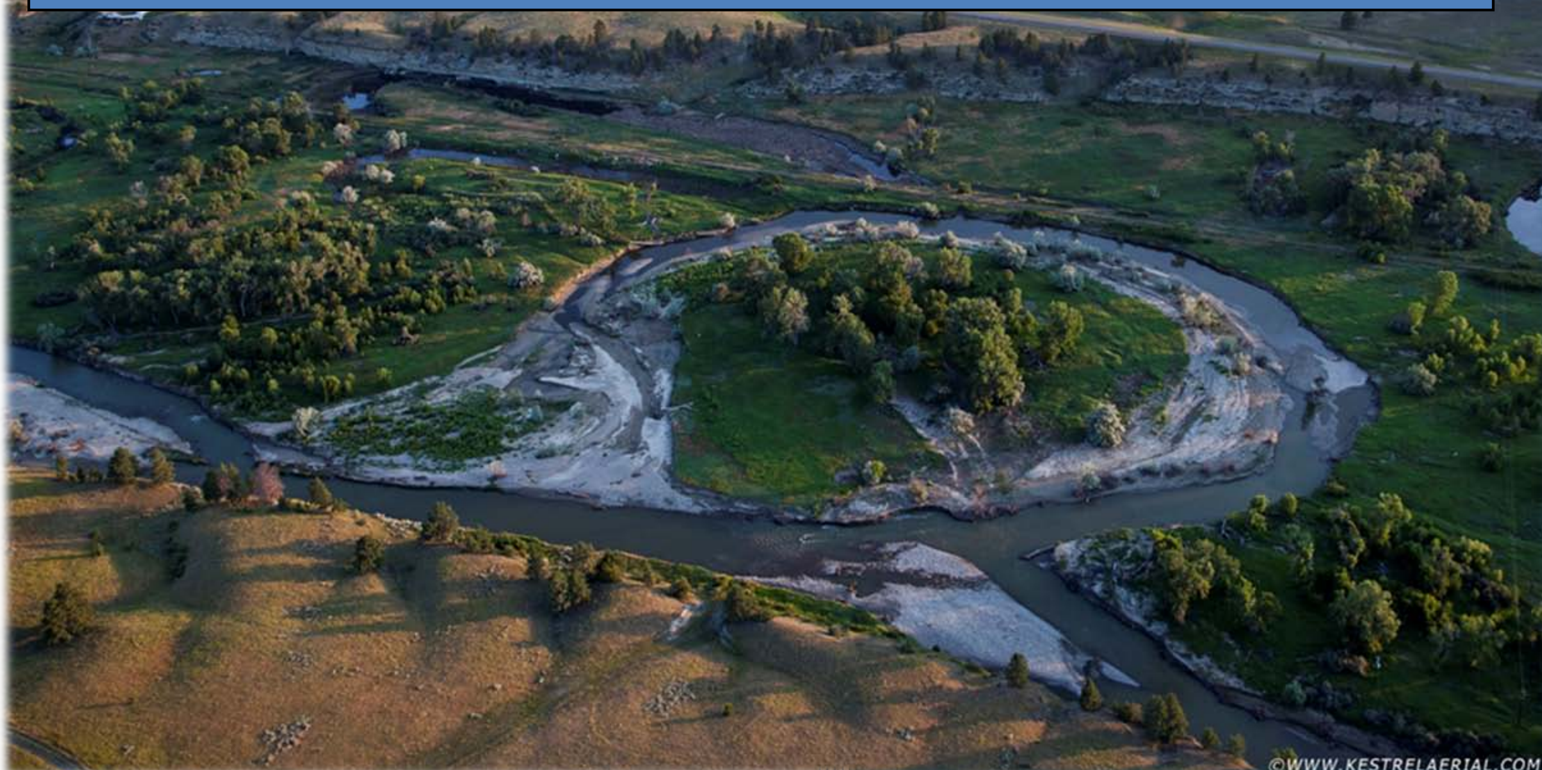
Report

July 17, 2012

Musselshell River Flood Rehabilitation River Assessment Triage Team (RATT) Summary Report



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1 Introduction

During the spring of 2011, the Musselshell River experienced unprecedented flooding that resulted in extensive damage to irrigation infrastructure, roads, bridges, residential structures, and productive agricultural fields. The peak of the flood is estimated to have had a 157-year return interval, or a 0.6% chance of occurring any given year. The flood was also long-lasting; in places, major flooding persisted for over three weeks, causing extensive bank erosion, and numerous avulsions. The river corridor was dramatically changed, and many of these changes will persist for decades (Figure 1).

In an effort to characterize these impacts and develop response strategies, the Musselshell Watershed Coalition (MWC), which is a partnership of water associations, conservation districts, and agencies, secured a Reclamation and Development Planning Grant to assemble and support a River Assessment Triage Team (RATT). This effort is the result of unprecedented cooperation among landowners, communities, local, state, federal agencies, private consultants, and Montana's full congressional delegation who created this opportunity to develop strategic approaches to flood damage rehabilitation and long-term river management. An objective of the MWC is to continue to pursue collaborative basin-wide water management using this historic event as a means to secure more cost-effective and resilient irrigation infrastructure, while improving riverine function and ecological sustainability.

The following report describes the results of the RATT work that was performed during late 2011 and early 2012. The RATT team visited landowners in the river corridor, assessed flood impacts on each property, developed conceptual rehabilitation alternatives to address those impacts, and identified potential conservation opportunities. Additional work performed to date includes mapping of specific flood impacts on the river such as avulsions and railroad berm breaches. The goal of the RATT effort is to effectively document the nature and impacts of this flood, and to identify means of responding to the event that can support local economies while promoting the sustainability of both long-term land uses and ecological function of the Musselshell River.

Figure 1. Pre flood (left) and post-flood (right) aerial view of lower Musselshell River below Mosby at RM 25.

This report is organized into the following chapters:

Chapter 1: Introduction.

Chapter 2: General setting.

Chapter 3: A description of the riparian vegetation of the Musselshell River corridor.

Chapter 4: The state of knowledge regarding the Musselshell River fishery.

Chapter 5: A summary of the 2011 flood event.

Chapter 6: Musselshell River geomorphology with an emphasis on the types of geomorphic impacts associated with the flood.

Chapter 7: Conceptual treatment alternatives for a range of flood impacts.

Chapter 8: Water rights considerations associated with potential remediation/restoration measures.

Chapter 9: Monitoring strategies and recommendations.

Chapter 10: A summary of relevant funding programs.

Appendix A: A glossary of terms commonly used in this report.

Appendix B: A summary of minimum flow recommendations developed by Montana Fish Wildlife and Parks.

Appendix C (on accompanying DVD): A series of 35 Site Reports generated by the RATT from fall 2011 through spring 2012.

Appendix D (on accompanying DVD): A series of 23 maps that show features mapped as part of this effort. The base maps are 2011 post-flood air photos (NAIP), and features identified include diversions, bridges, abandoned channel segments, isolated meanders, and rail berm breaches

1.1 Methods

This report leverages information from several sources. From fall 2011 through early winter 2012, the RATT team visited flood-impacted areas accompanied by local agency personnel and landowners to discuss site conditions and concerns (Figure 2). The types of sites visited included avulsions, abandoned or damaged irrigation infrastructure, excessive bank erosion, damaged fields, damaged siphons, and lost access to property. During these site visits, the RATT team assessed flood impacts and then developed restoration and/or rehabilitation strategies to address those impacts. This information was used to generate 35 individual site summary reports which were provided to local Conservation Districts (Appendix C). Additional information has since been collected on system-wide flood impacts. A Geographic Information Systems (GIS) project was constructed with pre-flood (2009) and post-flood (2011) air photo base maps. The Musselshell River centerlines for each of those air photo suites was mapped and used to create a river-mile index. Major features such as abandoned channels, rail road breaches, bridges, diversions, and meanders isolated by the rail line were also mapped (Appendix D).

Figure 2. River Assessment Triage Team (RATT) observing bank erosion site, lower Musselshell River.

This information has been further supplemented by low-altitude, aerial photographs collected by Chris Boyer of Kestrel Aerial Services Inc. Photos were provided to the RATT team from flights taken in April 2010, late May 2011, mid-June 2011, mid-September 2011, and early November 2011.

1.2 Summary of Major Findings

The following is a brief summary of major findings and recommendations described in this report:

- 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 nine 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 graded were mapped on post-flood air photos;
- Several diversion structures were flanked or abandoned;
- Dozens of irrigation pumps were abandoned;
- Floodplain deposition was several feet thick in some areas, commonly in agricultural fields;

- Vast carpets of cottonwood and willow seedlings were established by the flood; and,
- Effective rehabilitation strategies can address both short-term needs as well as the longer-term processes of system recovery.

1.3 Acknowledgements

The RATT team is comprised of Tom Pick (USDA Natural Resources Conservation Service), Warren Kellogg (Independent Contractor), Karin Boyd (Applied Geomorphology, Inc.), Mike Ruggles (Montana Fish, Wildlife, and Parks), and Scott Irvin (Montana Department of Natural Resources and Conservation). We extend our sincere thanks to Bill Milton of MWC for his vision and persistence in the promotion of collaborative approaches to water management in the Musselshell River basin. The local NRCS and Conservation District offices were instrumental in providing background information and scheduling site visits; to that end, we extend our gratitude to Krist Walsted, Reba Ahlgren, Ken Mosdal (NRCS Roundup Field Office), Donna Pedrazzi, and Shirley Parrot (Lower Musselshell Conservation District), Sue Potter-FitzGerald and BG FitzGerald (NRCS Jordan Field Office), Nikki Rife and Heather Richter (NRCS Winnett Field Office), Diane Ahlgren (Petroleum Conservation District), Lloyd Rowton (Petroleum County), John Oiestad (NRCS Harlowton Field Office), and Monty Sealey (Musselshell County). All of these people engaged in our work, scheduling field visits and assisting us in the field, and thus were critical to the ground work associated with this effort. Rena Ruffin (NRCS Economist) provided cost information used in site reports. Chris Boyer of Kestrel Aerial Services, Inc. provided an extensive suite of photographs taken from his plane before, during, and after the flood of 2011. Anne Tews (Montana Fish, Wildlife, and Parks) provided an internal review of the fisheries summary. And lastly, we would like to thank all of the producers of the Musselshell River Valley who requested our assistance, provided access to their lands and shared their experiences regarding the nature of the flooding, its impacts, and associated challenges they currently face.

2 General Setting

The Musselshell River drainage consists of approximately 8,000 square miles of central Montana (Figure 3). Elevations range from about 9,000 feet on the northern slopes of the Crazy Mountains in southern Meagher County to approximately 2,000 feet at the river mouth in northern Petroleum/Garfield Counties. The general terrain includes expansive grass and shrub lands, broken and rolling foothills, and a low density drainage network. The largest town in the area is Roundup, which is located near the middle of the watershed in west-central Musselshell County and has a population of about 2,000 people.

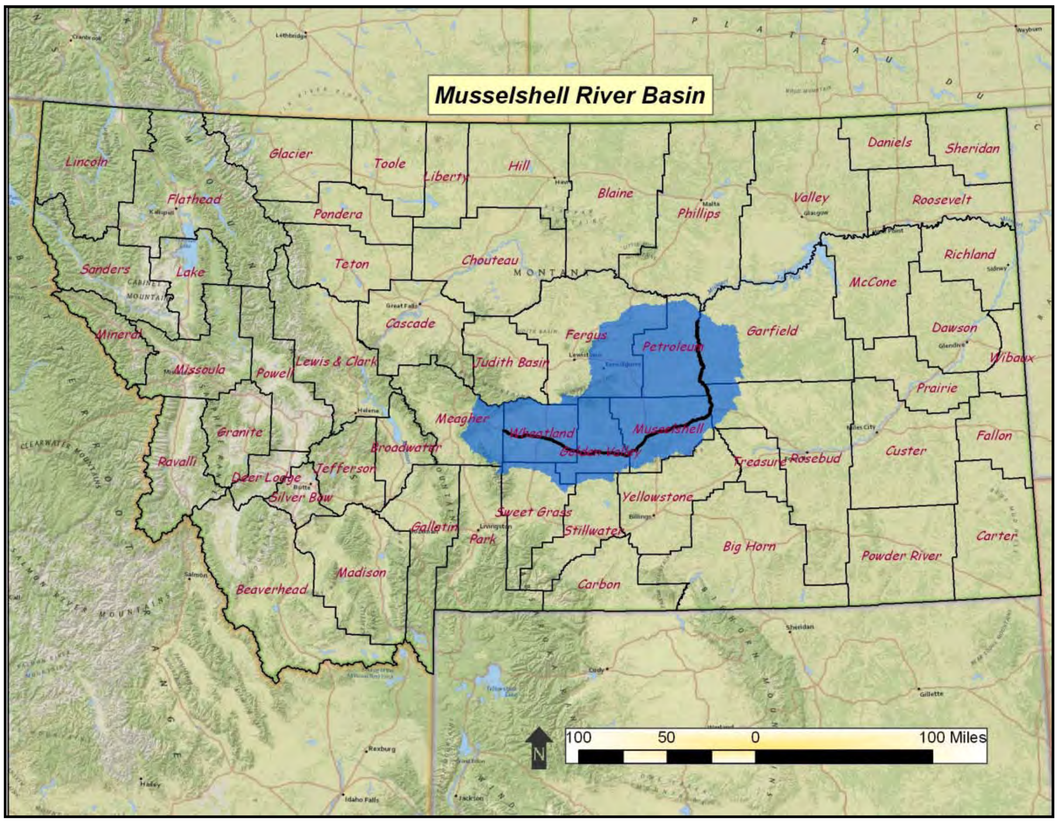

Figure 3. Musselshell Watershed in Montana, with assessment reach (black line) and counties labeled.

The main stem of the Musselshell River flows from the confluence of the North and South Forks near Martinsdale for nearly 340 miles to Fort Peck Reservoir. The River Assessment Triage Team (RATT) covered this entire extent of river, with field sites ranging from west of Harlowton to north of Mosby.

Throughout this report, site locations are referred to by River Mile (RM). To accurately define river miles, the 2011 NAIP aerial imagery was used to digitize the post-flood river centerline. The 2009 centerline was digitized as well to help quantify changes in channel length due to the flood. For spatial referencing, however, the 2011 centerline is used to most accurately depict current channel lengths and locations. Figure 4 shows a map of the overall project area and River Mile references for major points of interest are listed in Table 1.

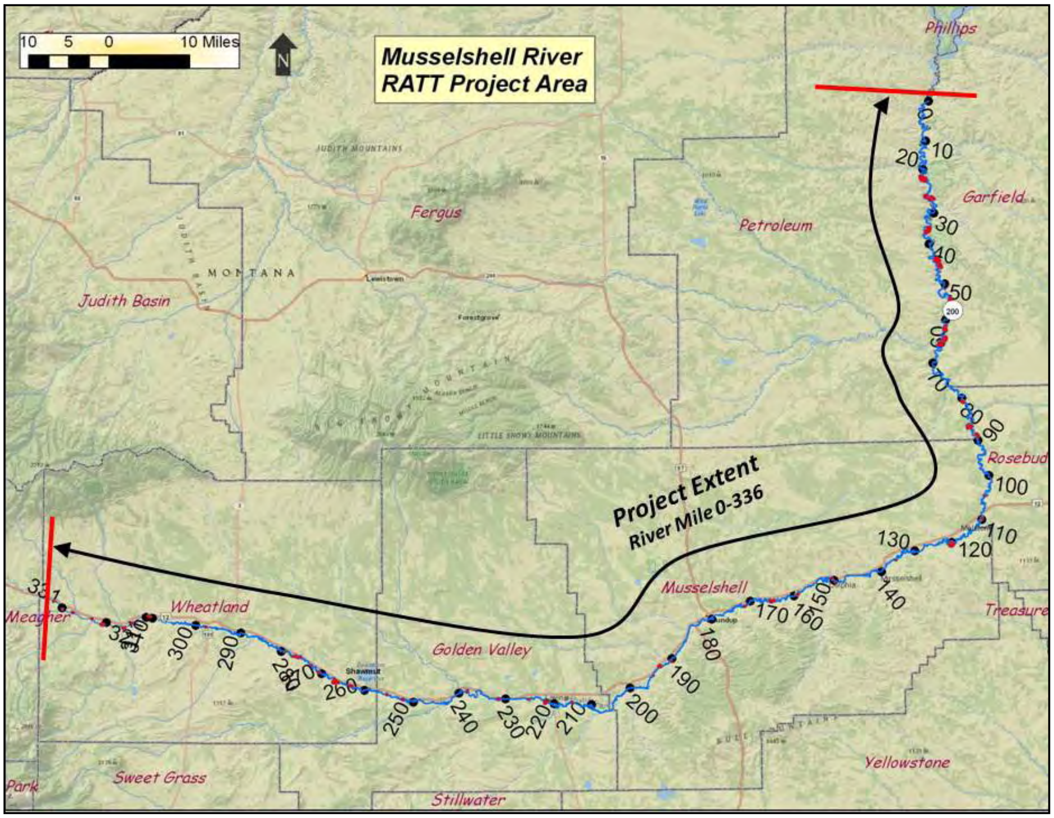

Figure 4. River Assessment Triage Team (RATT) Project Area; 2011 river miles are shown on digitized river centerline.

Table 1. 2011 River Mile locations of major features, Musselshell River Valley

Location	*2011 River Mile (RM)*		*Location*	*2011 River Mile (RM)*
Mouth (CMR Wildlife Refuge)	0		Delphia	150.5
Lodgepole Creek	8		Roundup	181
Dovetail Creek	14		Bundy	204
Blood Creek	19.7		Lavina	219.5
Calf Creek	27.3		Careless Creek	239.2
Hwy 200 (Mosby)	56.8		Ryegate	246.2
Flatwillow Creek	65		Barber	256
Garfield/Rosebud County Line	76.5		Shawmut	268
North Willow Creek	76.6		Harlowton	298
Melstone	115		South Fork Musselshell	335.9
Musselshell	140.5			

2.1 The Milwaukee Railroad

The Chicago, Milwaukee, St. Paul and Pacific Railroad—otherwise known as the Milwaukee Road, began operating between Milwaukee and Waukesha, Wisconsin in 1850. Between 1906 and 1909, the railroad extended through Montana to Seattle/Tacoma on the west coast. In Montana, the Milwaukee Road extended west from the North Dakota border near Baker to the Yellowstone River at Terry, following the Yellowstone River to Forsyth (Figure 5). At Forsyth, the track veered northwest towards the Musselshell River, reaching it a few miles east of Melstone. From Melstone, the rail line followed the Musselshell River valley westward past Harlowton and Two Dot, extending up the South Fork Musselshell River towards Ringling. The line through Roundup and Harlowton was completed in 1908 (Pederson, 1980).

In 1928, the railroad reorganized as the Chicago, Milwaukee, St. Paul & Pacific Railroad. The Milwaukee Road had over 650 miles of electrified track, and supported both freight and passenger trains. Electric engines were used between Harlowton and Avery, Idaho (Graetz, 2003). The railroad abandoned two-thirds of its track in 1977, and was acquired by Soo Line Corporation in 1985 (Rails to Trails Conservancy, 2004). The section of track between the North Dakota state line and Miles City was originally filed for abandonment in 1981, but that abandonment filing was withdrawn and the track was passed to Burlington Northern. The entire Milwaukee Road track west of Miles City was authorized by the Interstate Commerce Commission (ICC) for abandonment on January 30, 1980 (Rails to Trails Conservancy, 2004). This abandonment involved more than 500 miles of Milwaukee Road main line in Montana.

Figure 5. Route of the Chicago, Milwaukee & St Paul Railway through Montana (Rails to Trails Conservancy, 2004).

2.1.1 Impacts of Railroad Development

When the Milwaukee Road was constructed in the early 20th Century, the Musselshell River was dramatically altered to accommodate the railroad right-of-way. To minimize both the length of track and the need for bridges, the river was straightened and shortened. According to an article in the Billings Gazette (Graetz, 2003), "In building the route [through the Musselshell River Valley], workers moved the river's channel more than 100 times". In the GIS project for this study, a total of 82 meanders were mapped that are currently isolated behind the abandoned rail line between Melstone (RM115) and River Mile 322, which is approximately 25 miles upstream of Harlowton. Figure 6 shows an example of several isolated channel segments a few miles upstream (west) of Musselshell. Only the most obvious channel remnants on the opposite side of the rail line were measured; the total channel shortening is greater than that (Figure 6). The Musselshell River Assessment Report (Lower Musselshell Conservation District, 2004) describes 140 meanders as shortened or cut off from the river, indicating that the results provided here are conservative.

