by the 20-percent rule.
B.3	Summary of record extension methods used to construct congruent periods of record for additional flood frequency analyses.
B.4	Flood frequency analyses based on constructed congruent periods of record.

Table B.1: Flood frequency data for gages on the Musselshell River

Station number	Station name	Drainage area, in square miles	Period of systematic record	Regulated?	Year of regulation	Percent regulated in 2011
Gaging stations in the Musselshell River Basin						
06115500	North Fork Musselshell River near Delpine	37.3	1941-1979	No	NA	0.0
06116000	North Fork Musselshell River at Delpine	47.3	1909-1911, 1922-1932	No	NA	0.0
06118000	North Fork Musselshell River near Martinsdale	248	1908-1914	Yes	1938	41.4
06118500	South Fork Musselshell River above Martinsdale	268	1942-1979	No	NA	0.6
06119500	South Fork Musselshell River near Martinsdale	280	1908-1914, 1930, 1932	No	NA	0.6
06119600	Musselshell River near Martensdale	537	2003-2014	No	NA	19.4
06120500	Musselshell River at Harlowton	1108	1909-2014	Yes	1956	24.7
06122800	Musselshell River near Shawmut	1484	1986-1997	Yes	1978	20.5
06123030	Musselshell River above Mud Creek, near Shawmut	1518	1998-2014	Yes	1941	20.1
06123500	Musselshell River near Ryegate	1957	1947-1979	Yes	1941	17.9
06125600	Musselshell River above Big Coulee Creek at Lavina	2691	2012-2014	Yes	1941	NA
06126050	Musselshell River near Lavina	2947	1992-2011	Yes	1941	14.2
06126500	Musselshell River near Roundup	3998	1946-1948, 1950-2014	Yes	1941	13.8
06127500	Musselshell River at Musselshell	4534	1929-1930, 1932, 1946-1979, 1983-2013	Yes	1941	15.6
06130500	Musselshell River at Mosby	7784	1929, 1931-1932, 1934-1946, 1948-2014	Yes	1941	24.7

Station number	Station name	Period of record for which analysis was performed	Notes on flood frequency analysis	Peak discharge, in cubic feet per second, for indicated exceedance probability, in percent									
				66.66667	50	42.91845	20	10	4	2	1	0.5	0.2
				Peak discharge, in cubic feet per second, for indicated return interval, in years									
				1.5	2	2.33	5	10	25	50	100	200	500
Gaging stations in the Musselshell River Basin													
06115500	North Fork Musselshell River near Delpine	1941-1979	Bulletin 17B	64.8	88.7	101	160	214.8	291.2	352.6	417.2	485.2	580.5
06116000	North Fork Musselshell River at Delpine	1909-1911, 1922-1932	Bulletin 17B	71.3	120.8	149.8	318.9	514	836.4	1132	1474	1865	2460
00611800	North Fork Musselshell River near Martinsdale	1908-1914	--	--	--	--	--	--	--	--	--	--	--
06118500	South Fork Musselshell River above Martinsdale	1908-1979	Bulletin 17B, combined with 06119600. Historic analysis=106 yrs (1909-2014), 1975 (5240 cfs)	597.6	753.2	831.4	1263	1713	2435	3102	3897	4843	6374
06119500	South Fork Musselshell River near Martinsdale	1908-1914, 1930, 1932	Data combined with 06118500	--	--	--	--	--	--	--	--	--	--
06119600	Musselshell River near Martensdale, MT	2003-2014	Bulletin 17B, Historic Analyis=35 yrs (1980-2014), 2011 peak (4,780 cfs)	521.6	650.1	714.8	1085	1483	2142	2770	3538	4476	6041
06120500	Musselshell River at Harlowton	1909-2014	Bulletin 17B, entire period of record	685.4	987.3	1146.1	1942	2713	3824	4736	5713	6754	8232
06122800	Musselshell River near Shawmut	1986-1997	Data combined and presented with 06123030	--	--	--	--	--	--	--	--	--	--
06123030	Musselshell River above Mud Creek, near Shawmut	1986-2014	Bulletin 17B, combined with 06122800, post-regulation period	378.8	625.6	771.2	1720	2965	5361	7912	11280	15660	23420
06123500	Musselshell River near Ryegate	1947-1979	Bulletin 17B	919.9	1399	1662.4	3133	4744	7348	9722	12480	15670	20590
06125600	Musselshell River above Big Coulee Creek at Lavina	2012-2014	--	--	--	--	--	--	--	--	--	--	--
06126050	Musselshell River near Lavina	1992-2011	Bulletin 17B	628.8	854.6	975.5	1755	2726	4589	6613	9369	13100	20100
06126500	Musselshell River near Roundup	1946-1948, 1950-2014	Bulletin 17B	873.6	1321	1570.2	3096	4944	8288	11690	16020	21500	30940
06127500	Musselshell River at Musselshell	1946–79, 1983–2011	Bulletin 17B	704.8	1105	1332.9	2737	4460	7589	10760	14800	19870	28520
06130500	Musselshell River at Mosby	1929, 1931–32, 1934–40	Bulletin 17B, pre-regulation period	2987.8	4371	5114.9	9156	13440	20220	26290	33270	41250	53480
		1941–46, 1948–2011	Bulletin 17B, post-regulation period	2216.8	3441	4122.6	7944	12160	18970	25170	32350	40600	53290
		1929-2014	Bulletin 17B, entire period of record	2307.8	3556	4247.1	8081	12260	18940	24960	31880	39780	51830