A photo of the easternmost meander on Figure 6 that was taken during the 2011 flood (Figure 7) shows that there is no surface water connection between the two features, rendering the abandoned channel an off-stream wetland. In some cases however, culverts connect the old swales to the river to allow for irrigation water withdrawal from the abandoned channels. Furthermore, breaching of the rail berm during the flood in some places reconnected the surface water connectivity between the main channel and isolated remnants (Figure 8).

Of the 207 miles of river affected, a total of 35 miles of meander length was measured as having been isolated by the rail berm (Figure 9). This isolation occurs at a relatively consistent rate of 1000 feet of isolated meander length per mile of existing channel, which is 19% or nearly one fifth of the channel length. The majority of the isolation occurred on the north side of the river (Figure 7), and all of it was upstream of the Melstone area.

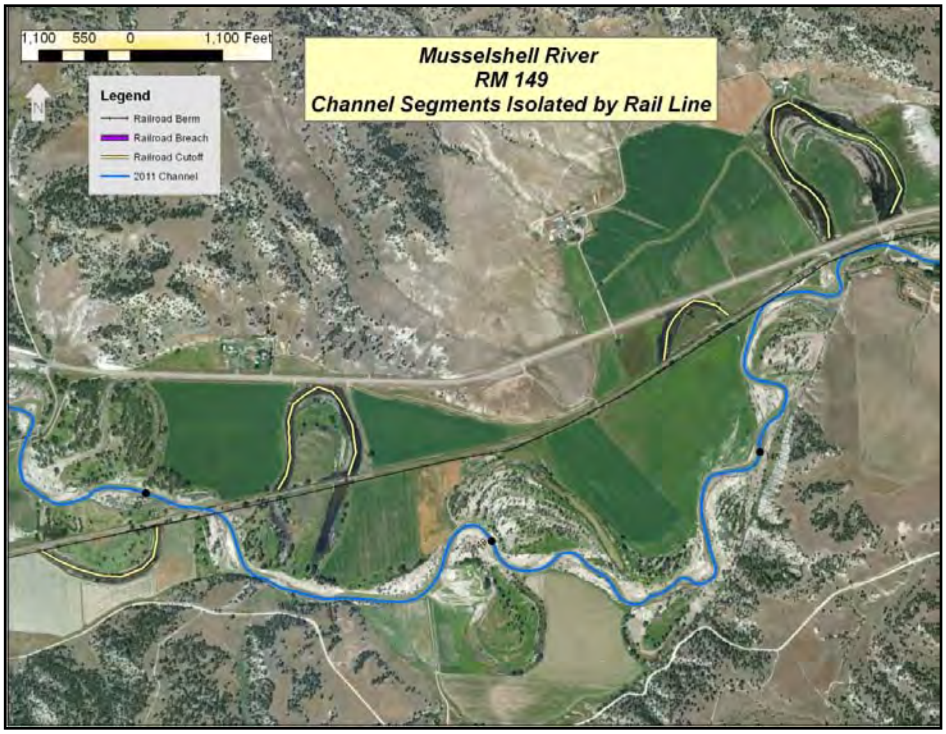

Figure 6. Air photo showing mapped meander segments isolated by rail berm, RM 149.

Figure 7. View north at RM 147 (5 miles west of Musselshell) of isolated meander, note Goffena Diversion dam and June 16, 2011 flood condition (©www.kestrelaerial.com).

Figure 8. View upstream at RM 205 showing rail berm breach and floodwater access to previously isolated channel (©www.kestrelaerial.com).

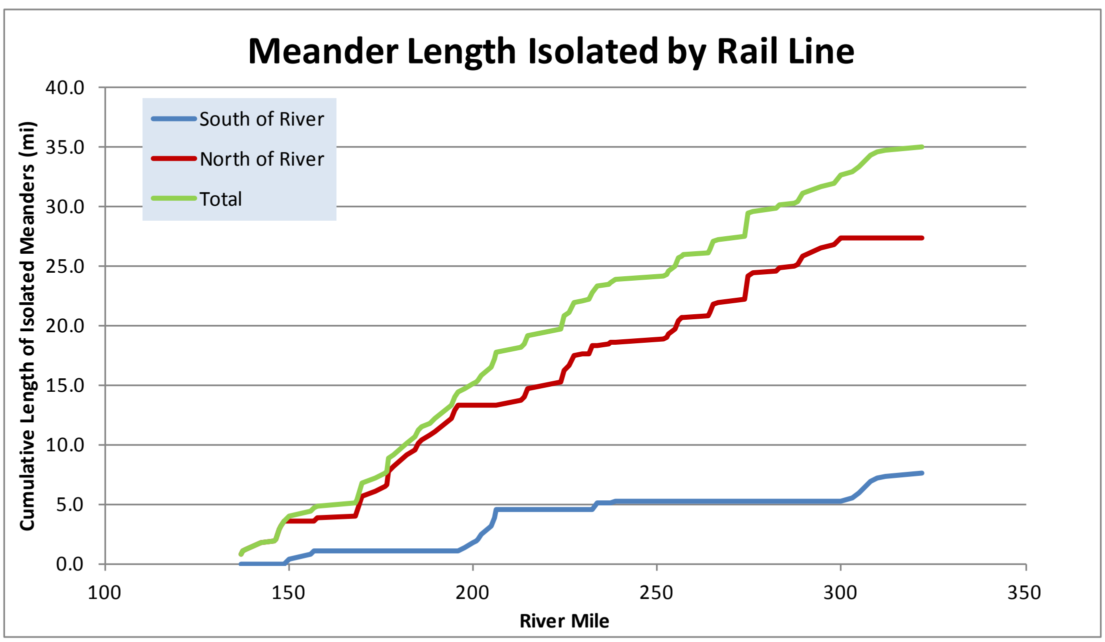

Figure 9. Estimated cumulative length of meanders isolated by abandoned rail line, Musselshell River.

3 Riparian Conditions

Riparian areas are river margin plant habitats and communities that that occupy very limited but highly productive and diverse habitat along the Musselshell River. These narrow, isolated ribbons of lush growth serve to create, filter, and protect the valuable alluvial floodplain soils and provide cover and forage for both livestock and wildlife. The root systems of plants native to riparian areas strengthen banks and woody debris can slow the erosive power of flood waters. Common native woody plant communities range from plains cottonwood and peachleaf willow stands on the lower reaches, to black cottonwood, thinleaf alder, sandbar willow, water birch, and red osier dogwood communities in the upper reaches. Undergrowth is dominated by native forbs, grasses, sedges and rushes. Common chokecherry, silver buffaloberry, various willow species, western snowberry, honeysuckle, boxelder maple, green ash and black hawthorn are native species that vary in density and frequency along the Musselshell.

Riparian plant community health varies along the Musselshell River. There are some riparian areas that have good native species and age class diversity that provide excellent, long-term wildlife cover and bank stability, although many reaches of the Musselshell River have been heavily impacted over time and lack these attributes. Over 100 years of railroad and highway construction, irrigation development, field clearing, channel straightening, channel downcutting, and heavy grazing pressure has significantly limited the river's ability to sustain native riparian plant communities. In 2004, an extensive functional assessment of the Musselshell River riparian corridor completed by the conservation districts and Musselshell River Watershed Coalition (Lower Musselshell Conservation District, 2004) rated the majority of the riparian corridor as being either "Not Sustainable" or "Sustainable-at Risk".

The 2011 flood created a rare opportunity to improve the diversity and distribution of riparian plant communities on the Musselshell River. Flood-induced erosion has locally reconnected the river to previously isolated tracts of floodplain. Extensive coarse sediment deposits in the channel and on the adjacent floodplain have created a perfect seedbed for cottonwood and willow species. An incredible number of seedlings were observed by the RATT team during the summer and fall of 2011, especially in the middle and lower portions of the basin (Figure 10).

Whereas the Musselshell River used to commonly go dry in the summer, recent changes in cooperative water management have prevented complete dewatering during the late irrigation season. By taking advantage of opportunities associated with these sustained low flows in conjunction with vast swaths of flood-related native riparian seedlings, sound livestock grazing practices, and carefully managed wildlife numbers, the health and extent of the Musselshell River riparian resource has the potential to improve significantly within a few years time.

Figure 10. Cottonwood seedlings on floodplain, RM 27.

Noxious weed infestations are also a major issue along the Musselshell River stream corridor. Upstream from Harlowton, there are extensive infestations of leafy spurge, spotted knapweed, and Canada. Downstream from Harlowton, these same weeds continue to be common, along with ever-increasing infestations of Russian olive and salt cedar. Over the last 50 years, the non-native Russian olive has spread rapidly along the Musselshell River. Large patches can be found on riparian sites in the mid and lower reaches of the river in areas formerly occupied by native riparian plants.

Salt cedar (tamarix) is a highly aggressive invasive species that has recently been expanding along the bars and banks of the Musselshell main stem. It currently occurs below Cushman, but is expected to spread west unless controlled. Salt cedar studies done in other areas indicate this exotic will affect the quality and quantity of water in the Musselshell River. Invasion of these plants is more problematic in highly controlled river systems such as the Musselshell River where these plants can interfere with regeneration and growth of native riparian species.

4 Fisheries

Detailed fisheries studies from 1979 through 1986 divided the Musselshell into three zones: cold water, transitional, and warm water (Wiedenheft 1979, Wiedenheft 1980, Marcuson and Cardinal, 1981, Vaughn and Fredenberg, 1984, Fredenberg 1985, Fredenberg, 1986). The cold water zone extends from the confluences of the North and South Forks of the Musselshell near Martinsdale (RM 336) to Barber (RM 256). The transitional zone begins at Barber and extends to Roundup (RM 180). The warm water zone begins at Roundup, Montana and extends to RM 0 at the confluence with the Missouri River (Figure 11).

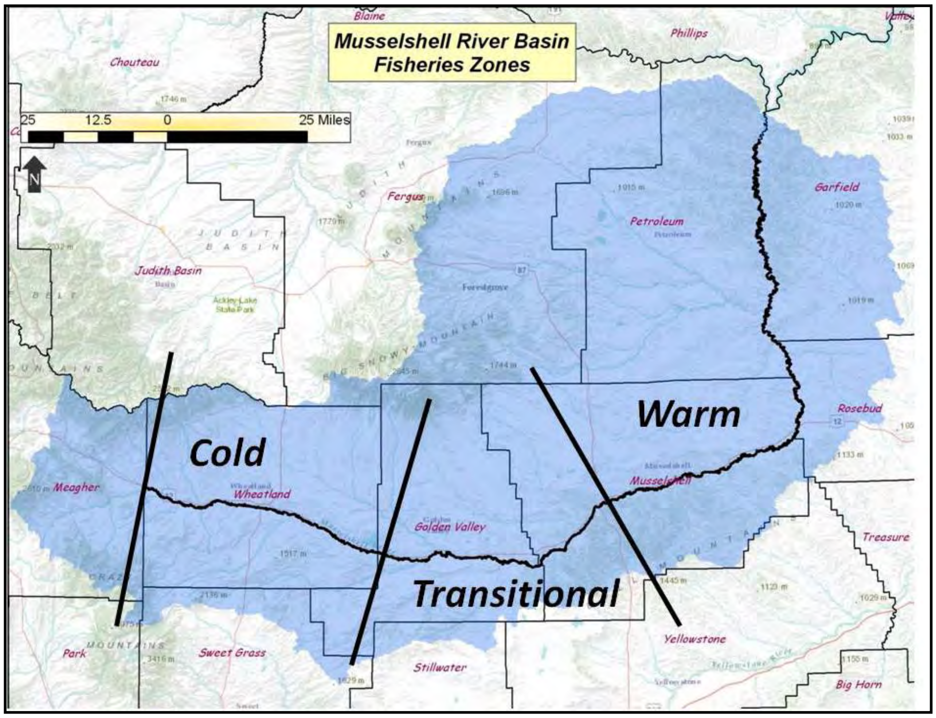

Figure 11. General detail of Musselshell River fish description zones.

Between 1928 and 2012, over 42.5 million fish were stocked in the Musselshell watershed by Montana Fish Wildlife and Parks. The most commonly stocked species has been rainbow trout with over 27 million individuals totaling more than 1 million pounds stocked. Many of these have been stocked in major reservoirs in the drainage such as Martinsdale, Bair Reservoir, Deadmans Basin, Lebo, and Yellow Water. Essentially all direct stocking of trout into the river was halted by 1980. Most rainbow trout recently found in the river are from reservoir stocking. Westslope cutthroat trout that were stocked into Bair Reservoir were recently found pioneering the river below the dam; they are native to Montana but not the Musselshell River. Arctic grayling, which are native to Montana but not the Musselshell watershed, were stocked in the upper reaches of the South Fork of the Musselshell in two separate ponds in 1961. MFISH records indicate neither stock became self reproducing.

4.1 Cold Water Zone--Upper Reaches to Barber (RM 336 to RM 256)

The cold water zone of the Musselshell River is influenced by several tributaries aside from the North and South Forks. Those tributaries include Daisy Dean, Little Elk, Haymaker, Big Elk, Hopely, Antelope, Lebo, and American Fork Creeks. The average width of the Musselshell River in this zone in 1979 was reported to be 60 feet and had a gradient of 20.5 feet per mile (Wiedenheft 1979). Musselshell River substrates were dominated by gravels and cobble in this zone.

The cold water zone is affected by several irrigation storage reservoirs, including Bair Reservoir on the North Fork, Martinsdale, an off-channel reservoir on the South Fork, and Deadmans Basin, which is an off-channel reservoir. These reservoirs collectively store about 106,616 acre feet of water at full pool.

Eleven irrigation diversions or in-stream dams were reported in the North Fork, South Fork, and mainstem of the Musselshell River in Wiedenheft's 1979 report. These eleven diversions were capable of diverting a total of 1,400 cubic feet per second (cfs) of water. Uncounted stock dams, smaller diversion dams and other obstructions are in the tributary streams in this zone. Water storage and irrigation infrastructure have been both supportive and detrimental to fish populations in this reach. Although some structures prevent upstream fish passage and others essentially dewater the channel, late season delivery of stored water sometimes helps maintain the fishery in periods of drought.

Water quality-issues are a concern due to severe degradation of the riparian corridor associated with agricultural development (Wiedenheft, 1979). Agricultural runoff and irrigation returns can increase salinity, nutrient levels and sediment load which increase water temperature, turbidities, and decreases dissolved oxygen. Water chemistry data indicate these influences occur throughout Musselshell watershed, increasing in severity in the downstream direction.

4.1.1 Fish Assemblage and Population Density

The cold water zone and associated tributaries support many species of fish such as brook trout, brown trout, rainbow trout, Yellowstone and Westslope cutthroat, mountain whitefish, longnose dace, mottled sculpin, longnose, shorthead redhorse, white, and mountain suckers, fathead minnows, flathead chubs, common carp, stonecat, lake chub, northern redbelly dace, and northern redbelly finescale dace hybrids. The mainstem supports a good population of brown trout which have comprised about 96% of the total trout population. In the tributaries, brook trout comprise up to 56% of the total trout, with lower numbers of rainbow and brown trout, mountain whitefish, mottled sculpin, and both species of cutthroat trout.

Several brown trout population estimates have been completed at the Selkirk Fishing Access Site, and MTFWP currently tries to get new estimates every three years. Estimates were made or attempted in 1984 through 1998, 1992, 1994, 1997, 1999, 2001 through 2010, and 2012. Several attempts to estimate populations between 2001 and 2008 were not completed as recapture rates were low and the sampled population consisted of just a few larger spawners and a small number of juveniles. The poor population structure during this time was related to poor in-stream flow conditions during the drought. Population estimates ranged from a low of 17 fish caught in one shocking effort to an estimated 890 fish per mile in 1992 which was attributed to a good spawn in 1991. On average, the population estimate is approximately 300 fish per mile with about 150 of quality size and the remainder consisting of yearling fish.

A population estimate of brown trout above and below Deadmans diversion dam was conducted in three locations in 1984. The upper site was 1.8 river miles above the diversion dam the next two sites were approximately 15 and 21 river miles downstream of the diversion. The upper section found 116 brown trout per mile while 34 and 35 brown trout per mile were found in the downstream sites, respectively (Vaughn and Fredenberg, 1984). The decline in the number of trout below the diversion was attributed to dewatering as a result of the dam in conjunction with long, wide, shallow riffles that likely restrict movements in summer months.

In 1986, a mountain whitefish population estimate conducted at the Selkirk site resulted in 108 whitefish per mile. The whitefish ranged in size from 10.5 to 17 inches (Fredenberg 1987).

From 2003 through 2006 a prairie streams survey conducted in central and eastern Montana included several sites on the Musselshell River and tributaries. Two cold water zone sites were evaluated in 2006 including the Selkirk Fishing Access site and a site adjacent to the Barber Bridge. A total of 146 fish were caught at the Selkirk site and 50 fish were caught at the Barber site. Although more fish were caught at the Selkirk site, more species were captured at the Barber site. Six species were caught at the Selkirk site including white sucker, longnose sucker, longnose dace, brown trout, northern redbelly dace, lake chub, and introduced brown trout. At the Barber site, eight species were caught, including longnose dace, common carp, white sucker, fathead minnow, lake chub, brassy minnow, mountain sucker, redhorse sucker, and introduced common carp.

In 2009, a MTFWP Angler Survey indicated that the cold water zone of the Musselshell River received 1,750 angler days with an additional 1,200 angler days in the North and South Forks.

4.2 Transition Zone—Barber to Roundup (RM 252-RM 180)

The transition zone of the Musselshell is influenced by several tributaries such as Fish, Careless, Big Coulee, Painted Robe, Dean, Current, Goulding, Pole, and Halfbreed creeks. The tributaries in this reach are prone to dewatering and are normally dry or intermittent during irrigation season. The average width of the Musselshell River in this zone in 1979 was reported as 85 feet and had a gradient of 6.6 feet per mile (Wiedenheft, 1979). The gradient is about one third of that upstream in the cold water section. Substrates in this section were characterized by gravels, sand, silt, and isolated sandstone rock slabs along sandstone cliffs.

Although there are no storage reservoirs in this zone, Deadmans water enters this reach from Careless Creek. Four major irrigation diversions capable of diverting a total of 200 cfs were documented in this section (Wiedenheft, 1979). A review of 2005 aerial photos and field visits made by FWP staff in 2011 and 2012 indicate that there at least 10 diversions in this section and several additional rock weirs appeared to be in place to raise the river stage for irrigation pumps.

Fish passage is probably limited in this zone, and many fish are likely transported onto fields each year or trapped in canals and siphons. Water quality issues stem in part from irrigation returns increasing salinity, as the zone is high in nutrients and sodium sulfate. Changes in operations of Deadmans releases through Careless Creek have reduced some of the issues but they still remain. Dewatering is also a concern as it reduces the extent and quality of fish habitat.

4.2.1 Fish Assemblage and Population Densities

The transition zone supports at least 17 total fish species, although the measured abundances of sport fish have been relatively low. Documented species include stonecat, several minnow species including carp, fathead minnow, flathead chub, lake chub, longnose dace, and western silvery minnow, sucker species including longnose, mountain, river carpsucker, and shorthead redhorse suckers, smallmouth bass, brown trout and mountain whitefish. Additionally Deadmans Reservoir supports populations of rainbow trout, kokanee salmon, and tiger muskie. Historically, Atlantic salmon and coho salmon were stocked into Deadmans, but those species are no longer found in the reservoir or river. It's likely some catfish and sauger utilize this zone near Roundup but they have not been reported in any survey since 1979. Discussions with longtime anglers indicated sauger and catfish were more common in the 1950's and 1960's as far up as Lavina. Although brown trout and some rainbow trout are found in the upper transition zone, the population pales in comparison to that of the cold water zone.

The lack of warm water game fish in the transition zone may be in part due to irrigation diversions that inhibit fish movement, as catfish and sauger have been shown to move several hundred miles in short time periods in water without major obstructions. Additionally, forage fish populations have been identified that should support higher abundances of predatory fish, and smallmouth bass were stocked between Lavina and Roundup from 1977 to 1981. Although smallmouth bass growth rates in the transition zone were some of the fastest documented in Montana, the fish did not rapidly colonize as expected, and many were found in the warm water zone below the transition zone. Anglers have reported catching large smallmouth bass at Roundup with lower numbers caught near Lavina. This suggests that upstream expansion is limited by several dams that create barriers and dewater the channel. In combination with several barriers to upstream movement, many sections likely become too warm in the fall for a large population of smallmouth bass. However, these warm waters could provide good habitat for catfish if they could migrate upstream. Without barriers, sauger would likely be found in this zone each spring; although by midsummer they would migrate back to the Warm water Zone and Missouri River.