Table B.3: Details for performing a record extension on the Musselshell River gages

Target stations for which peak streamflows were synthesized					Index stations used for sythesis of peak streamflows						
Station number	**Station Name**	**Drainage area, in square miles**	**Period of systematic record**	**Ungaged period requiring synthesis of annual peak streamflows**	**Station number**	**Station name**	**Drainage area, in square miles**	**Number of annual peak streamflows synthesized based on this station**	**Correlation coefficient for concurrent data for target and index station**	**Standard error of prediction of MOVE.1 analysis**	**Years for which peak was adjusted using drainage area ratio**
Gaging stations in the Musselshell River Basin											
06119600	Musselshell River near Martensdale, MT	537	2003-2014	1941-2002	06120500	Musselshell River at Harlowton	1108	7	0.89	34.575	1942, 1948, 1967, 1975, 1979
					06123030	Musselshell River above Mud Creek, near Shawmut	1518	17	0.94		
					06126500	Musselshell River near Roundup	3998	33	0.90		
06120500	Musselshell River at Harlowton	1108	1941-2014	--	--	--	--	--	--	--	--
06123030	Musselshell River above Mud Creek, near Shawmut	1518	1986-2014	1941-1985	06120500	Musselshell River at Harlowton	1108	41	0.94	44.838	1948,1967, 1975, 1979
06123500	Musselshell River near Ryegate	1957	1947-1979	1941-1946, 1980-2014	06120500	Musselshell River at Harlowton	1108	34	0.86	54.523	1997, 2011
06126050	Musselshell River near Lavina	2947	1992-2011	1941-1991, 2012-2014	06120500	Musselshell River at Harlowton	1108	5	0.90	18.765	1948, 1951, 1967, 1975, 1978, 1979, 2014
					06126500	Musselshell River near Roundup	3998	41	0.99		
					06127500	Musselshell River at Musselshell	4534	1	0.98		
06126500	Musselshell River near Roundup	3998	1946-1948, 1950-2014	1941-1945, 1949	06118500	South Fork Musselshell River above Martinsdale	268	4	0.72	55.232	--
					06120500	Musselshell River at Harlowton	1108	1	0.81		
					06127500	Musselshell River at Musselshell	4534	1	0.96		
06127500	Musselshell River at Musselshell	4534	1946-1979, 1983-2013	1941-1945, 1980-1982, 2014	06120500	Musselshell River at Harlowton	1108	5	0.84	50.387	1981, 2014
					06126500	Musselshell River near Roundup	3998	2	0.96		
06130500	Musselshell River at Mosby	7784	1941-1946, 1948-2014	1947	06123500	Musselshell River near Ryegate	1957	1	0.62	84.65	--

Table B.4: Flood frequency analysis for gages on the Musselshell River in which the record was extended

Station number	Station name	Period of record for which record extension was evaluated and flood frequency data developed	Methods used to develop extended record	Peak discharge, in cubic feet per second, for indicated exceedance probability, in percent									
				66.66667	50	42.91845	20	10	4	2	1	0.5	0.2
				Peak discharge, in cubic feet per second, for indicated return interval, in years									
				1.5	2	2.33	5	10	25	50	100	200	500
Gaging stations in the Musselshell River Basin													
Computations based on updated drainage areas and updated Q for 06130500 (4/24/2015)													
06119600	Musselshell River near Martinsdale, MT	1941-2014	MOVE.1, drainage area adjustment	667	890	1,004	1,583	2,151	2,994	3,717	4,522	5,417	6,753
06120500	Musselshell River at Harlowton	1941-2014	None	638	919	1,067	1,836	2,610	3,768	4,756	5,848	7,050	8,816
06123030	Musselshell River above Mud Creek, near Shawmut	1941-2014	MOVE.1, drainage area adjustment	489	826	1,024	2,173	3,495	5,673	7,665	9,968	12,590	16,580
06123500	Musselshell River near Ryegate	1941-2014	MOVE.1, drainage area adjustment	839	1,236	1,452	2,662	3,991	6,167	8,184	10,570	13,370	17,790
06126050	Musselshell River near Lavina	1941-2014	MOVE.1, drainage area adjustment	936	1,373	1,611	2,990	4,561	7,241	9,824	12,980	16,820	23,130
06126500	Musselshell River near Roundup	1941-2014	MOVE.1	898	1,340	1,584	3,045	4,773	7,831	10,880	14,700	19,460	27,520
06127500	Musselshell River at Musselshell	1941-2014	MOVE.1, drainage area adjustment	781	1,229	1,484	3,035	4,909	8,252	11,580	15,750	20,900	29,540
06130500	Musselshell River at Mosby	1941-2014	MOVE.1	2,226	3,445	4,122	7,904	12,060	18,750	24,810	31,820	39,850	52,170