Deadmans Reservoir was included in the transition zone because reservoir return water enters the Musselshell River transition zone through the Barber Canal and Careless Creek. Any fish that move out of the reservoir could reach the river, however increased populations of rainbow trout, Kokanee salmon, and tiger muskie have not been documented in the transition zone. In 2009, the MTFWP Angler Survey indicated the reservoir received 9,702 angler days of which 8,885 were from resident anglers. The reservoir ranked statewide as the 82nd most fished water out of over 1,430 different waters reported. The reservoir provides habitat for white sucker, shorthead redhorse, and longnose sucker. The Deadmans fishery relies heavily on a stocking program; without stocking this reservoir would provide a limited fishery for brown trout.

In 2009, a MTFWP Angler Survey indicated that the transition and warm water zones collectively received 3,647 angler days. More fishing tends to occur in the downstream warm water zone relative to the transition zone.

Fatmucket mussels (*Lampsilis siliquoidea)*, are the most widespread and abundant freshwater mussels in Montana. Historically, the transition zone had abundant fatmucket populations, although it appears that their numbers have locally declined over time. This drop in the fatmucket populations may be due to dewatering as well as decreased populations of stonecats, channel catfish, and sauger, as these fish serve as hosts that move juvenile mussels to new areas. Without these fish, the recovery of mussel populations could be limited (David Stagliano MTNHP personal communications).

4.3 Warm Water Zone—Roundup to Mouth (RM 180 to RM 0)

The warm water zone of the Musselshell River is influenced by several tributaries, including Willow, Flatwillow, Box Elder, Fattig, Hawk, Rattlesnake, Calf, and Lodgepole creeks. The average width of this zone in 1979 was reported as 100 feet and had an average gradient of 3 feet per mile, which is half of the average gradient upstream (Wiedenheft, 1979). Substrates in this zone are dominated by silt and sand with some interspersed gravels and bedrock.

In 1979, five major irrigation diversions identified in this zone were capable of diverting a total of 418 cfs. Petrolia Reservoir, an on-stream reservoir on Flatwillow Creek, has about 9,000 acre feet of storage, and severely limits downstream flow in Flatwillow Creek during low-water periods. At least seven dams can be found between Roundup and the Davis/Korenco Dam, which is three miles downstream of the town of Musselshell.

In this zone, the river has been fragmented during most flow conditions by diversion dams and check dams. The Delphia Melstone Dam at Musselshell and the Davis/Korenko Dam downstream have been shown to regularly preclude fish passage. Although channel catfish and smallmouth bass have been documented moving upstream of the Dephia Melstone Dam, their movements were made during high water and the population surveys haven't found substantial populations of game species above this structure. Other upstream dams likely reduce fish passage into the transition zone.

4.3.1 Fish Assemblage and Population Densities

The warm water zone has been documented to support at least 31 fish species, including black bullhead, channel catfish, and stonecat (catfish family), brassy minnow, carp emerald shiner, fathead minnow, flathead chub, longnose dace, plains minnow, sand shiner, spottail shiner, and western silvery minnow (minnow family), walleye and sauger (perch family), longnose sucker, blue sucker, mountain sucker, river carpsucker, shorthead redhorse, smallmouth buffalo, bigmouth buffalo, and white sucker (sucker family), black crappie, bluegill, green sunfish, and smallmouth bass (sunfish family), and burbot, freshwater drum, goldeye, and northern pike. Many of these species are primarily found below the Delphia-Melstone Dam at the town of Musselshell. Paddlefish were also reportedly found in a field near Melstone after the 2011 flood.

Fisheries studies determined that although the Davis/Korenco Dam and Delphia-Melstone Dam create barriers for fish most of the time, catfish and bass were able to occasionally pass upstream. Sauger and walleye were not documented passing the diversion dams, although they may have during the 2011 flood. One burbot and a freshwater drum were caught below the Davis Dam in 1981 by FWP and a second burbot was reported by an angler as far up as Shawmut (Marcuson and Cardinal, 1981). These fish likely migrated during spring flows from the Missouri River.

MTFWP reported that in 2009, 3,647 days of angling pressure occurred in this zone (MTFWP 2010). Recreational fishing has been popular for decades, as in 1963 reported angling pressure for the lower 80 miles was 2,360 angling days.

Similar to the transition zone, historically abundant populations of fatmucket mussels in the warm water zone have apparently declined through time. Additionally, the black sandshell mussel (*Ligumia recta)* has been documented in this zone. While not native to Montana, this mussel is native to North Dakota and was likely introduced through fish stocking from North Dakota hatcheries in the past.

5 Musselshell River Flooding

The Musselshell River a snowmelt-fed system that typically floods in the spring until about mid-June, when flows typically reach on the order of 800cfs at Roundup. Flows commonly cease or become a trickle in late summer and early fall unless off-stream storage is supporting the system. Dewatering has been a persistent issue in the Musselshell River basin. As far back as 1949, a Water Resource Survey completed by the Montana State Engineers office classed the Musselshell River as an intermittent stream due to its historic unreliable flows in the lower parts of the river. In 1991 the Montana State Legislature designated the Musselshell River as a chronically dewatered stream. In 2003, Montana Fish Wildlife and Parks identified 309 miles of the Musselshell River, extending from the Deadmans Basin Supply Canal to the mouth, as chronically dewatered.

5.1 The 2011 Flood

The 2011 water year in the Musselshell River Basin proved to be exceptional in several ways. During the late winter months of 2011, SNOTEL (SNOwpack TELemetry) sites in the upper watershed recorded a slightly above average snowpack (Figure 12). Following the month of March, when snowfall was near average, precipitation became extremely heavy in April, May, and June. The SNOTEL data shown in Figure 12 is from a site in the Little Belt Mountains where maximum snowpack typically reaches 10" of water content on April 13th (Snow Water Equivalent, or "SWE Avg" in Figure 12). In 2011, however, the snowpack reached over 17" of water content and did not begin to melt until May 2nd, three weeks later than usual ("SWE WY2011" in Figure 12). By this time, the snowpack had reached 154 percent of average maximum water content. Runoff fell into full swing two weeks later as a series of moisture laden storms hit Montana. From May 20th to June 10th over 300 percent of average rainfall (for the same time period) was recorded in the Musselshell Basin (Figure 12 and Figure 13). In some places over eight inches of rain fell over those three weeks. These rainfall events rapidly melted the remaining snowpack, resulting in record-breaking runoff rates and volumes in the Musselshell Basin.

Beginning about May 21, 2011, unprecedented flooding occurred along the entire length of the Musselshell River. On May 26, the USGS gage at Roundup recorded a volume of 15,000 cubic feet per second (cfs); the typical flow on this date is around 300 cfs (Figure 14). At 15,000 cfs, the water was about five feet above flood stage, which caused severe flooding in the community of Roundup (Figure 15 and Figure 16). The flood briefly receded in early June, and then peaked again on June 8th. Flows were at least 1,000 cfs over typical conditions well into July.

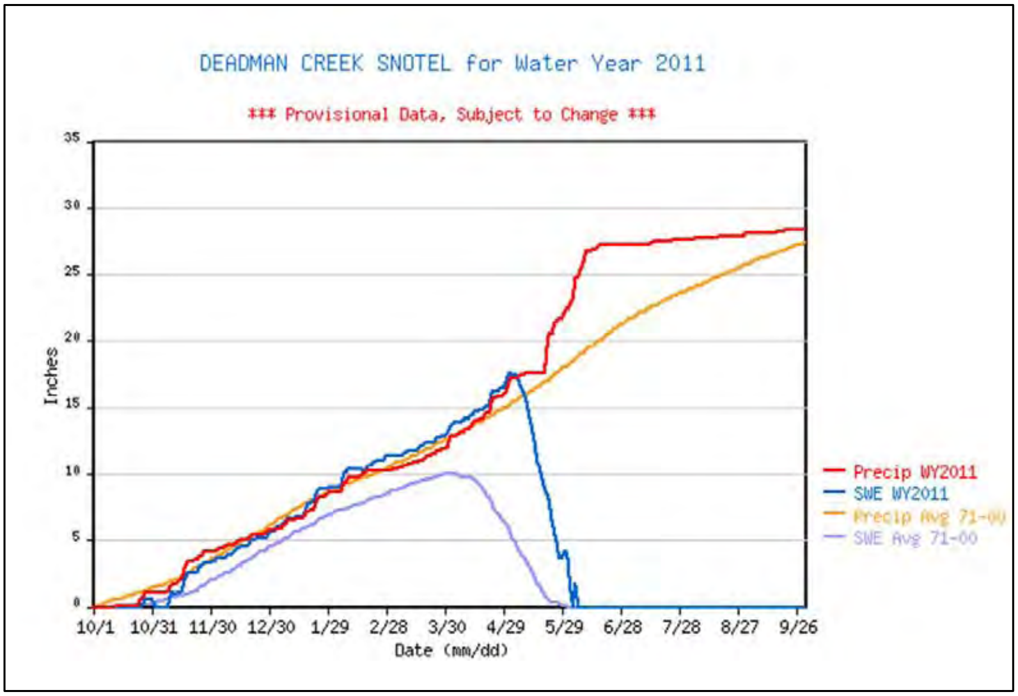

Figure 12. NRCS Snotel data for 2011 Water Year at Deadman Creek (Little Belt Mtns).

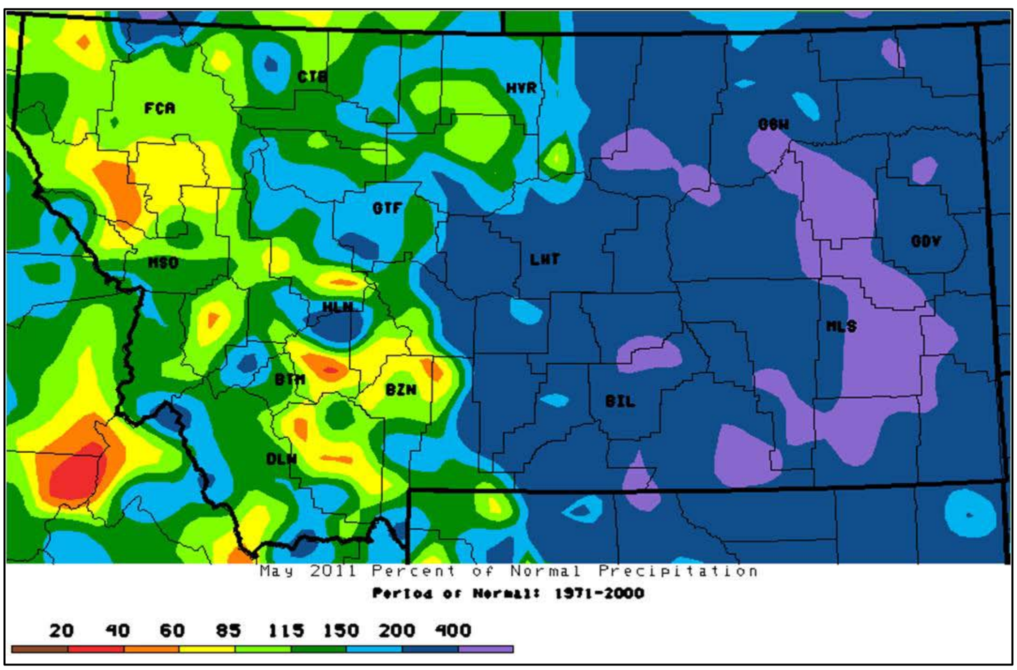

Figure 13. Percent of normal precipitation throughout Montana, May 2011 (National Weather Service).

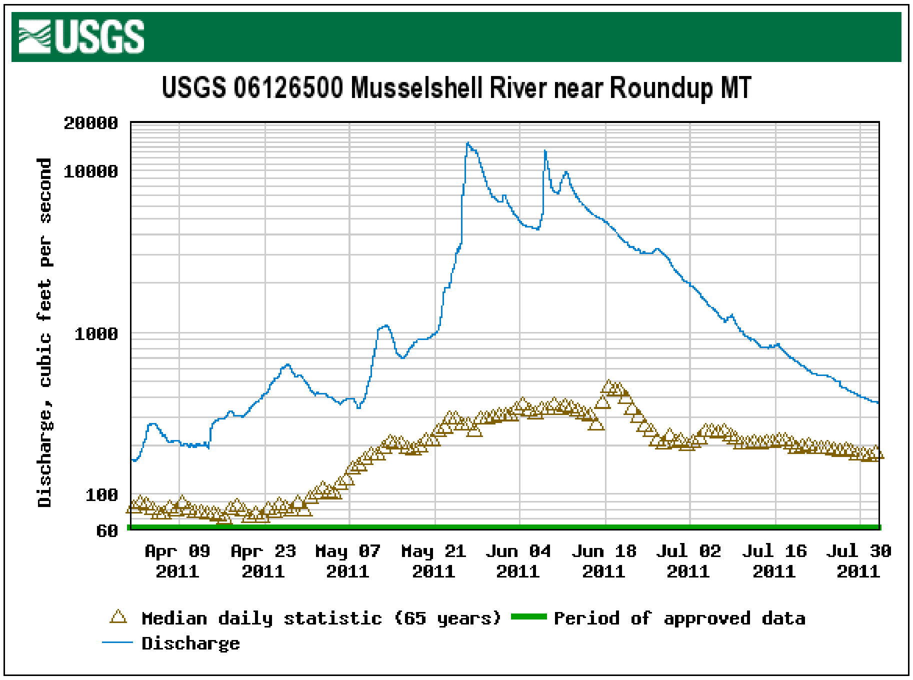

Figure 14. Musselshell River discharge at Roundup during 2011 flood.

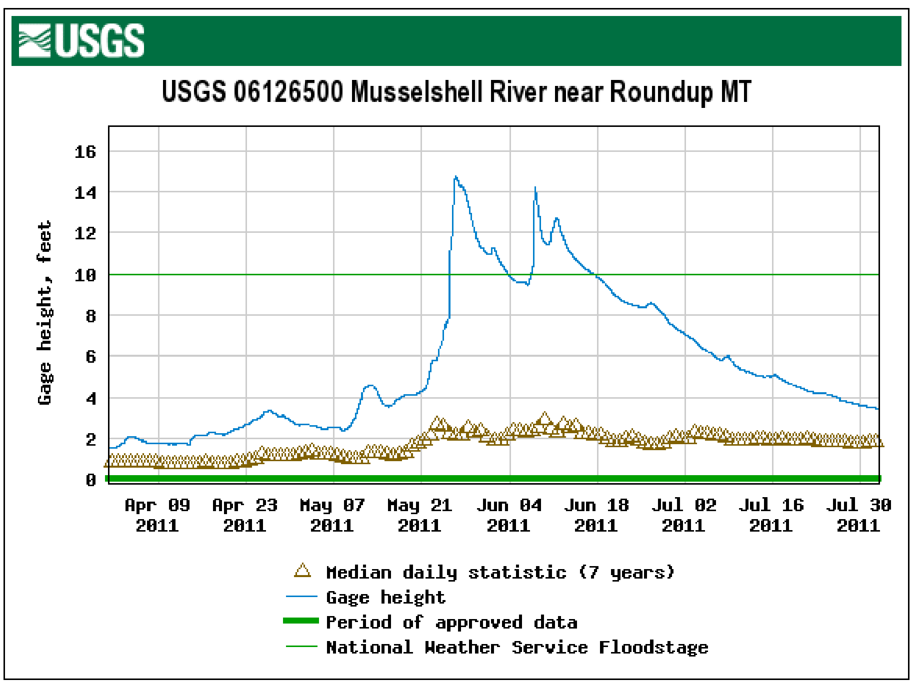

Figure 15. Musselshell River gage height at Roundup during 2011 flood; flood stage shown in green.

Figure 16. May, 26, 2011 photo of flooding in Roundup (©www.kestrelaerial.com).

The lower Musselshell experienced multiple flood crests between May 11 and June 10 when the flood waters finally began to subside (Figure 17 and Figure 18). The river first crested at Mosby at about 16 feet on Monday, May 23 with flood stage at 10 feet. The USGS gage at Mosby May 23 peak was 25,100 cfs, which is about thirty times the average discharge for this gage at this time (Figure 19). Total annual runoff at Mosby for the 2011 water year exceeded the long-term average runoff by a factor of seven.

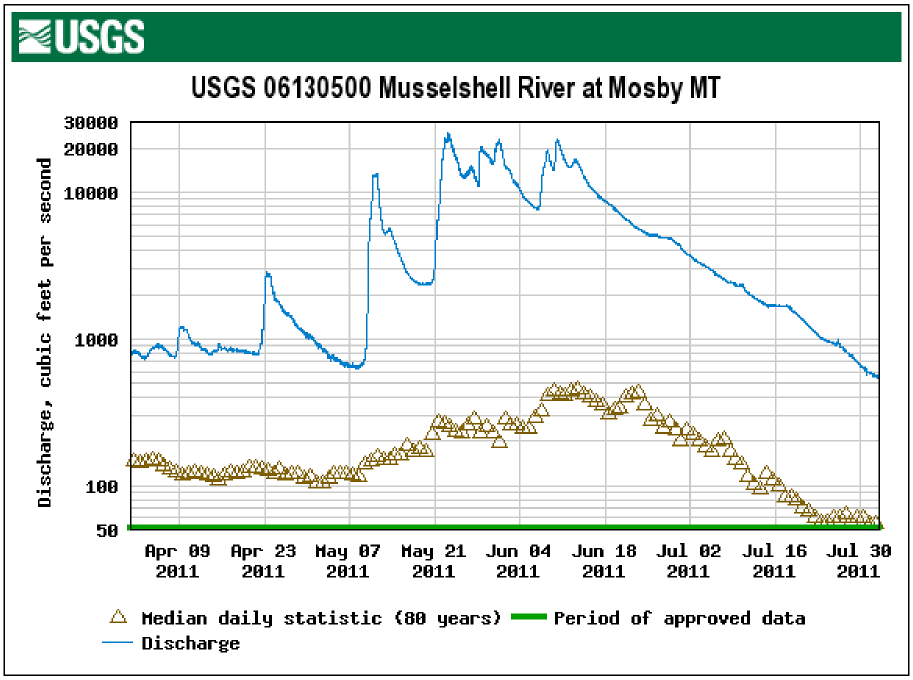

Figure 17. Musselshell River discharge at Mosby during 2011 flood.

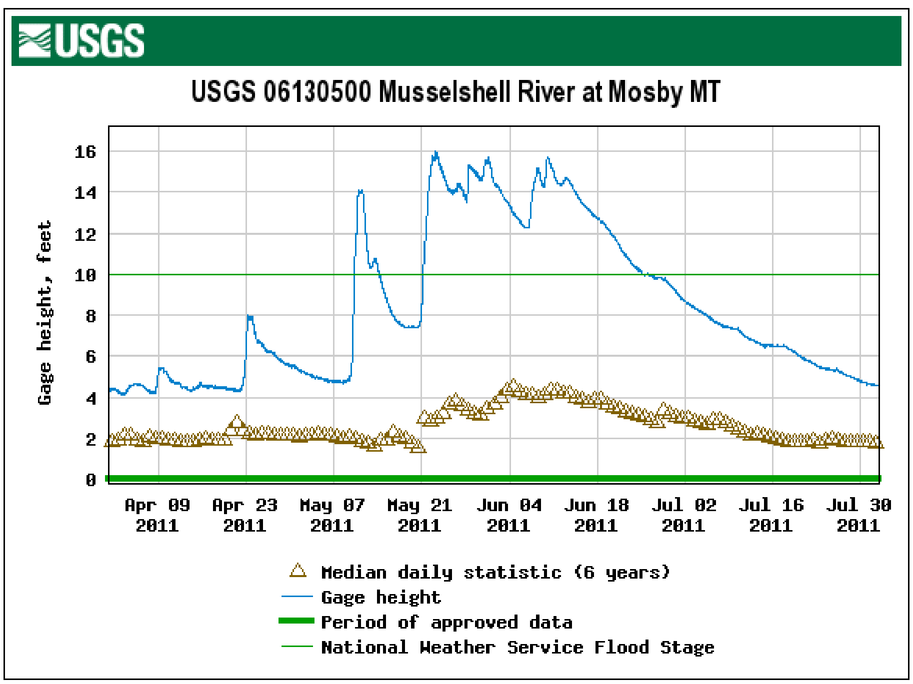

Figure 18. Musselshell River stage at Mosby during 2011 flood; green line is flood stage.