Appendix B: Logarithmic Interpolation and Drainage Area Transfer Calculations

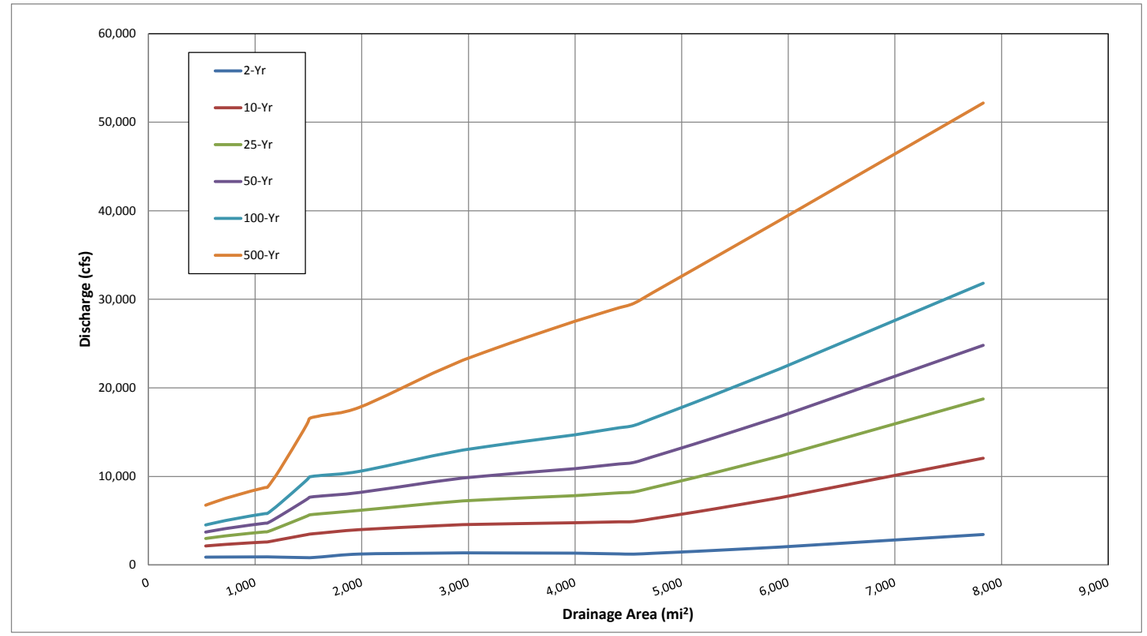
Count	Node/USGS Station ID	Location Description	County	County Reach River Station (miles)	Incremental Basin Area (mi^2)	Cumulative Basin Area (mi^2)	Log Interpolation of Gaged Analysis Estimated Discharge (cfs) 50% Annual Chance 2-year	10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance 500-year
1	**06119600**	**Musselshell River near Martinsdale, MT**	**Wheatland**	**325.5**	**536**	**536**	**890**	**2,151**	**2,994**	**3,717**	**4,522**	**6,753**
2	100	River Mile 322.4	Wheatland	322.4	7	544	890	2,159	3,007	3,734	4,543	6,786
3	200	Daisy Dean Creek	Wheatland	319.2	27	570	892	2,186	3,052	3,794	4,620	6,905
4	300	Little Elk Creek	Wheatland	315.4	131	701	900	2,309	3,256	4,067	4,968	7,444
5	400	Alkali Creek	Wheatland	309.4	36	737	902	2,339	3,308	4,136	5,055	7,580
6	500	Mexican John Creek	Wheatland	300.2	210	948	912	2,499	3,578	4,500	5,520	8,304
7	600	Mud Creek	Wheatland	295	33	981	913	2,522	3,617	4,552	5,586	8,407
8	700	Milton Creek	Wheatland	292.1	113	1094	918	2,595	3,742	4,722	5,804	8,747
9	**06120500**	**Musselshell River at Harlowton, MT**	Wheatland	289	**24**	**1118**	**919**	**2,610**	**3,768**	**4,756**	**5,848**	**8,816**
10	900	American Fork	Wheatland	279.5	113	1231	888	2,863	4,290	5,533	6,925	10,770
11	1000	River Mile 268.7	Wheatland	268.7	222	1453	838	3,356	5,360	7,174	9,258	15,190
12	1100	River Mile 262	Wheatland	262	42	1495	830	3,449	5,568	7,500	9,729	16,110
13	**06123030**	**Musselshell River above Mud Creek, near Shawmut**	**Wheatland**	**253.8**	**21**	**1515**	**826**	**3,495**	**5,673**	**7,665**	**9,968**	**16,580**
14	1200	River Mile 245	Golden Valley	245	80	1596	893	3,586	5,766	7,763	10,082	16,809
15	1300	Fish Creek	Golden Valley	235.2	29	1624	918	3,619	5,799	7,798	10,122	16,889
16	**06123500**	**Musselshell River near Ryegate**	Golden Valley	231.6	**351**	**1975**	**1,236**	**3,991**	**6,167**	**8,184**	**10,570**	**17,790**
17	1400	Ninemile Creek	Golden Valley	221.5	688	2663	1,337	4,409	6,951	9,378	12,319	21,636
18	1500	Fivemile Creek	Golden Valley	217	22	2684	1,340	4,421	6,974	9,413	12,371	21,751
19	1600	Big Coulee Creek	Golden Valley	209.7	245	2929	1,371	4,551	7,222	9,795	12,937	23,032
20	**06126050**	**Musselshell River near Lavina**	**Golden Valley**	**205.7**	**19**	**2948**	**1,373**	**4,561**	**7,241**	**9,824**	**12,980**	**23,130**
21	1700	Painted Robe Creek	Golden Valley	199.5	25	2973	1,372	4,567	7,257	9,852	13,025	23,242
22	1800	River Mile 195	Musselshell	195	165	3138	1,366	4,604	7,358	10,032	13,315	23,969
23	1900	Dean Creek	Musselshell	190.7	28	3167	1,365	4,610	7,375	10,062	13,364	24,092
24	2000	Goulding Creek	Musselshell	185.7	67	3233	1,363	4,624	7,415	10,132	13,478	24,379
25	2100	Currant Creek	Musselshell	182.8	75	3308	1,360	4,640	7,459	10,210	13,605	24,700
26	2200	Horsethief Creek	Musselshell	177.2	235	3543	1,353	4,688	7,591	10,448	13,991	25,685
27	**06126500**	**Musselshell River near Roundup**	**Musselshell**	**175.1**	**455**	**3998**	**1,340**	**4,773**	**7,831**	**10,880**	**14,700**	**27,520**
28	2400	N-F Ditch	Musselshell	169.5	10	4008	1,338	4,776	7,839	10,893	14,720	27,558
29	2500	Willow Creek	Musselshell	162.4	21	4028	1,333	4,781	7,855	10,920	14,760	27,635
30	2600	Parrot Creek	Musselshell	158.7	276	4304	1,276	4,850	8,068	11,274	15,290	28,654
31	2700	Krueger Spendiff Ditch	Musselshell	151.3	79	4384	1,260	4,869	8,128	11,374	15,440	28,943
32	2800	Fattig Creek	Musselshell	146.3	31	4415	1,254	4,877	8,152	11,412	15,498	29,055
33	**06127500**	**Musselshell River at Musselshell**	**Musselshell**	**133.8**	**136**	**4550**	**1,229**	**4,909**	**8,252**	**11,580**	**15,750**	**29,540**
34	2900	Chandler Ditch	Musselshell	124.7	175	4725	1,320	5,225	8,736	12,209	16,538	30,730
35	3000	Lost Horse Creek	Musselshell	108.2	91	4816	1,369	5,394	8,993	12,542	16,954	31,354
36	3100	Horse Creek	Petroleum/Garfield	102.6	71	4887	1,407	5,525	9,193	12,801	17,277	31,835
37	3200	River Mile 93.2	Petroleum/Garfield	93.2	71	4958	1,446	5,658	9,395	13,062	17,601	32,318
38	3300	River Mile 84.1	Petroleum/Garfield	84.1	45	5003	1,472	5,744	9,525	13,229	17,810	32,627
39	3400	Rattlesnake Creek	Petroleum/Garfield	74	33	5036	1,490	5,807	9,620	13,352	17,962	32,853
40	3500	North Willow Creek	Petroleum/Garfield	68.2	262	5298	1,641	6,316	10,387	14,338	19,183	34,648
41	3600	River Mile 62	Petroleum/Garfield	62	610	5908	2,019	7,567	12,251	16,712	22,096	38,844
42	3700	Flatwillow Creek	Petroleum/Garfield	57.2	22	5931	2,033	7,614	12,320	16,800	22,203	38,997
43	**06130500**	**Musselshell River at Mosby**	**Petroleum/Garfield**	**48.4**	**1898**	**7828**	**3,445**	**12,060**	**18,750**	**24,810**	**31,820**	**52,170**