Figure 19. View upstream at RM 48 below Mosby on May 23, 2011 (©www.kestrelaerial.com).

5.2 Flood History

The 2011 flood was by far the largest measured at Roundup since 1946, when records began (Figure 20). The 15,000 cfs flood exceeded a 100-year event by 3,800 cfs, or 25%. The biggest flood recorded prior to 2011 occurred in 1967; at 9,610 cfs, it just exceeded a 50-year event. It is interesting to note that the 2011 flood occurred following 30 years of minimal flooding; over the 32 years between 1979 and 2011, a 10-year flood event was exceeded only once, in 1997.

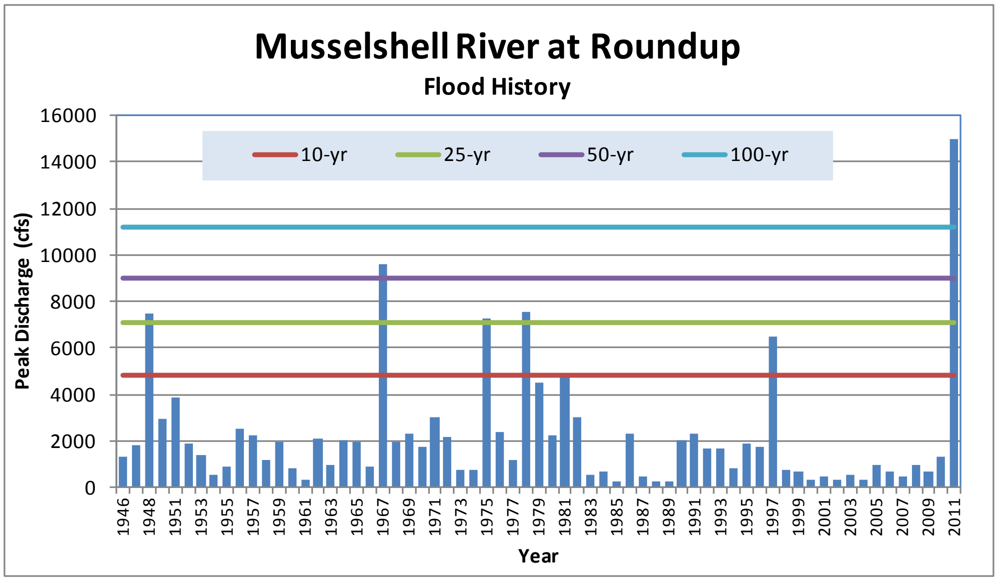

Figure 20. Annual peak discharges for Musselshell River at Roundup, 1946-2011.

One of the most striking aspects of the 2011 Musselshell River flood was its long duration of very high flows. When considering a fairly common flood event such as the maximum flow anticipated to occur every 2 years (referred to as the 2-year flood or "Q2"), 2011 was a long event, but not particularly unusual. Figure 21 shows the number of days that the measured mean daily flow exceeded the 2-year flood (Q2) at Roundup and Mosby between 1950 and 2011. Typically, when Q2 was reached, it occurred for a few days. However, it was not uncommon for the Q2 to be exceeded for weeks. During an especially wet period between 1975 and 1981, the mean daily streamflow exceeded the Q2 flood every year, and in 1975 the Q2 flood discharge was exceeded for 41 days at Roundup. In 2011, mean daily flows exceeded the Q2 for a similar amount of time, 42 days at Roundup and 48 days at Mosby.

The uniqueness of the Musselshell River 2011 flood can be seen in Figure 22, which shows the number of days that the 10-year flood discharge has been exceeded during any given year since 1950. These data show that at Mosby, the 10-year flood discharge (the discharge with a 10% chance of occurring any year) was exceeded for 19 days at Mosby, and for 22 days at Roundup. Previous to that, the longest duration of a flood of that magnitude was in 1966, when the 10-year event was exceeded for 11 days.

The long period of duration and repeated peaks in flood stage caused dramatic changes to the Musselshell River and imparted extensive damages to infrastructure and property in the river corridor.

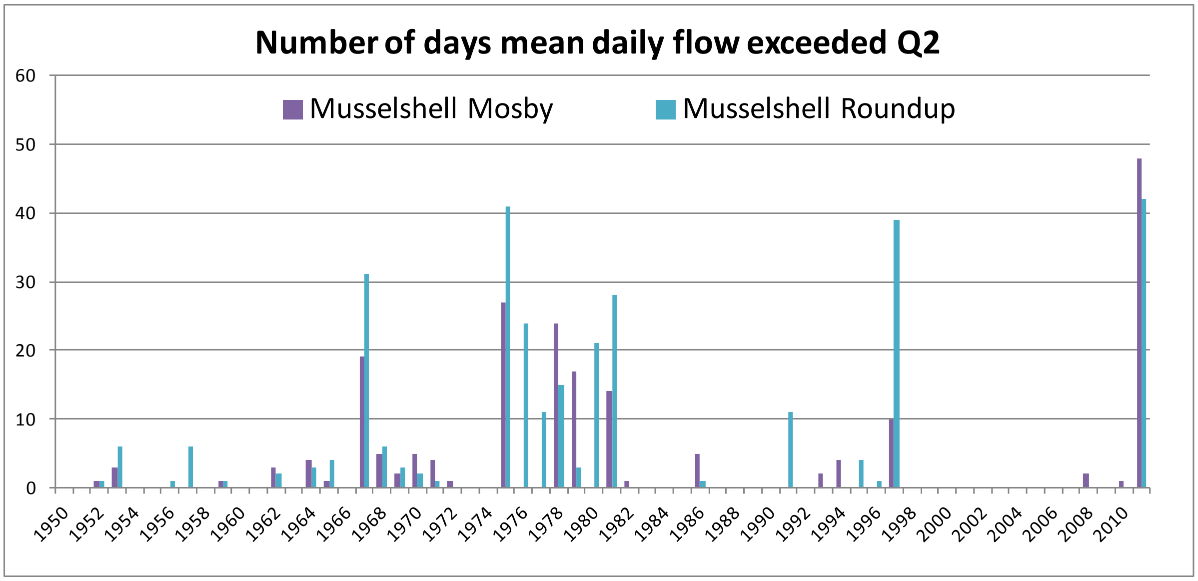

Figure 21. Number of days per year (1950-2011) that the mean daily discharge exceeded the 2-year flood, Roundup and Mosby gages.

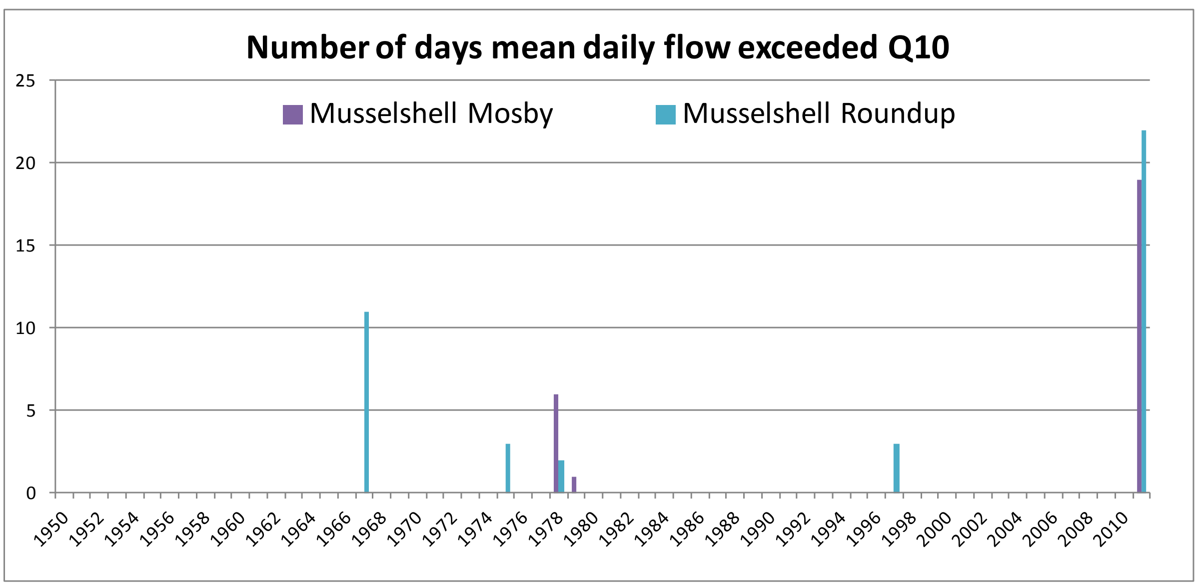

Figure 22. Number of days per year (1950-2011) that the mean daily discharge exceeded the 10-year flood, Roundup and Mosby gages.

6 Geomorphology and 2011 Flood Impacts

This chapter describes the general geomorphic characteristics of the Musselshell River, with an emphasis on how the river responded to the 2011 flood event. These responses include the carving of new channels, excessive bank erosion, damage to siphons, breaching of the railroad berm, damages to diversion structures, extensive sediment deposition on the river floodplain, damages to pump sites, scouring of the floodplain, and lost access to property. Chapter 7 describes conceptual approaches for addressing each of these impacts.

6.1 Geologic Setting

The project area is underlain primarily by Tertiary and Cretaceous –age sedimentary rocks that include sandstones, siltstones, and shales. In the upper part of the basin, the river valley is bounded by sandstones and shales of the Cretaceous-age Colorado Shale, Eagle Sandstone, Judith River Formation, and Claggett Shale (Figure 23). Between Ryegate and Melstone, the prominent geology is the younger Tertiary-age Fort Union Formation (shale, siltstone, sandstone, and coal seams). Below Mosby, the river valley margins consist primarily of Bearpaw Shale, which is an extensive marine deposit that can be found in Montana, Alberta, and Saskatchewan. This clay-rich unit formed during the last major expansion of the Western Interior Seaway approximately 70 million years ago. The Bearpaw Shale is infamous for forming "gumbo", which can create virtually impassable road conditions when wet.

In the upper part of the watershed, the edges of the river valley are fairly erosion resistant due to sandstone outcrops (Figure 23). In lowermost reaches, however, the Bearpaw shale is prone to both erosion by the river and mass failure when it becomes saturated. Hillslope sloughing on the edges of the river valley are common on the lower river where Bearpaw shale is predominant (Figure 24). The geologic conditions create the basic setting for the pre-settlement form and pattern of the River as it traverses the Musselshell River Valley.

Figure 23. Erosion-resistant sandstone valley wall near Ryegate (RM 239), June 16, 2011.

Figure 24. View downstream of Musselshell River below Mosby showing hummocky Bearpaw shale mass failures (landslide) in foreground; note leaning power pole in center of photo (arrow).

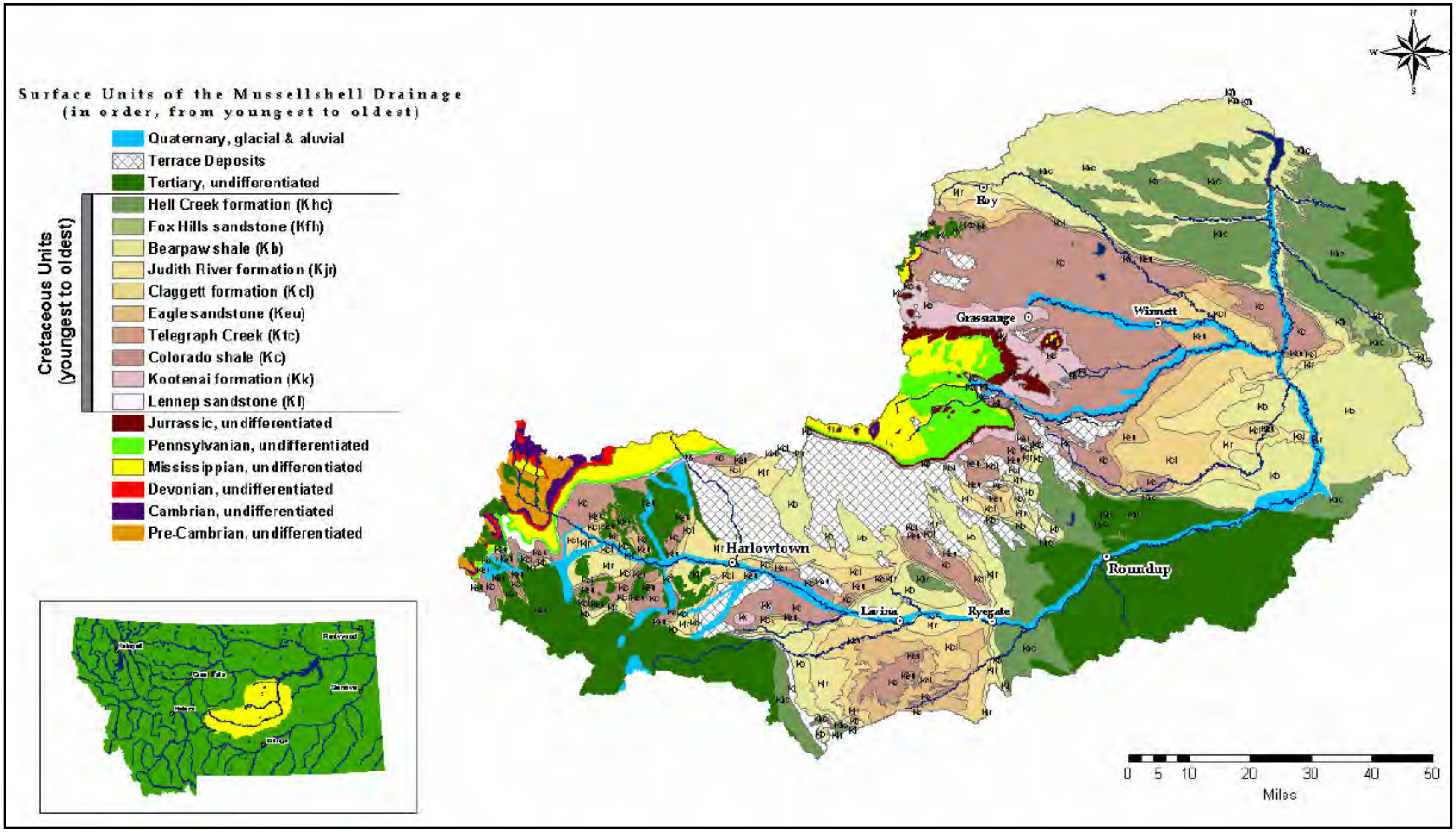

Figure 25. Generalized geologic map of Musselshell Watershed (Lower Musselshell Conservation District, 2004)

6.2 Pre-Flood Condition

From Martinsdale to Fort Peck Reservoir, the Musselshell River is an alluvial river, meaning that it flows through sediment deposited by the river itself. As a result, the river is in a constant state of sediment reworking, as it builds bars, erodes banks, and conveys sediment downstream. Over time, alluvial rivers experience bank erosion and occupy a corridor that extends beyond their current channel boundaries (Figure 26). As a river migrates back and forth across its floodplain, it creates a floodplain surface in its wake that is accessible for floodwaters to dissipate energy and store fine sediment. In most snowmelt-driven stream systems, the river fills its active channel cross section on the order of every 2 years, and then begins to access that floodplain surface. It is not uncommon for rivers to have a low elevation floodplain that sits within a higher, less accessible floodplain. In many alluvial systems, extensive floodplain inundation does not occur until a larger flood event such as the 10-year flood.

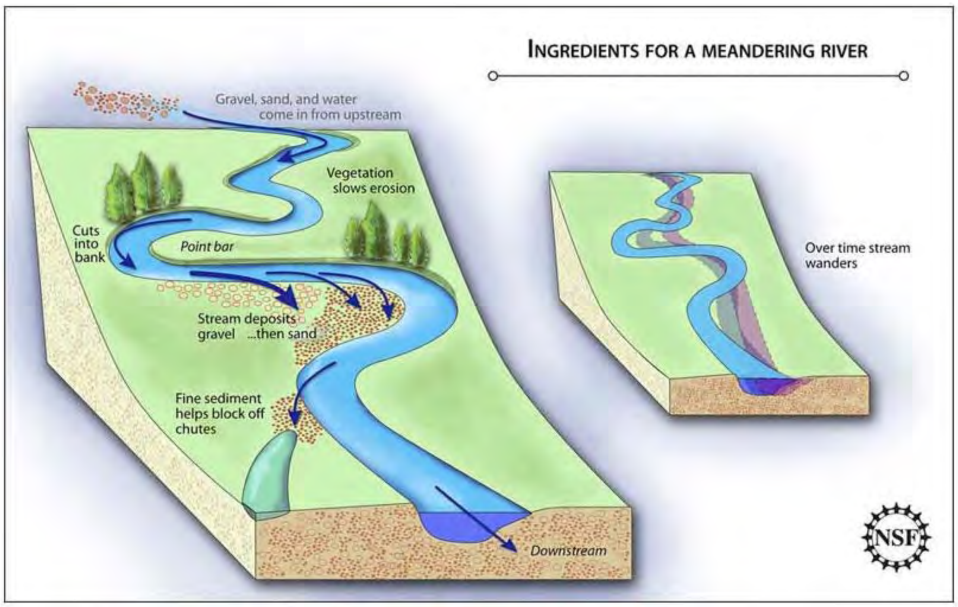

Figure 26. Schematic drawing of meandering river migration concept (www.berkeley.edu).

On the Musselshell River, the streambanks are generally erodible, and the channel has migrated across its floodplain through time. Floodplain swales are very common and record historic channel locations. General Land Office Survey maps from the early 1880s show the Musselshell River as a sinuous channel with a wide riparian corridor that suggests a low, frequently flooded floodplain (Figure 27 and Figure 28).

Since the 1880s, the historic connectivity of the Musselshell River to its floodplain has been impacted by the river's response to straightening by the railroad in the late 1800s. River straightening, or channelization, has been a common practice in the west to support river navigation, flood control, and efficient transportation infrastructure layout. The physical response of rivers to straightening is well-documented. Essentially, the shortening of a meandering river causes that river to steepen. This in turn results in an increase in stream velocities, which causes downcutting in systems where the bed materials are erodible. Downcutting increases bank height and causes an “entrenched” condition where the historic floodplain becomes perched above the channel and thus less accessible by floodwater. The long-term trajectory for these settings is for the entrenched channel to lengthen by eroding the high banks. As the channel meanders in the widening entrenched cross section, it deposits sediment that forms a new “inset” floodplain surface at a lower elevation that can relieve flood energy and support riparian vegetation.

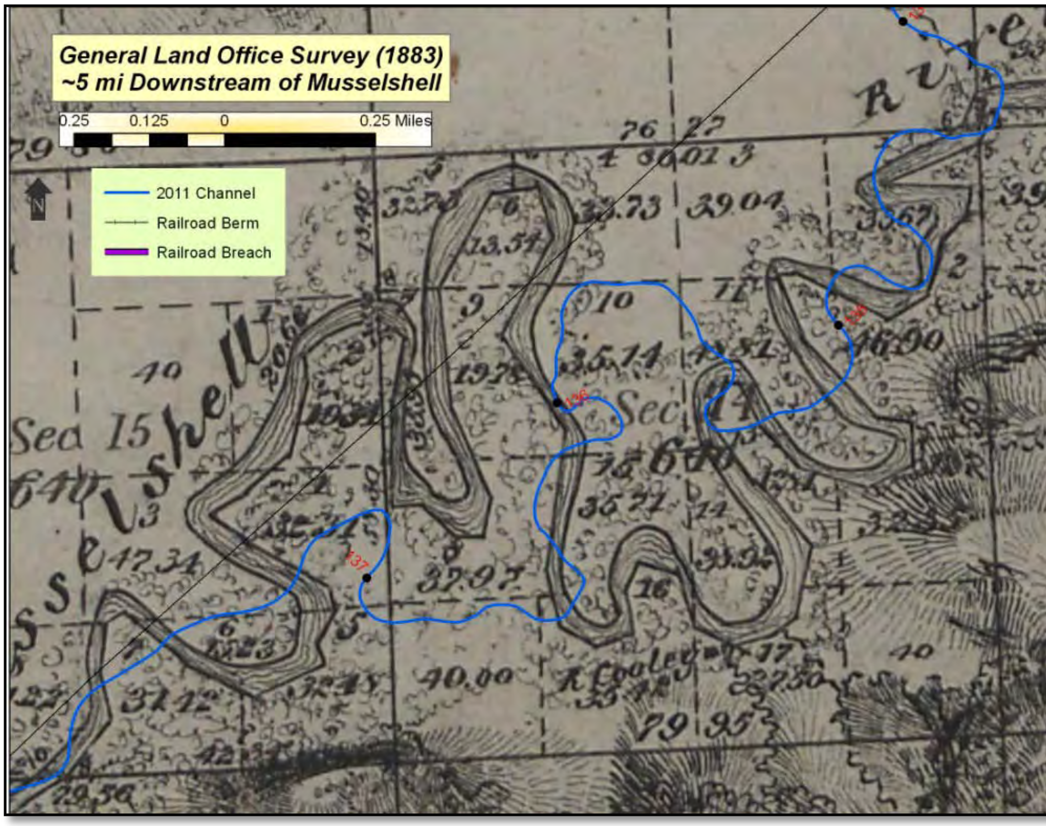

Figure 27. General Land Office (GLO) survey map from 1883 showing sinuous channel downstream of Musselshell; blue line is 2011 channel course, and 1908 railroad grade is in black.

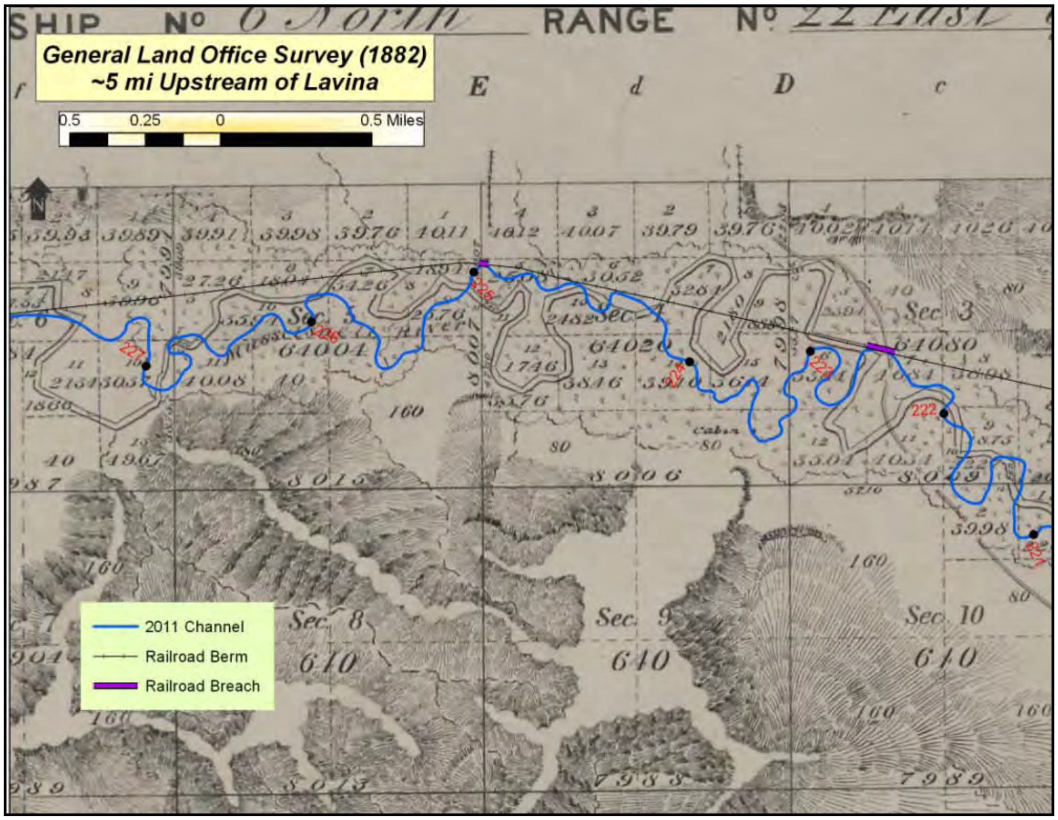

Figure 28. General Land Office (GLO) survey map from 1882 showing channel course upstream of Lavina; blue line is 2011 channel and 1908 railroad grade is in black.

The Musselshell River above Melstone displays these conditions of a straightened entrenched channel. The NRCS Riparian Assessment report that was completed prior to the 2011 flood (Lower Musselshell Conservation District, 2004) describes entrenched channels upstream of Roundup where the historic floodplain is perched an average of 6-10 feet above the water table. Pre-flood banks were commonly up to 10 feet high and little inset floodplain had developed in many areas (Figure 29). Downstream of Roundup where the valley bottom widens, the channel was described as in the "early stages of recovery" following downcutting, which included development of an inset surface and reduced entrenchment (Figure 30).

Figure 29. Photo of ~10 ft bank in entrenched channel segment pre-flood, Musselshell River (Lower Musselshell Conservation District, 2004)

Figure 30. Pre-flood photo of historic floodplain (left) and inset surface development (right) downstream of Roundup (Lower Musselshell Conservation District, 2004).

Although this effort did not include a detailed analysis of the historic migration rates of the Musselshell River, vegetation patterns and channel planform trends suggests that overall, this "recovery" process, which includes bank erosion, channel lengthening, and inset floodplain formation, has been relatively slow, considering the primary impact occurred over a century ago. Locally severe bank erosion has been a problem for some time, primarily where vegetation density and rooting development is low on soft banks, but open bar surfaces in the pre-flood (2009) imagery are uncommon, and vegetation patterns commonly suggest low rates of movement. Both of these are indicators of relatively slow rates of lateral channel movement. Downstream of Melstone, overall channel planform change appears to have been similarly subdued. Thus the development of an inset surface, indicating geomorphic recovery of the system to channelization had not substantially progressed prior to the 2011 flood.

The slow progression of geomorphic recovery of the Musselshell River upstream of Melstone is in part related to the fact that since 1982, Musselshell River flooding has been rare; over the last 30 years the 2-year flood has rarely been exceeded for more than a few days (Figure 21). Water regulation and dewatering of the system may also have reduced the overall rates of channel change. These conditions seem to have limited the process of inset floodplain development on the Musselshell River over the past several decades.

6.3 Flood Impacts

A cursory assessment of pre-flood conditions on the Musselshell River suggest that it was geomorphically prone to major adjustment in the event of an extreme flood such as that of 2011. During the 2011 flood, entrenched channel segments experienced high velocities that caused in-channel erosion, destabilization of extensive swaths of vegetation, and channel widening. The long duration of the flood caused streambanks to become deeply saturated, and as flows dropped, banks rapidly failed as they were unable to support their weight. Gravitational failure and river erosion of high banks resulted in massive sediment loading downstream that caused floodplain aggradation and contributed to avulsions. The perched, sparsely vegetated historic floodplain was inundated for weeks, which resulted in local scour and new channel excavation on the erodible surface. This response of the Musselshell is not uncommon in that within straightened systems, the most dramatic advances in channel recovery typically occur during large, long-lasting floods. Now, upstream of Melstone the post-flood channel morphology includes a much broader inset floodplain surface in many areas, indicating a major progression towards a longer term condition of geomorphic stability.

The following sections describe some of the geomorphic manifestations of the 2011 flood, as well as impacts of those changes to infrastructure and property. Appendix D contains a series of maps that show these features on the 2011 post-flood NAIP imagery.

6.3.1 Project Reaches

In order to spatially summarize flood impacts, the 362 mile project reach has been subdivided into ten reaches (Figure 31 and Table 2). The reach subdivisions reflect changes in boundary conditions such as valley bottom width and geologic influences as well as flood response. The reaches range in length from less than 20 miles to almost 70 miles.

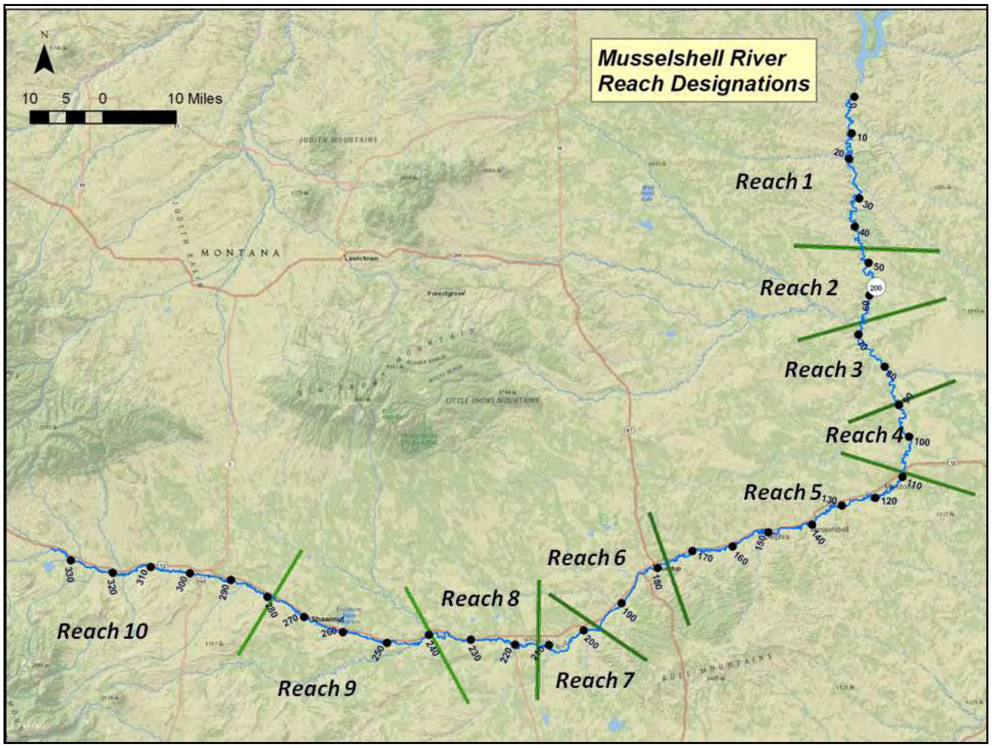

Figure 31. Project reach breaks, Musselshell River corridor.

Table 2. Project reach descriptions, Musselshell River corridor.

Reach	River Mile (2011)	Length (miles)	Comment
1	0 - 45.6	45.6	Downstream of Cat Creek Rd: wide valley bottom in Bearpaw Shale. Numerous 2011 avulsions, extensive floodplain deposition.
2	45.6 - 66.3	20.7	Narrow river corridor downstream of Flatwillow Creek; numerous 2011 avulsions.
3	66.3 - 89.0	22.7	Minimal irrigation with high terraces; little channel shift since 1919.
4	89.0 - 109.0	20	Little planform change during 2011 flood. No railroad influence.
5	109.0 - 177.5	68.5	Through Melstone, Musselshell, and Delphia: floodplain deposition and some large avulsions. Numerous oxbows isolated by railroad.
6	177.5 - 196.2	18.7	Relatively narrow valley bottom confined by Tertiary hillslopes. Dissected hillslopes create breaks. Channel commonly follows valley wall.
7	196.2 - 213.3	17.1	Fairly wide and sinuous to Careless Creek; numerous 2011 flood breaches through rail grade, commonly where rail line isolates oxbows.
8	213.3 -239.2	25.9	Lavina: Long channel segments isolated by rail line. Low sinuosity. Cretaceous sand/shale valley wall.
9	239.2 - 278.5	39.3	Ryegate, Shawmut: Channel commonly follows south valley wall. Extensive railroad encroachment into stream corridor. Cretaceous valley wall.
10	278.5 - 335.9	57.4	Above Deadmans Diversion: moderately sinuous with numerous small 2011 avulsions.

6.3.2 Avulsions

Perhaps the most dramatic flood impact on the Musselshell River during 2011 was a multitude of avulsions. An ***avulsion*** is the rapid formation of a new river channel across the floodplain that captures the flow of the main channel thread. Avulsions typically form by headcutting, where a new channel erodes in an up-valley direction, starting from a headcut where overbank flows re-enter the main channel over a steep bank. On the Musselshell, these headcuts tended to form multiple fingers that migrated up valley (Figure 32).

Figure 32. Avulsion in process through core of bendway at RM 87, May 23, 2011; arrows show main channel path (©www.kestrelaerial.com).

Many of the avulsions occurred in areas where long sinuous channels were dramatically shortened due to new channel cutting through the neck of the bend. In most cases this was followed by deposition on the upstream limb of the abandoned channel that isolated the cutoff from the main thread under normal flow conditions. The lower portions of abandoned channels commonly hold standing water (Figure 33 and Figure 34).

Figure 33. Abandoned channel at avulsion, RM 222 just above Lavina; flow is left to right; note dry channel on upstream (left) limb of abandoned channel segment, or "oxbow" (©www.kestrelaerial.com).

Figure 34. Abandoned channel caused by avulsion at RM 27 near Calf Creek; flow is from left to right (©www.kestrelaerial.com).

Over the 336 mile project reach, 59 avulsions were mapped by comparing the 2009 centerline to the post-flood 2011 centerline (Table 3). A total of 36.9 miles of 2009 channel were abandoned during the flood, with the abandoned segments ranging in length from 280 ft to 14,300 ft. The longest single abandoned segment was 2.6 miles long in Reach 1 below Cat Creek (Figure 35). Figure 36 shows the length of channel abandoned at each avulsion by reach, as well as the cumulative loss of 2009 channel length as calculated in the upstream direction. However, although the avulsions resulted in lost channel length, it is important to consider that the avulsions themselves create new channel length. A summary of that data (Figure 37) shows that although 36.9 miles of 2009 channel were abandoned during the flood, new channels regained 9.1 miles of that lost length. Every reach except for Reach 7 experienced at least one avulsion (Figure 38), and Reach 1 below Cat Creek experienced the greatest loss of length (Figure 39).

Balancing losses and gains, the avulsions resulted in a net loss of 27.9 miles of channel, which is 8% of the channel length between RM 0 near Fort Peck Reservoir and RM 336 near Martinsdale. That shortening was concentrated in the lowermost 89 miles of river (Reaches 1-3) and in Reach 9 (through Ryegate and Shawmut; Figure 39 and Figure 40). In Reaches 1 and 2, over 20% of the channel length was lost during the flood.

Table 3. Summary of 2011 avulsions by reach.

	Reach										
	R1	***R2***	***R3***	***R4***	***R5***	***R6***	***R7***	***R8***	***R9***	***R10***	***Total***
Total Number Avulsions	8	5	4	1	10	3	0	6	10	12	59
Lost length (mi)	10.92	5.51	3.37	0.16	4.46	1.09	0	2.74	5.78	2.88	36.91
Gained Length (mi)	1.49	1.13	0.86	0.03	1.29	0.54	0.00	0.58	1.84	1.30	9.05
Net Change (mi)	-9.43	-4.38	-2.51	-0.14	-3.17	-0.55	0.00	-2.15	-3.94	-1.58	-27.85
Reach Length (mi)	45.6	20.7	22.7	20.0	68.5	18.7	17.1	25.9	39.3	57.4	335.9
Percent Change in Total Channel Length	-21%	-21%	-11%	-1%	-5%	-3%	0%	-8%	-10%	-3%	-8%

Figure 35. View across river at RM 23 showing a 2.6 mile long abandoned channel, the longest segment measured; flow is left to right (©www.kestrelaerial.com).

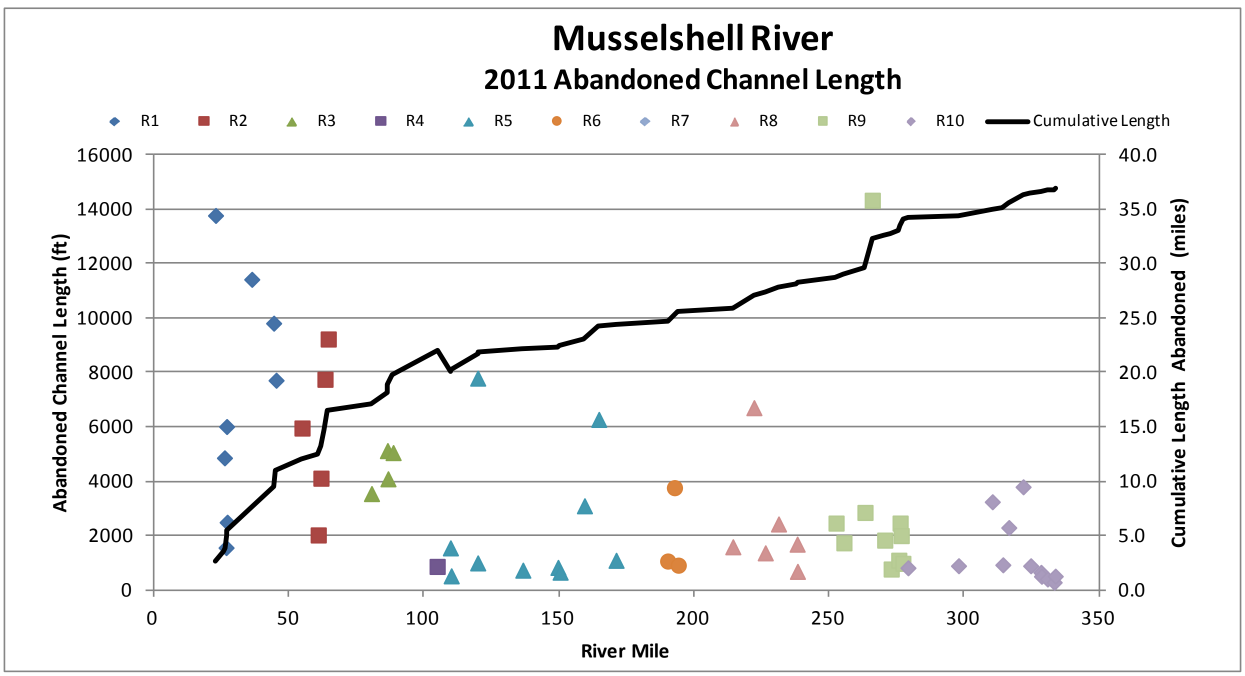

Figure 36. Abandoned channel length at each avulsion (points); cumulative loss shown as black line.

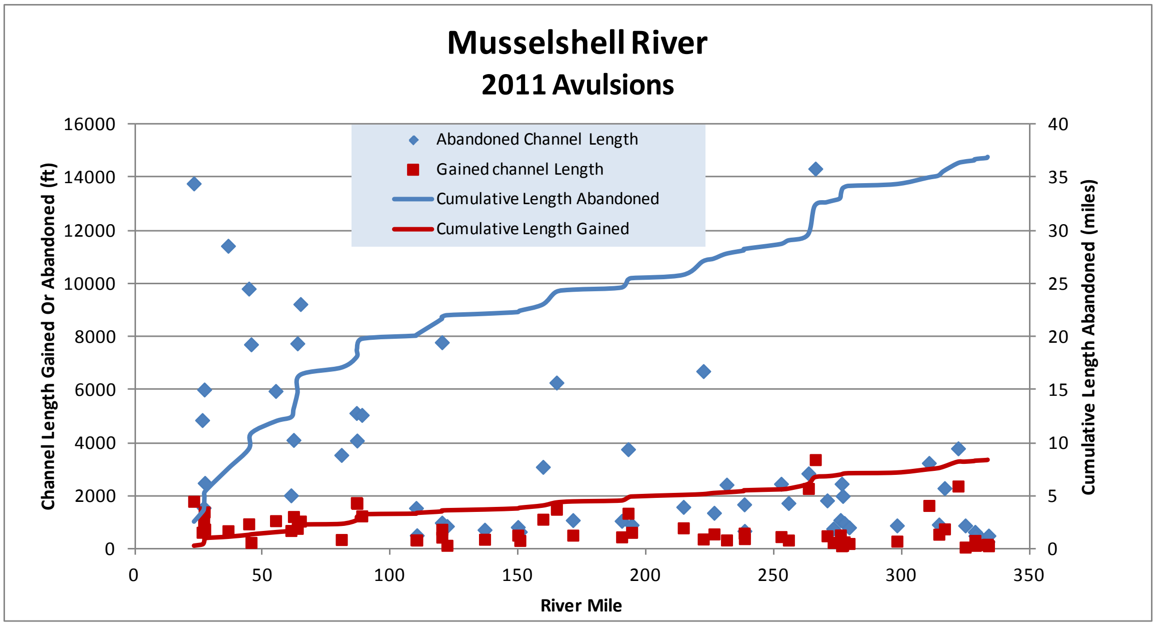

Figure 37. 2011 avulsion channel length losses and gains, showing cumulative change in upstream direction.