For locations that are ungaged and located between two gaged locations with reliable period of record (10 yrs)
Equation utilizes drainage areas and flows.

$$\log Q_{TU} = \log Q_{TG1} + \frac{\log Q_{TG2} - \log Q_{TG1}}{\log DA_{G2} - \log DA_{G1}}(\log DA_U - \log DA_{G1}),$$

where

$\log$	is the base 10 logarithm,
Q_{TU}	is the *T*-year flood at the ungaged site, in cubic feet per second,
Q_{TG1}	is the *T*-year flood at the upstream gaged site, in cubic feet per second,
Q_{TG2}	is the *T*-year flood at the downstream gaged site, in cubic feet per second,
DA_{G2}	is the drainage area at the downstream gaged site, in square miles,
DA_{G1}	is the drainage area at the upstream gaged site, in square miles,
DA_U	is the drainage area at the ungaged site, in square miles,



Node/USGS Station ID	Location Description	County	County Reach River Station (miles)	Individual Basin Area (mi^2)	Cumulative Basin Area (mi^2)	DA_U/DA_G	Drainage Area Gage Transfer Estimated Discharge (cfs) 50% Annual Chance 2-year	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
06130500	**Musselshell River at Mosby**	**leum/Ga**	**48.4**	**1898**	**7828**	**-**	**3,445**	**12,060**	**18,750**	**24,810**	**31,820**	**52,170**
3800	Cat Creek	leum/Ga	40.6	68	7896	1.01	3,459	12,107	18,822	24,904	31,938	52,357
3900	Cottonwood Creek	leum/Ga	30.4	81	7976	1.02	3,475	12,163	18,908	25,015	32,079	52,580
4000	Calf Creek	leum/Ga	19.4	84	8060	1.03	3,492	12,221	18,996	25,130	32,224	52,809
4100	Blood Creek	leum/Ga	11.6	245	8305	1.06	3,541	12,388	19,251	25,463	32,644	53,473
4200	Dovetail Creek	leum/Ga	7.3	243	8549	1.09	3,589	12,552	19,501	25,788	33,053	54,121
4300	Lodgepole Creek	leum/Ga	0	101	8650	1.10	3,608	12,619	19,604	25,922	33,222	54,388

For an ungaged site that is not located between two gaged locations
Recommended that the drainage ratio be within 0.5 to 1.5

Equation recommended by WRIR 03-4308

Only use if one site below Mosby
or low drainage ratio

*** Recommended ratio be within 0.5 to 1.5
*East Central Plains Region for regression coefficient

$$Q_{T,U} = Q_{T,G}\left(\frac{DA_U}{DA_G}\right)^{\exp_T}$$

where

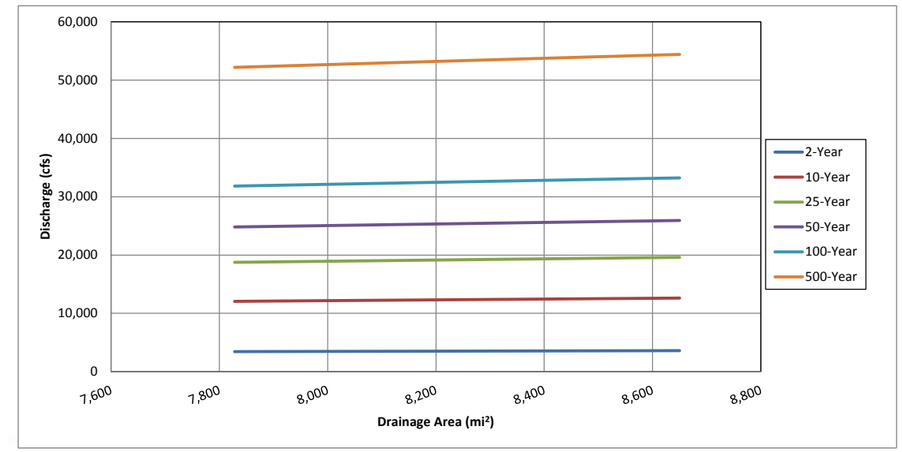
$Q_{T,U}$ is the T-year flood at the ungaged site, in cubic feet per second,

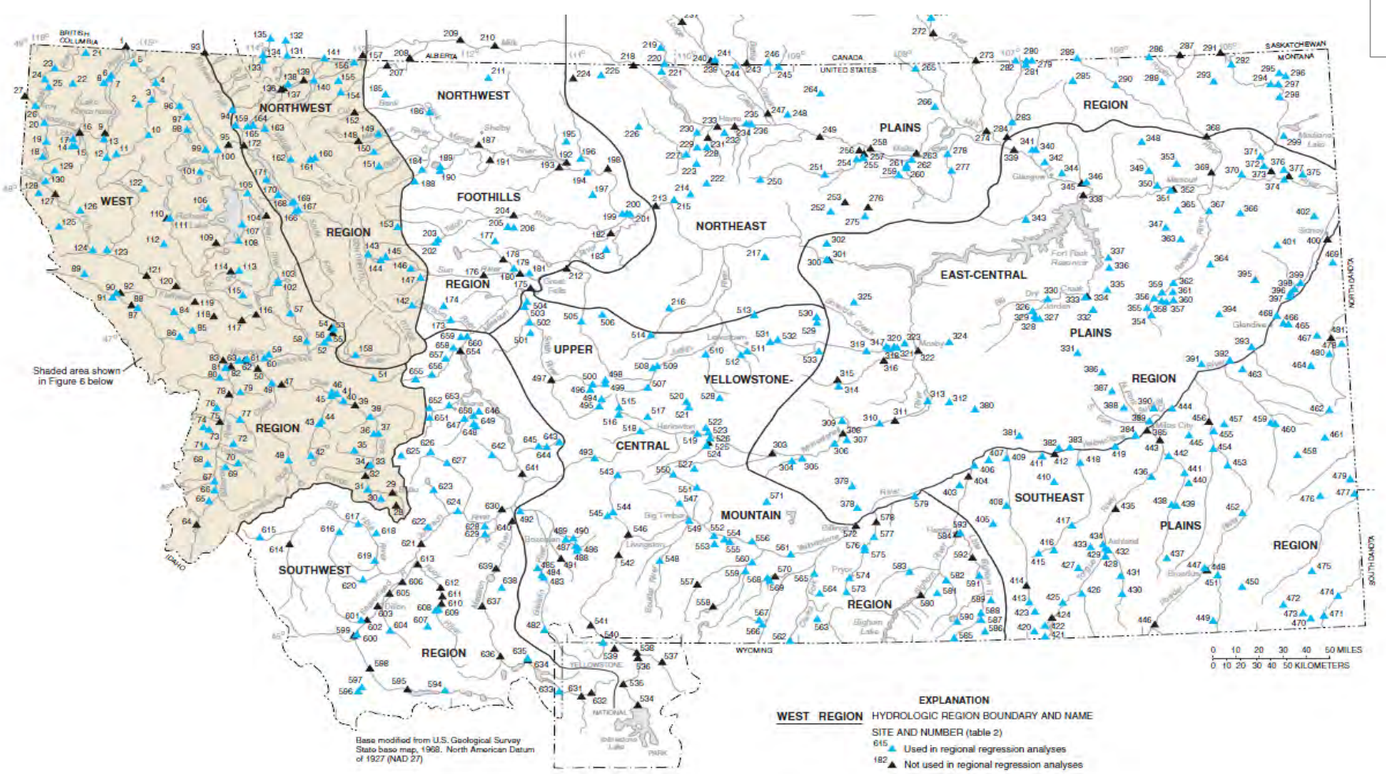
$Q_{T,G}$ is the T-year flood at gaged site, in cubic feet per second,

DA_G is the drainage area at the gaged site, in square miles,

DA_U is the drainage area at the ungaged site, in square miles,

$\exp_T$ is the regression coefficient for a simple OLS regression relating the log of the T-year flood to log of drainage area within each region.





.egression coefficients for ordinary least squares (OLS) regressions relating T-year flood (Q_T) to drainage area

od	Regression coefficient relating T-year flood to drainage area for indicated region: West Region	Northwest Region	Northwest Foothills Region	Northeast Plains Region	East-Central Plains Region	Southeast Plains Region	Upper Yellowstone-Central Mountain Region	Southwest Region
	0.851	0.884	0.609	0.620	0.464	0.516	0.877	0.894
	.818	.822	.587	.564	.459	.478	.768	.776
	.798	.789	.577	.536	.454	.458	.712	.720
	.776	.747	.566	.506	.446	.433	.656	.661
	.761	.722	.560	.486	.439	.418	.618	.622
	.747	.700	.555	.469	.432	.403	.587	.585
	.734	.685	.551	.453	.426	.389	.557	.550
	.717	.665	.547	.433	.417	.371	.523	.510

Appendix C: Digital Data and Calculation Files