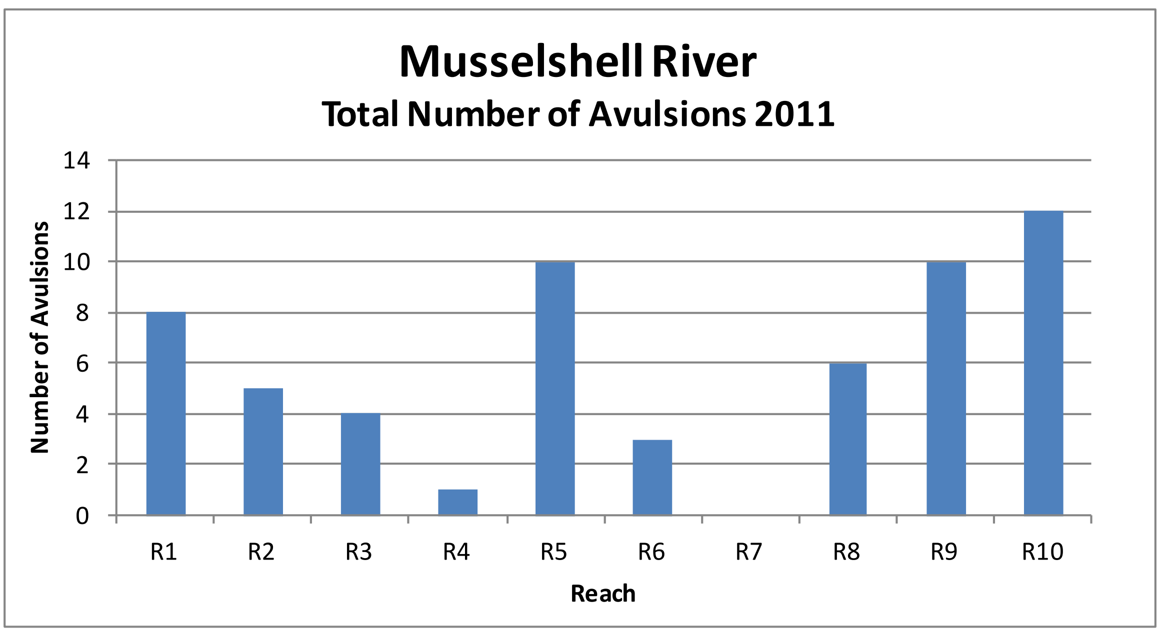

Figure 38. Total number of 2011 avulsions by reach, Musselshell River.

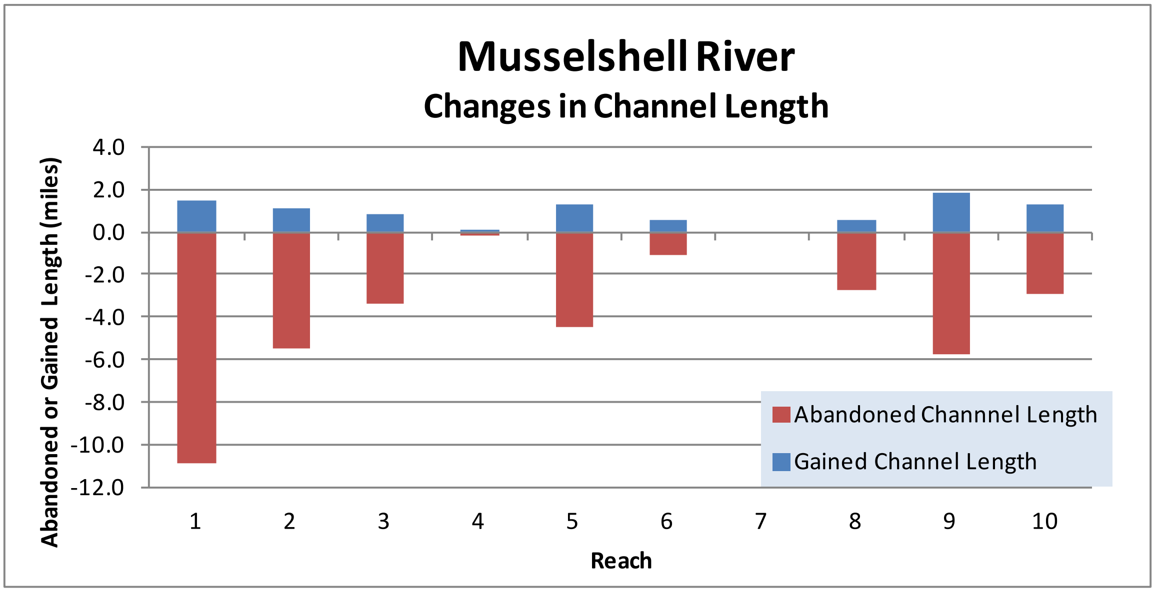

Figure 39. Gains and losses in channel length by reach.

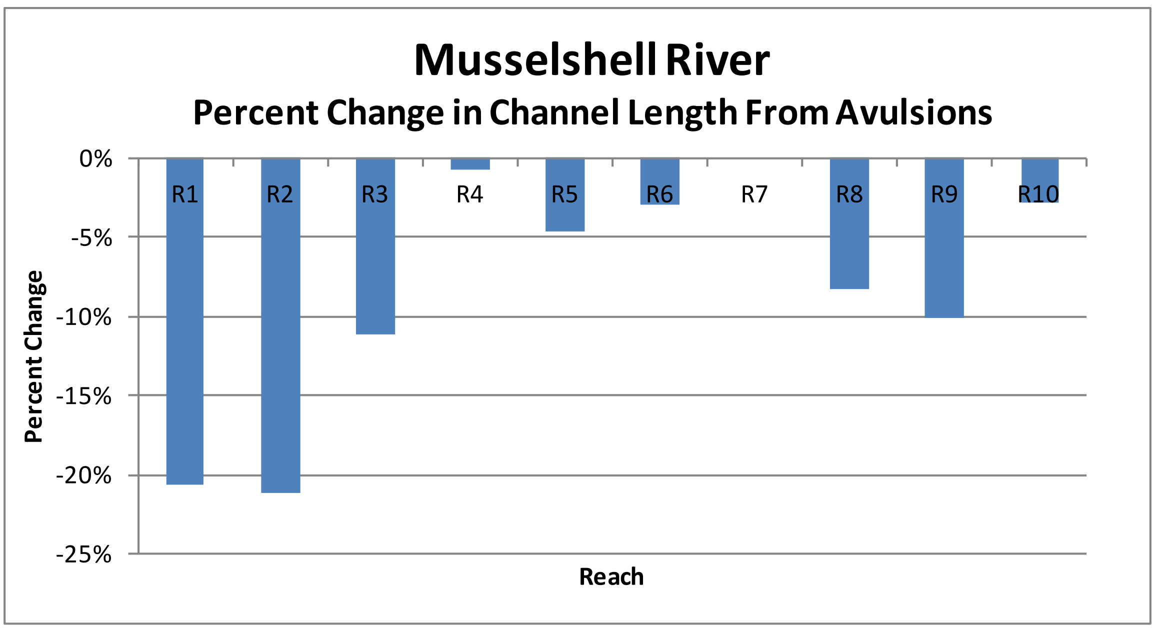

Figure 40. Percent change in channel length from avulsions.

In some places, avulsions began to develop but did not completely capture the main channel. In these areas, the avulsions serve as split flow channels or high flow channels, or left discontinuous channels on the floodplain surface (Figure 41 and Figure 42). These "failed" avulsions now pose a pathway for potential growth or complete avulsion during future flood events.

Figure 41. View upstream of avulsion at RM 159.9 showing post-flood split flow condition (©www.kestrelaerial.com).

Figure 42. Failed avulsion at RM 16; flow is right to left (©www.kestrelaerial.com).

6.3.3 Bank Erosion

A bank erosion inventory was not performed as part of this analysis, so the quantitative extent of severe bank erosion is not available. However, field observations and cursory air photo analysis indicate that bank erosion was indeed severe throughout the entire project area during the 2011 flood. In upper reaches, bank erosion within the entrenched channel resulted in exposure of vertical high banks and local breaching of the old railroad grade (Figure 43 and Figure 44). Bank erosion often created a low bar on the opposite bank that will establish as an inset floodplain surface. This process of high bank erosion, channel widening, and low inset bar/floodplain surface development appears to have been pervasive in channel segments that were entrenched prior to the flood.

Figure 43. Right bank erosion at RM 205 showing 2009 channel in blue and migration distance in feet (note breached rail berm in yellow).

Figure 44. View upstream of right bank erosion at RM 205; note low gravel bar on right and breached berm in background.

In lower reaches of the river, long duration flooding coupled with massive sediment loading from upstream resulted in extensive bank migration and point bar formation. At River Mile 41, flood-induced bank migration exceeded 850 feet (Figure 45). This consisted of high bank erosion and very large point bar formation on the opposite bank (Figure 46). The material eroded from the high bank consists of fine grained alluvial deposits derived in part from the clay-rich Bearpaw Shale. In places, undermining of this shale in the valley wall has resulted in erosion of the valley margin (Figure 47). Thus bank erosion associated with the flood included not only riverbanks and terraces, but locally the valley wall was undermined and destabilized.

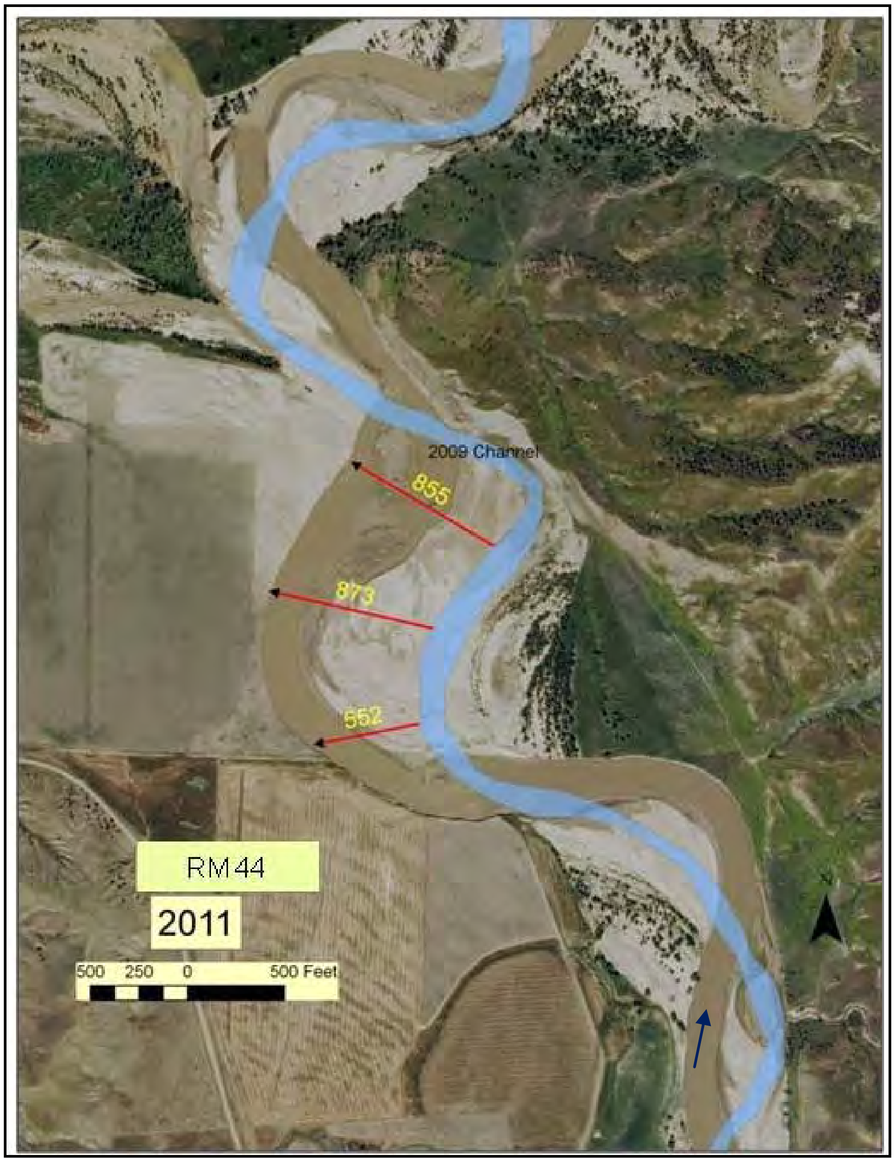

Figure 45. Left bank erosion (measured in feet) showing 2009 channel in blue superimposed on 2011 air photo.

Figure 46. View upstream of eroding bankline, RM 44.

Figure 47. View of mass failing Bearpaw Shale in west valley wall, Reach 1.

Figure 48. View upstream of massive point bar (left) and valley wall erosion on cutbank (right), Reach 1.

Bank erosion claimed at least one residential structure during the flood (Figure 49). According to local reports, this structure was undermined during a period of especially rapid bank erosion as floodwaters receded.

It is important to recognize that the bank erosion and channel migration that occurred during the flood lengthened the channel in many areas, which can contribute to inset floodplain development and long-term geomorphic stability. This was most evident in areas of high sediment loading, such as at River Mile 265 near Shawmut, where an avulsion upstream delivered large quantities of sediment downstream that formed point bars (Figure 50). These point bars accelerated bank erosion and channel migration on the opposite bank.

Figure 49. Collapse of house into river, RM 42 (©www.kestrelaerial.com).

Figure 50. View downstream of point bar formation, bank erosion, and channel lengthening near Shawmut (RM 265) (©www.kestrelaerial.com).

6.3.4 Breached Railroad Grade

In many instances, bank erosion upstream of Melstone resulted in local breaching of the historic railroad grade. A total of 31 complete breaches were mapped in the project reach. Of those 31 breaches, 24 are located on the north side of the river (left bank), and 7 are located on the south side. There are three clusters of breaches:

- RM 192 to RM 205: Twelve breaches on both north and south sides of river between Painted Robe Creek and Naderman Diversion;
- RM 228 to RM 233: Six breaches on north side of river near Ninemile Creek; and,
- RM 259 to RM 266: Seven breaches on north side of river just downstream of Shawmut.

In several cases, breaches formed where the railroad grade isolates historic Musselshell River meanders (Figure 52). Just downstream of Shawmut at RM 263.3, the main channel has relocated to the north side of the berm (Figure 53).

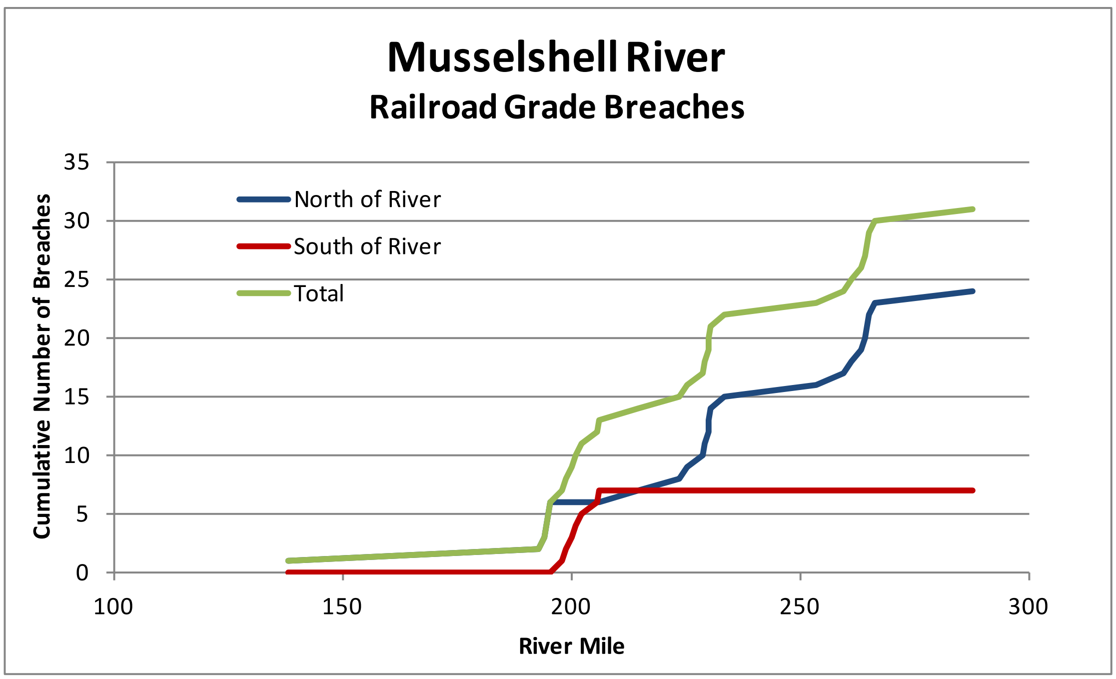

Figure 51. Cumulative number of breaches in railroad grade (moving upstream).

Figure 52. View downstream of breached railroad grade at RM 206 (©www.kestrelaerial.com).

Figure 53. View upstream (west) of long railroad grade breach east of Shawmut at RM 263 (©www.kestrelaerial.com).

6.3.5 Siphon Damage

Several irrigation canal siphons were significantly damaged by the flood. Damages consist of both exposure of the siphon in the channel bed, as well as bank erosion that exposed sections of siphon previously buried behind the stream bank. Figure 54 shows the Delphia-Melstone North Ditch Siphon, which experienced over 60 feet of right bank erosion that flanked protective armor. A large cottonwood had lodged on the exposed pipe last fall, however that debris has since been removed.

Figure 54. November 2, 2011 photo of Delphia-Melstone North Ditch Siphon (RM 138) showing exposed pipe and flanked right bank armor (©www.kestrelaerial.com).

6.3.6 Diversion Structure Damage

The 2009 and 2011 air photos were used to map in-stream diversions. The mapping was fairly cursory and the results should be considered approximate, as some smaller structures may have been missed. The mapping shows that from the North Fork/South Fork Musselshell River confluence to Melstone, a total of 29 in-stream diversions can be clearly identified on air photos. This translates to a frequency of one structure about every 6.7 river miles (Figure 55). Within that overall trend, there are two distinct clusters of diversions. The first extends from Egge Diversion downstream to Stella Dam/Eliason (RM 210 to RM 187), where on average there is one diversion every 3.7 miles. The second cluster is from Harlowton to Shawmut (RM 303 to RM 277) where there is approximately one diversion every 2.9 river miles. No in-stream diversions were identified below Melstone.

Several damaged structures were visited in the field by the RATT team. Damage at these structures consisted of flanking around abutments (Egge Diversion), or complete avulsion around the structure (Naderman Diversion). These diversions were rendered completely non-functional by the flood. Figure 56 and Figure 57 show an example of flanking at the Egge Diversion, and the avulsion around Naderman Diversion Dam is shown in Figure 58 and Figure 59.

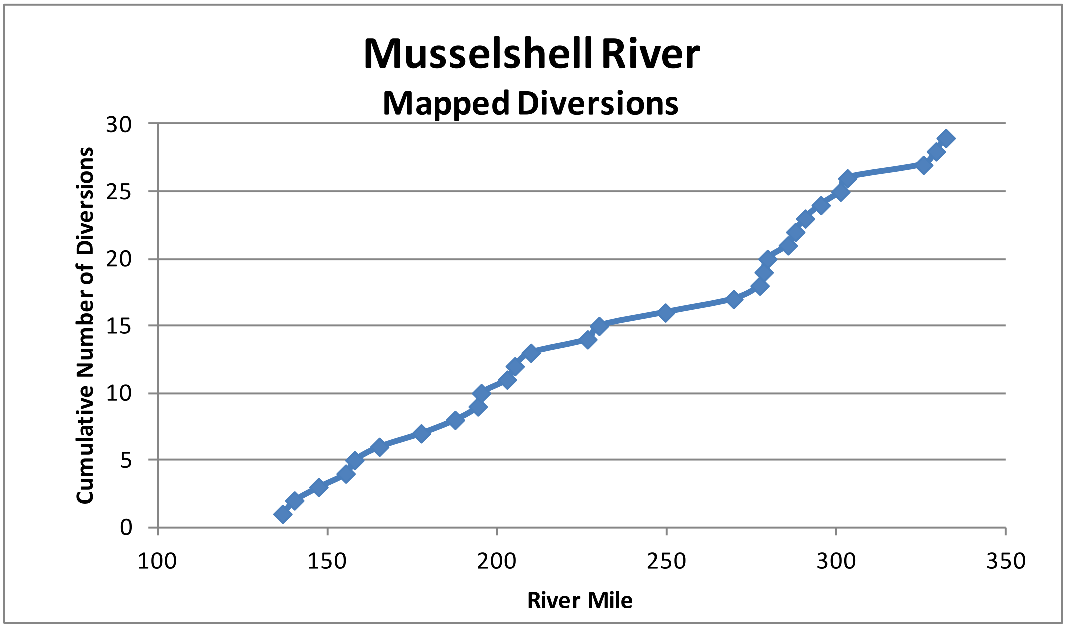

Figure 55. Cumulative frequency of mapped in-stream diversions.

Figure 56. Egge Diversion (RM 210) on June 16, 2011 showing active flanking on near (right) bank (©www.kestrelaerial.com).

Figure 57. Post-flood image of flanked Egge Diversion Dam (©www.kestrelaerial.com).

Figure 58. June 16 2011 flood image of Naderman Diversion at RM 194.2 (left foreground) showing active avulsion around structure (©www.kestrelaerial.com).

Figure 59. Post-flood view of abandoned Naderman Diversion (©www.kestrelaerial.com).

6.3.7 Floodplain Deposition

The Musselshell River flood of 2011 transported immense quantities of bedload sediment. Since the flows were out of bank for weeks, much of this sediment accumulated in low energy floodplain environments. The floodplain deposition was most substantial, both with regard to lateral extent and depth, on lower reaches of the river (Figure 60), where hundreds of acres of irrigated fields were buried by up to several feet of sand and finer sediment. Much of the deposition buried agricultural lands, and some recreational properties were affected (Figure 61). In many areas, these sediments have been densely colonized by seedlings of plains cottonwood and several species of willow (Figure 62 through Figure 64).

Figure 60. View upstream of floodplain deposition in Reach 1 (RM 36) (©www.kestrelaerial.com).

Figure 61. Floodplain deposition on meander core at RM 35, Reach 1 (©www.kestrelaerial.com).

Figure 62. June 16, 2011 photo of sediment deposition on irrigated field, RM 35.5 (©www.kestrelaerial.com).

Figure 63. September 13 2011 photo of field at RM 35.5 showing cottonwood colonization on new sediment (©www.kestrelaerial.com).

Figure 64. Cottonwood seedlings on floodplain sediment, RM 50.

6.3.8 Floodplain Scour

Flood-related erosion of the river's floodplain generally consisted of avulsions (Section 6.3.2), as well as channelized flow that did not develop into avulsions and local scour holes created by floodplain dike breaches (Figure 65 and Figure 66). Although these features are fairly small relative to other impacts, dozens of small headcuts formed across the floodplain that channelized flows and drove local scour. These features disrupt agricultural land use practices throughout the corridor (Figure 67).

Figure 65. Floodplain erosion, RM 244 downstream of Ryegate (©www.kestrelaerial.com).

Figure 66. Large floodplain scour hole formed by velocity concentrations through a breached elevated ditch that served as a floodplain dike, RM 50.

Figure 67. Fall 2011 land use modifications around area of floodplain scour near Ryegate (©www.kestrelaerial.com).

6.3.9 Pump Site Damage

Pump site damage is commonly due to bank erosion at the pump site, and in some cases, erosion of receiving ditches (Figure 68) or channel scour at the pump site. In many cases pump sites were completely lost due to bank erosion (Figure 69). Several pump sites were lost due to channel avulsions where the new channel by-passed the pump.

Figure 68. Pump site erosion and receiving ditch damage, RM 195.2 (©www.kestrelaerial.com).

Figure 69. View downstream of destroyed pump site, RM 25.

6.3.10 Transportation Infrastructure Damage

The transportation infrastructure damaged by the flood includes roads and bridges that were impacted by both bank erosion and avulsion. In lower reaches of the river, farm access roads on erodible Bearpaw shale were seriously damaged and in some cases completely lost (Figure 70). At River Mile 120, an avulsion at Harvey Road completely destroyed a road embankment that crossed the river floodplain (Figure 71). Upstream of Melstone, some of the old railroad grade bridges were damaged; many of these bridges continue to provide road access, although several appear to be largely abandoned (Figure 72).

Figure 70. View upstream of field road damage, RM 43.

Figure 71. View downstream of an avulsion at Harvey Road (RM 120) that destroyed a road embankment (©www.kestrelaerial.com).

Figure 72. View upstream of flanked railroad bridge, RM 233 (©www.kestrelaerial.com).

7 Restoration Alternatives and Long-Term Opportunities

As described in Section 6.3, the Musselshell River was dramatically altered by the floods of 2011. These changes have created tremendous uncertainty for farmers, ranchers, residents, recreationalists, land managers and irrigators with respect to the cost of restoring historic uses and the future condition of the river. To that end, it is important to track and better understand over time how these changes play out, and how well flood response projects perform. The Lower Musselshell Conservation District typically receives five to ten 310 permit applications in an average year; in 2011, the CD received 67, and by early spring 2012, an additional 20 had been submitted. Producers are actively developing plans for recovering land uses and irrigation capabilities throughout the basin. We recommend that this work be accompanied by the consideration of larger management concepts to optimize long-term water use, economic stability, and overall ecological function of the Musselshell River.

In the process of visiting over 40 sites that experienced some form of flood damage, the RATT team developed conceptual alternatives for rehabilitation of infrastructure and/or river stability, with an emphasis in integrating opportunities for enhancing long-term sustainability of the river corridor with respect to geomorphic and riparian function (Appendix C). This Chapter describes some of these approaches with respect to specific impacts. These approaches are general, and in practice need to be specifically adapted to site conditions.

7.1 Avulsions

As described in Section 6.3.2, the 2011 flood caused 59 avulsions, where a prominent new channel was carved during high water. Some of these avulsions have captured the entire flow of the Musselshell, and others serve as split flow channels or high flow channels. The lengths of the abandoned channels range from hundreds of feet to miles. Rehabilitation approaches for avulsion impacts should consider several issues such as the instability of the new channel, access to isolated property, access to irrigation infrastructure, opportunities for reducing flood energy by storing floodwater, and opportunities for promoting geomorphic and riparian recovery of the river corridor. How landowners approach dealing with avulsions depends largely on their anticipated land uses, irrigation water requirements, access requirements, and budget.

A complete avulsion is one where the new channel has captured the main Musselshell River (Figure 73). This occurred at dozens of locations throughout the river corridor. In many cases, the avulsions were bendway cutoffs, where a long loop of river was shortened by the carving of a new channel across the “neck” of the bend. Issues commonly associated with these avulsions include loss of access to agricultural ground, lost water sources on the abandoned channel (i.e. irrigation pumps and diversions), and instability of the new channel. A partial avulsion is a new channel that has connectivity with the main river channel on its upper and lower ends, but has not captured the main channel at normal flows. An example of this type of avulsion is shown in Figure 74.

Figure 73. View south of complete avulsion, RM 222, upstream from Lavina.

Figure 74. View upstream of partial avulsion, RM 165.

7.1.1 Complete Avulsions

When avulsions capture the entire flow of the river, approaches and issues that might be considered in addressing the impact include the following:

No Action: In many cases, the most appropriate approach for addressing a complete avulsion is No Action, because it can be extremely difficult and costly to successfully re-route a river back to its original course. If the no action alternative is adopted, there may be remaining issues with lost pump sites and lost pump site access. In these situations, we recommend that water users convert to temporary pumps and relocate points of diversion, using the abbreviated process (Chapter 8) as possible. Another consequence of No Action is the preservation of a new channel that is relatively steep and likely unstable as it redevelops a stable cross section. In these situations, we recommend against aggressive armoring of this new channel, as it will evolve over time to an appropriate size and layout. The new channel should revegetate naturally with time. Opportunities associated with this approach include maintaining the abandoned channel as a wetland area that provides flood storage and areas of groundwater recharge, and promoting riparian recovery within the new channel.

Convert Avulsion to High Flow Channel/Wetland Swale: One alternative that the RATT team discussed at several sites is the conversion of the new avulsion to a high flow channel/wetland swale, coupled with the recovery of the pre-flood channel. This approach was discussed in areas where a complete avulsion was considered to be especially difficult to accommodate due to infrastructure or access issues. However, this approach will require significant engineering design, implementation investment, and maintenance, as it will require hard engineering measures. For example, if the new channel has downcut below the abandoned segment, it will be necessary to incorporate grade controls and potentially bank armor to prevent the avulsion from re-occurring, and to redirect low flows into the perched, original channel. Grade controls constructed as overflow weirs would also be necessary to control flows entering the new channel. Overflow structures such as armored berms could also serve as access routes across the avulsion. Opportunities provided by this approach include the creation of wildlife and wetland habitat in the high flow channel (avulsion), and creation of a high flow channel that can relieve pressure on the main thread during floods.

If the channel is to be re-routed back to its original course, we recommend that this option be carefully considered with respect to impacts to adjacent areas. The Washington Streambank Integration Guidelines (WDFW, 2003) states the following regarding this alternative:

"As long as large storm events occur, avulsions will also occur. After large storm events, the human response is often to "fix" the avulsion (e.g. put the channel in its pre-avulsion location and armor the bank) to withstand the next large event. These "fixes" are often structural and are designed to withstand these few large events; but, more often than not, they unintentionally exacerbate bank erosion along downstream and upstream properties."

7.1.2 Partial Avulsions

Where a new channel has been carved in the floodplain yet has not entirely captured the river, we recommend that landowners consider adopting the channel as a high flow channel/wetland swale as is described above for complete avulsions. Woody debris can be placed in the swales to improve habitat and slow flow velocities. The channel can be revegetated with wetland plants if it remains sufficiently wet, otherwise can be revegetated with appropriate, stabilizing woody and herbaceous plants.

If the feature is relatively small, it could be regraded, infilled, and compacted to prevent another avulsion from occurring. Buried grade controls may also be appropriate to prevent a new channel to re-form. These areas could then be reclaimed as fields or pasture.

7.1.3 Long-Term Strategies

During the 2011 flood, the Musselshell River lost a net 8% of its length as avulsions which amounted to almost 37 miles of abandoned river channel. The abandoned channels have been replaced by newly carved channels that are typically straighter and shorter than their predecessors. As the new channels are steeper, they typically downcut (erode their beds and deepen) and perch the abandoned channel above the riverbed. Sediment tends to accumulate in the abandoned channels where velocities are slow. As a result, the abandoned channels are commonly perched above new channels, and/or plugged with sediment. From a long-term strategy perspective, re-activating abandoned channels can be both costly and counter-productive. Re-accessing a perched channel can require raising the bed of the new channel with grade controls, excavating the old channel, or both. Bank armor is typically required to prevent flanking of grade controls. Since the old channels are relatively long and flat, and the system is continuing to respond to the flood, sediment accumulation can become chronic, creating long-term maintenance issues that are necessary to keep the re-activated channel open and prevent the recurrence of an avulsion due to channel plugging.

In most cases it will be necessary to accommodate avulsions by modifying land use practices, points of diversion, and access routes. There may also be a long-term tendency for the river to begin regaining the lost channel length that was lost because of the avulsions. This is often manifested by active river migration and associated bank erosion in the vicinity of the avulsion. It is also important to note that the abandoned channels can provide excellent wetland habitat, seasonal fish habitat, and flood storage; these benefits should be considered in overall land use planning.

Long-term strategies to prevent future avulsions include managing land uses in sensitive areas. For example, where a sharp bendway is prone to overflow and an avulsion, maintaining a woody riparian plot in that bendway would help prevent that erosion. If these areas are used as fields, it would be appropriate to maintain a sod grass hayland pasture without tillage.

7.2 Bank Erosion

Bank erosion was extensive along the Musselshell River during the 2011 flood. The erosion typically occurred where the river widened, on bendways, where the river carved new channels (avulsions), and at hard in-channel structures. Above Melstone, bank erosion was accelerated by the confinement of floodwaters due to the elevated Highway 12 right-of-way and the abandoned Milwaukee Railroad grade. The erosion produced a massive quantity of sediment that was in part deposited as new sand and gravel bars within the widened channel. The bar growth in turn put additional pressure on banks that were relatively stable before the flood.

Future erosion rates at any given location will depend on river flows, site configuration, and bank resiliency. In some areas such as developing bendways where soils are highly erodible and unprotected by native vegetation, relatively rapid erosion rates may continue. At these sites, the immediate need for bank erosion should consider the level of threat, and the value of property or infrastructure being threatened. In other areas, the response will be much slower, negating the value of costly stabilization.

The RATT team cautions landowners in placing bank armor over the next several years unless absolutely necessary, as the river is continuing to adjust to the flood and site conditions are changing. Any riprap project is designed for site specific conditions in terms of project length, depth of scour, and rock size, which typically requires the services of a Montana certified Professional Engineer. On the Musselshell, ongoing channel adjustments will alter these site conditions, which will change the appropriate treatment design. In the near term, new bank armor projects will have a high risk of needing to be lengthened or maintained, or conversely, the bank armor may end up sitting high and dry if the channel shifts away. New armor may impact flow paths and erosion rates on the opposite bank or above and below the project, potentially impacting adjacent landowners. It is important that any perceived need for bank stabilization is carefully weighed against the value of the land or structure being protected, the initial and long-term maintenance costs, and the interference of excessive bank stabilization with the natural recovery of the river (recreation of meander patterns and establishment of native riparian vegetation). Cost considerations should also include the expense of mitigation; any armor over 150 feet long would likely require mitigation by the US Army Corps of Engineer's 404 Permitting Program (http://dnrc.mt.gov/Permits/StreamPermitting/JointApplication.asp).

7.2.1 Short-Term Strategies

Bank erosion treatments can range from No Action to aggressive armoring. No Action is appropriate where the consequences of erosion are acceptable. In some cases, the most cost-effective approach is to apply soft treatments that are relatively inexpensive, to monitor the bank to see how much more erosion occurs, and to use aggressive and costly armor only when it is absolutely necessary. A range of erosion control strategies that were discussed in the field by the RATT team are summarized below. For further information regarding erosion control strategies, see the Washington Integrated Streambank Protection Guidelines (WASHGP, 2003; http://wdfw.wa.gov/publications/00046/).

- ***Bank Shaping and Planting:*** Where a high eroding bank is creating erosion concerns, but the area threatened is not particularly valuable, grading the high bank to a lower slope and planting that surface will help stabilize the bank and slow erosion rates. This can be difficult when upper bank areas are too dry to support woody vegetation. These areas may require excavating deep holes and deeply seating willows to access groundwater.

- ***Bankfull Bench Construction:*** Once concept to consider is excavating and planting a fairly wide (~20 ft) bench at the normal high water elevation. Rounded cobble could be used to reinforce the bank toe, and the bench can be densely planted with deep rooted woody vegetation or sod mats and monitored for additional retreat. Plantings on a low elevation bench will have a higher survival rate than those on a high bank due to their proximity to the water table. In the event that the bank erosion continues, the bench provides a "sacrificial" zone that provides some time for vegetation to establish and reinforce the bank, and for bank erosion to slow. If the bank erodes through the bench or to whatever limit is established, it can then be treated more aggressively.

- ***Rock Toe:*** Another alternative is to install a rock toe up to the normal high water mark and then slope the upper bank back to 3:1 or greater, and plant the bank with native, deep rooted, grasses, woody species, and/or sod mats. The rock toe will protect the lower bank where the erosive pressures are highest, while allowing for upper bank plantings. The rock can be sized to be mobilized under higher flows that will reduce the negative long-term impacts of hard armor.

- ***Flow Deflectors:*** Flow deflectors such as barbs might be considered, but we would caution that the performance of flow deflectors is related to the "angle of attack" of the river, and this angle will change as the river stabilizes following the flood. Very commonly, flow deflectors require careful design and placement, often with riprap reinforcement between the barbs due to scallop erosion caused by changes in the main flow path of the river.

- ***Blanket Riprap:*** Blanket riprap should be considered where high value infrastructure or property is severely eroding. This would consist of sloping banks to a 3:1 slope, placing a gravel blanket, and installing properly sized rock that is keyed into the bed of the channel at calculated depths of scour. This alternative should be used sparingly, and only to assure full protection of valuable resources.

- ***Riparian Buffers:*** Maintaining good buffers against irrigated fields will reduce slumping of irrigation saturated banks and help slow bank migration. Riparian buffers should be considered in any bank protection strategy, to provide habitat and improve bank resilience.

7.2.2 Long-Term Strategies

The severe bank erosion that happened during the flood has generated much discussion over the need for bank stabilization throughout the system. The RATT team is concerned that extensive, aggressive armoring will be counterproductive to river stability and function in the long run. The Musselshell River is naturally a fairly low gradient, sinuous river. The flood shortened the river by 8%, and with time, some of that length will be regained by channel migration and bank erosion. It is important that stakeholders understand that this lengthening is critical to the long-term stability of the river. If armoring becomes pervasive, this recovery process will be impeded and long term stability issues such as downcutting, water table lowering, and localized severe erosion should be expected. Extensive armoring would lock the river into a configuration that is not fully recovered from the flood, which will create additional erosion problems, armor projects, and lost river health. If the goal for the system includes long-term stability, ecological function, and resilience to flooding, erosion control should be considered in terms of its cumulative impact to system recovery.

7.3 Siphon Damage

Siphons provide critical irrigation infrastructure on the Musselshell River, and as such work has already been undertaken to repair flood-induced siphon damage. Alternatives discussed by the RATT team at damaged siphons include reconstructing the approaches on both banks as necessary, armoring banks, removing lodged debris, and realigning and repairing flanked armor. At any site, the configuration of the river channel upstream of the siphon should be considered to minimize the risk of armor flanking at the site. On bendways, armor should extend upstream to a point above the apex of the bendway.

Where siphons are exposed in the channel, we recommend that they be protected with carefully-placed rock to prevent ice and debris from lodging on the pipe. The rock should slope gradually both upstream and downstream of the pipe to minimize the grade break in the bed.

Additional alternatives discussed at relatively small siphons include converting siphons to pumps, re-building the structures as flumes, or abandoning the siphon and associated irrigation if the costs outweighed the benefits. Converting siphons to overhead flumes on the Musselshell would probably require a mid-channel support that would be costly to construct and maintain.

In the long-term, siphons should be located in areas where river migration rates are low, such as immediately downstream of bedrock bluffs. If the channel is downcutting in response to the flood, the siphons should be placed deep enough to accommodate future changes in grade. These actions will minimize the need for bank armor in the future, and reduce the risk of siphon failure during a future flood.

7.4 Breached Dikes

Over the past century, the railroad berm above Melstone has confined the Musselshell River to an unnaturally narrow corridor and confined floodplain. In 2011, the flood eroded and overtopped the berm in several places, which allowed water to access the historic floodplain. Water that flowed through breaches also had to return; this caused additional overtopping and berm failure, which created bank erosion sites, headcutting problems, and sediment slugs that caused additional stability problems downstream.

At many sites, reconstructing the berm would block a return point for floodwater, which would make flooding worse on irrigated fields. To that end, we do not recommend reconstructing berm breaches that currently allow floodwater to return to the river.

7.4.1 Long-Term Strategies

One opportunity on the Musselshell is to evaluate the benefit of the berm breaches with regard to overall floodplain function. Upstream of Melstone, the 31 mapped breaches in this embankment have dramatically altered floodplain access in the system. The embankment is now a discontinuous berm that runs parallel to the river creating punctuated river/floodplain connectivity, and it will continue to decay with future flooding or bank erosion. Certain breaches may provide important entry and return points for flood overflows that will contribute substantially to long-term system stability and reduce future flood damages. It is important to remember that floodplains are temporary, low-cost, water storage 'reservoirs'. The more that floodwaters are allowed to occupy the historic floodplain, the more downstream flood stage is reduced and the longer-term seasonal stream flow is increased. We recommend that the abandoned line not be considered as an informal flood control feature, but as a potential liability upon severe flooding. Removal or selective breaching of the berm could improve floodplain access and improve the overall resiliency of the Musselshell River to major flooding in the future.

We would recommend that floodplain management efforts consider developing an overall floodplain management plan that considers strategic dike repair or breaching.

7.5 Diversion Structure Damage

The flanking of diversion structures has included extensive erosion, downcutting of the channel, and perching of irrigation infrastructure. In these situations, rerouting of the river back over the dam would require extensive reconstruction of the channel to its pre-flood configuration. Because of the severity of the flooding on the Musselshell, the system will continue to respond to the flood impacts over at least the next several runoff seasons, including adjustments in channel shape and downstream gravel movement. Because of these ongoing responses, the reconstruction of in-stream structures will be risky and likely require substantial maintenance for the life of the structure. Reconstruction of flanked diversion dams will also re-create a fish passage barrier and fish entrainment issue at the site that was removed by the flanking.

If diversion structures are rebuilt, or if the channel is re-routed over a structure, we recommend that fish passage be included in project design, to capitalize on the opportunity to reestablish connectivity for the Musselshell River fishery.

Alternatives discussed for flanked diversion dams include converting to a single pump at the dam site or multiple pumps at other locations that can efficiently convey water to receiving open ditches or irrigation systems. Placing pumps at flanked dams can capitalize on any remaining backwater and scour holes. Pump sites require power which may not be close to the site; the cost of bringing in power is an important consideration in costing alternatives.

If concrete diversions are retired, channel grade and water depth could be maintained by substituting the damaged structure with a fish-friendly, low-head check structure that could be installed as either a permanent or seasonal structure. These structures could extend part way or across the channel to ensure backwatering at the pump site during the irrigation season.

7.6 Floodplain Deposition

Floodplain deposition resulted in up to several feet of sediment on irrigated fields, especially on the lower river below the Flatwillow Creek confluence (Reaches 1 and 2). The material ranges from massive sand to finer grained sediment that formed deep cracks and large clods following the flood (Figure 75 through Figure 77). In most areas, fields with up to 2 inches of flood sediment may be relatively easily reclaimed for flood and sprinkler irrigation. In these cases we recommend that the fields be cultivated deeply to insure mixing of old and new soil followed by several seasons of planting to a cover crop mix and/or small grain (hay barley). This approach will provide time for freeze and thaw sequences to help break down the clay clods as well as to improve the organic matter and biologic activity in more sandy deposits. After several crops, the soil tilth or workability should be suitable for irrigated hay production. Areas with deeper deposition of sediment will require more intensive forms of restoration to include removal and re-leveling practices.

Areas with deeper deposition (> 2 inches) of sediment, particularly fine clay and coarse sand, will require more intensive forms of restoration to include sediment removal and/or land shaping and re-leveling practices on flood and sprinkler irrigated fields. The treatment should be based on an onsite investigation by a qualified soils specialist or agronomist.

We also recommend that landowners consider placing areas that can't be economically restored into USDA programs that are designed to protect riparian areas and promote the recovery of native woody vegetation in the stream corridor. This flood event has created a tremendous opportunity to develop a young class of riparian vegetation; in order to encourage the protection of these areas to increase the odds of survival of the young trees, the USDA has offered program options targeting riparian area protection. Additional programs may be available to help restore fields damaged by the flooding.

Figure 75. Massive sand deposition on irrigated field (3 ft probe), RM 43.

Figure 76. Deep desiccation cracks in floodplain deposits, RM 57.

Figure 77. RATT team evaluation of recently tilled blocky floodplain sediment, RM 26.

7.7 Floodplain Scour

Floodplain scour occurred in floodplain areas where avulsions failed or where flows were focused such as through breached dikes. Where local floodplain scour has occurred due to breaches in floodplain dikes we have recommended removing the entire dike if it is no longer necessary and using the material to fill the scour hole. The fill area should then be heavily vegetated with sod-forming grasses.

Where floodplain scour consists of floodplain channels with headcuts (failed avulsions), these features do not necessary create inherent instability under normal flow conditions, although they are likely to cause problems with field access and use, and in some cases may lead to a future avulsion (Figure 78). Such headcuts and discontinuous channels can be infilled with native soils and compacted. Armoring the downstream edge of the fill if there is a large grade change provides long-term stability in the event of another major flood, however, this step is unnecessary under most flow conditions if the headcut is shaped and heavily vegetated.

Figure 78. Example of floodplain scour extending into field, RM 27.5.

Long-term strategies to limit future floodplain scour include managing land uses in sensitive areas. For example, where a sharp bendway is prone to overflow and an avulsion, maintaining a woody riparian plot in that bendway would help prevent that erosion. If these areas are used as fields, it would be appropriate to maintain a sod grass hayland pasture without tillage.

7.8 Pump Site Damage

In many cases damaged pump sites require relocation. A good pump site is one that is stable and has deep water during most flow conditions. On the Musselshell, optimal sites appear to be against the bluff line where scour holes are deep and banks are relatively stable, near bridges where the channel is typically armored to protect the bridge, above backwatering diversion dams, in straight reaches which are typically stable, and on the downstream limb of bends, as long as bank erosion is not a problem. Also, we have seen several places where clay lenses in the channel create deep local scour holes that serve as excellent pump site locations.

In many locations, we have recommended that pump sites be transitory and portable, so that they can be relocated as needed as the channel continues to adjust in response to the flood. In the long-term, pump sites should be located in areas where migration rates are low, and the elevation of the riverbed appears stable. Another long-term opportunity is to work with DNRC Water Rights to seek ways to expedite the required process for moving a pump site.

7.9 Lost Farm Field Access

In many cases, avulsions destroyed access to irrigated fields, and regaining that access is critically important to producers. Constructing berms across avulsions to regain access is described in Section 7.1. When access is needed across the channel, low flow vehicle crossings were considered, specifically with regard to their location and construction. Crossings were sited at several locations to minimize the need to armor unstable banks, grade slopes, or import coarse material into the riverbed (Figure 79). Crossings were proposed where there was little evidence of recent channel movement.

Where necessary, river access ramps should be graded at a 10:1 slope, and surfaced with pit run gravel. The recommended crossing sites are shallow riffles where some existing gravels are already in place. Additional pit run may be necessary to supplement that bed material. When gravel is brought in to harden the channel bottom, the grade of the river needs to be maintained at a consistent grade above, across, and below the crossing.

Figure 79. View downstream of proposed low flow crossing site, RM 65.

7.10 Treatment Costs

Because of the range in approaches that can be taken, costs for treatment alternatives are not provided in this report. However, general unit costs for treatment elements derived from the NRCS 2012 cost list are shown below.

Table 4. Approximate unit costs for a range of treatment alternatives (NRCS, 2012).

Application	*Treatment*	*Unit Cost*
Seeding flood deposits	Riparian Herbaceous cover	Seed and seeding: $58.23 per acre Sprigging: $85.00 per thousand sq ft
Temporary riparian protection	Livestock Exclusion from riparian areas:	3 yr: $87 per acre
Cottonwood seedling protection, riparian buffer protection	Riparian fencing: 3-5 Barbed, Smooth Wire, Includes Installation	$1.81-$2.21 per ft
	Riparian Fencing: Permanent electric, includes installation, 205 smooth wire, including energizer	$1.27 per ft.
Diversion structure rehabilitation	Fish Passage	$4,800 each
Headgate rehabilitation	Fish Screen	$2,800 each
Erosion control	Streambank protection for channels with rock riprap	$10.64 per sq. ft.
	Streambank protection for channels above the Inert Slope Toe protection	$1.00 per sq ft.
Erosion control and channel restoration	Channel Restoration for channel with Bankfull discharge greater than 150 cfs, requiring floodplain construction , vegetation, and toe rock type bank stabilization	$205.54 per ft of channel
Access	Stream Crossing, Ford	$4.93 per sq ft.
Wetland restoration	Wetland Enhancement	$5,000 per quarter acre

8 Water Rights Considerations

The flood of 2011 created significant water right implications for water users on the Musselshell River and tributaries. Dozens of diversion structures were either destroyed or compromised, ditch segments were lost, irrigated cropland experienced extreme erosion, deposition, or were lost altogether, and fields were isolated by meander cutoffs. Collectively, these forces have necessitated legal changes to water rights and imposed an added burden on water users. In Montana, authorization must be acquired from the Department of Natural Resources and Conservation for changes to point of diversion, place of use, purpose of use or place of storage. For more information contact the Lewistown Regional Office at 406-538-7459 or http://dnrc.mt.gov/FieldOperations/regionaloffices/lewistown.asp.

8.1 Changing a Point of Diversion

Two administrative processes are available for changing a point of diversion, one requiring authorization prior to physically making the change, the other an ***abbreviated process*** of notification to the Department after the change has been implemented. The latter process is considered an exemption in Montana water law. This section will discuss the exempt process first.

Per statute (MCA 85-2-402(18)), the following criteria apply to changes of water rights for replacement points of diversion without the prior approval of the Department (criteria have been summarized):

- the existing point of diversion is inoperable due to natural causes (flood);
- there are no other changes to the water right;
- the capacity of the diversion is not increased;
- there are no other diversions or intervening water rights between the existing and replacement points of diversion, or written waivers are obtained from interveners;
- there is no change to the source of water and the replacement diversion is "*as close as reasonably practicable*" to the existing diversion;
- the existing diversion will no longer be used;
- the existing diversion has been used in the last 10 years prior to filing the notice for change with the Department;
- the change will not increase access to water availability, nor change the method of irrigation (e.g. flood to sprinkler conversion), or increase the amount of water diverted, used or consumed; and
- notice of the replacement point of diversion is submitted to the Department within 60 days after completion.

Many water users in the Musselshell Basin will likely be able to utilize the abbreviated or exempt process for their diversion changes, provided they're only moving minimal distance and conforming to a similar diversion structure (e.g. pump) as historically. Others may not meet the statutory criteria and will be required to submit an ***Application to Change a Water Right***, a more intensive process than the exempt notice. It is important that anyone desiring to make a water right change contact the Department's Lewistown Regional Office for consultation before planning or implementing the change.

If any of the aforementioned criteria are not met, an Application to Change a Water Right must be filed with the Department. This process includes a technical review by the Department to determine historic water use and compare to the proposed water use, a preliminary determination to grant or deny, a public notice process, an objection period, an administrative hearing, and final determination. The Department's decision in the matter can be appealed to district court. The process may take several months or more to complete, and the burden is on the applicant to prove the criteria.

8.2 Changing a Method of Diversion

In Montana the method of diversion can be changed without regulatory approval, provided no other element of the water right is being changed (place of use, purpose of use, place of storage, period of diversion, etc.). For example, if a producer opts to replace an old, existing headgate with a new headgate or pumping system and the pumping system is placed in the same footprint as the old headgate, and no other changes are made to the water right, then the change may occur without invoking the administrative process. However, this circumstance is not always the first choice of options. Often, a producer makes other changes to his/her water system, such as a move in diversion location or reconfiguration of the place of use, invoking the application process.

8.3 Changing a Place of Use

Any time the place of use of a water right is proposed to be changed, a water user must receive authorization from the Department. Examples of place of use changes are converting from a flood irrigated system to a sprinkler irrigated system (e.g. center pivot), when the sprinkler system applies water outside the exact boundaries of the flood system. It is common for a center pivot to sweep outside historically flooded boundaries, therefore invoking this process. The 2011 flood in the Musselshell eroded many irrigated parcels as well, setting the stage for place of use changes in the future. The same administrative process as described in the last paragraph of Section 8.1 above, requiring Department approval prior to project implementation, is required to make a place of use change.

8.4 Changing a Purpose of Use

In some cases in the Musselshell basin, irrigators who experienced complete or partial destruction of formerly irrigated fields, and have no irrigable land left to erect a new system, may wish to consider a purpose of use change. The option exists for these water users to propose a change to a different purpose than irrigation. The amount of water associated with the former place of use may be applied to the new purpose, provided the statutory criteria are proven and authorization granted by the Department prior to implementation.

9 Monitoring Strategies

The 2011 Musselshell River flood has redefined the baseline condition of hundreds of river miles by dramatically changing river form. As this assessment was completed within a year of the flood, it provides somewhat of a baseline description of post-flood conditions. In this report and in the supporting Map Appendix, we have identified many of these flood impacts in terms of their processes and locations. We have provided rehabilitation strategies that focus on opportunities to enhance system recovery and sustainability. To make the best use of these preliminary observations and recommendations, we recommend that the MWC continue to document the post-flood evolution of the river. Monitoring the recovery path of the river, water management in the basin, and the performance of rehabilitation projects will benefit landowners in balancing the site-specific need for projects and the longer-term cost effectiveness of integrated river corridor management. To that end, several topics that the RATT team has identified as important for overall system monitoring are briefly described below. Our goal is to provide feasible strategies that collectively support the livelihoods of water users while contributing to the physical and biological resilience of this remarkable river.

9.1 Floodplain and River Channel Function

The connectivity between a river and its floodplain is becoming increasingly recognized as an important component of river health and stability. On the Musselshell River above Melstone, this natural connectivity was severed by railroad and highway embankments (lost lateral connectivity), as well as downcutting caused by channel shortening when the rail line was built in 1908 (lost vertical connectivity). Although this floodplain isolation provided local flood protection, it accelerated flood damages within the confined river corridor. Floodwaters that were confined within the berms increased water depths and erosive energy in the downcut channel. The berms locally breached where they were overtopped, which allowed water to both pass into and out of previously isolated floodplain. As described in Section 6.3.4, a total of 31 complete breaches through the railroad grade were mapped in the project reach, such that the berm, which is not maintained, is now discontinuous. Because of the breaches, some historic floodplain connectivity has been re-gained by the flood. In addition, channel widening and channel movement has expanded a developing “inset” floodplain that is forming at a lower elevation on recent river deposits. This low floodplain has better groundwater access and supports colonizing woody riparian vegetation. This feature, which will be inundated much more frequently than the perched historic floodplain (probably every 2 years or so), will also improve long-term floodplain function. With these processes in mind, we recommend the following monitoring strategies to track and enhance channel and floodplain recovery.

- ***<u>Floodplain Mapping:</u>*** In terms of monitoring floodplain function, we would recommend that local officials are supported in their attempts to upgrade their flood mapping as they deem appropriate. One approach would be to take the photography collected by plane during the flood event by Kestrel Aerial Services (www.kestrelaerial.com) to map the extent of 2011 flooding. These boundaries will show the area flooded in 2011, but will not correspond to a 100-year floodplain map. In order to develop a 100-year flood boundary map, a hydraulic model would need to be constructed using river corridor topography and calculated 100-year flood discharges. The recently collected LiDAR (high resolution topography) data would provide an excellent topographic base for the modeling. The resulting 100-year floodplain map would clearly identify flood risks that could be applied as local communities see fit. Based on the damages we observed, we recommend that development in high risk areas is dissuaded to protect resident's safety as well as river function.

The 100-year floodplain maps could also be used to identify swaths of isolated floodplain, which may highlight locations where deliberate breaching of the berm will reduce future flood damages.

In the event that MWC is considering floodplain mapping, we recommend that local officials work with DNRC to define their goals and to decide if mapping to Flood Emergency Management Association (FEMA) standards are desired. If FEMA standards are pursued, a strict process must be followed, and some communities choose to develop the maps independent of that process. We also recommend that a series of lower flows be modeled. For example, the post-flood channel is typically larger and steeper than before the flood; the model could be used to calculate the current capacity of the channel in any given area. Modeling 2-year flows would help identify areas of optimal riparian recovery and restoration. Very low flow modeling can be used to help identify minimum instream flow requirements to sustain fish habitat (e.g. wetted perimeter analysis).

- ***<u>Channel Recovery:</u>*** As described previously, the Musselshell River above Melstone has a perched floodplain that supports a myriad of land uses, and a lower inset surface that has been developing since the river was straightened by the railroad. Downstream of Flatwillow Creek, the floodplain was locally perched during the flood due to avulsions, steepening, and downcutting. In these settings, the development of an inset floodplain within the entrenched channel is a critical aspect of river recovery. The surface will grow in extent as steep high banks erode and the channel migrates laterally across the floodplain, leaving the lower surface in its wake. This low floodplain surface, which is relatively frequently inundated, will have access to groundwater such that it will support woody riparian vegetation that increases the resiliency of the river corridor to further bank erosion or avulsion (Figure 80). The surfaces may also be aggressively colonized by invasive species. Monitoring the continued development of an inset floodplain and riparian colonization of that surface will show those areas where natural resilience is improving, or where invasive species are especially aggressive. The RATT team would recommend that unarmored areas where channel movement is creating an inset surface be monitored to demonstrate the process of geomorphic recovery and riparian response. This could be achieved by the following steps:
    1. Compare pre-flood (2009) and post-flood (2011) air photos to identify areas where erosion and channel widening occurred during the flood.
    2. Target sections of river where avulsions were concentrated and the river is therefore appreciably steepened.

3. Collect repeat channel cross sections to document changes in channel form.
4. Monitor these cross sections in the field for native cottonwood and willow seedling survival, continued colonization, and continued bank movement.
5. Monitor these cross sections in the field for noxious weeds and invasive species (eg: salt cedar Russian olive, leafy spurge, and spotted knapweed).
6. On a broader scale, use post flood aerial photos as they become available to monitor bank movement, channel lengthening, floodplain development, and riparian recovery.

The results of this monitoring could be used to develop management strategies for post-flood river processes. Sections of river that are experiencing especially rapid bank erosion may require different management strategies than those with lower rates of change. For example, where bank erosion is especially severe on a reach scale, restoration projects should focus on lengthening the channel and expanding the inset floodplain to speed up and guide the natural recovery process. The identification of the types and extents of invasive species is necessary to develop appropriate control efforts and to design revegetation strategies. And repeat cross sections will identify downcutting areas that may perch or undermine irrigation infrastructure. But perhaps most importantly, this monitoring will document the development of an inset riparian corridor that will ultimately improve the resiliency of the river compared to pre-flood conditions (Figure 80).

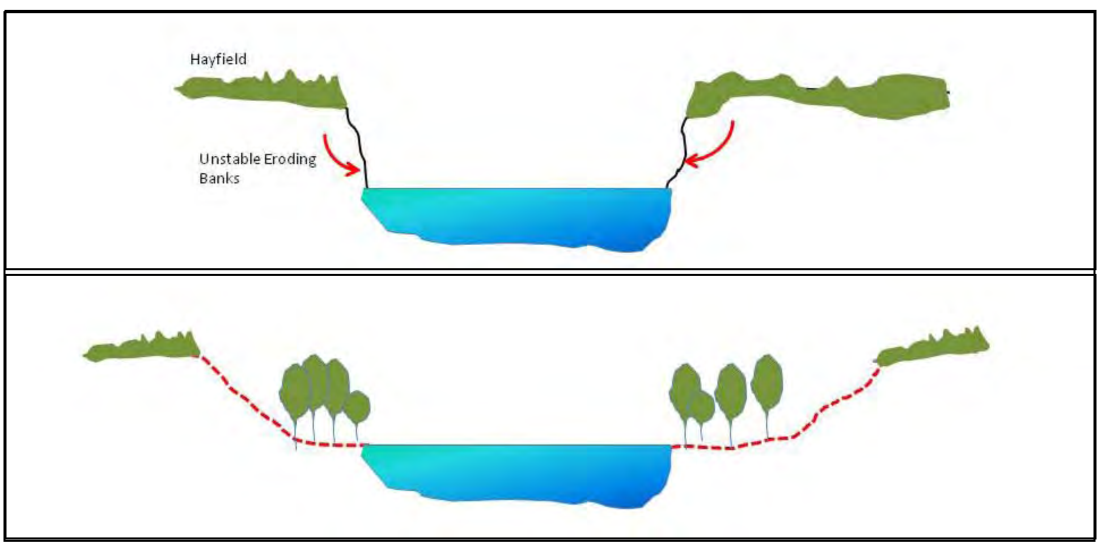

Figure 80. Schematic diagram showing entrenched cross section with perched floodplain (top), and long-term development of inset floodplain and riparian corridor (below).

- ***Channel Migration Zone Mapping:*** The aerial imagery compiled by the RATT team would be directly used in the development of a ***Channel Migration Zone (CMZ)*** map for the Musselshell River. Over the past several years, CMZ maps have been developed for portions of the

Yellowstone, Clark Fork, Ruby, and Flathead Rivers (Figure 81; DTM and AGI, 2009). The maps are created using suites of old and modern air photos, which are used to map historic channel locations and measure rates of channel migration. With this data, areas that are susceptible to future erosion over the next century are identified. The 100-year Channel Migration Zone maps have been used to show stakeholders rates of channel movement in specific areas, and to adjust land uses and proposed development locations accordingly. For example, the maps could be used to help locate stable areas to site crossings and irrigation infrastructure. CMZ mapping on the Musselshell River would require acquisition of historic imagery, digitization of banklines, measurement of change, and calculation of rates of change. With the 2011 imagery in hand, the CMZ will be especially instructive as the flood impacts will be included in the mapping and analysis. If an inventory of bank armor is available, it can be included in the CMZ to identify the extent of natural migration corridor isolated by the armor, which can help permitting agencies assess the overall impact of a given project on river geomorphology ("Restricted Migration Area", Figure 81).

CMZ mapping costs for a river the size of the Musselshell are typically on the order of several hundred dollars per mile. Completed CMZ maps can be downloaded from following sites:
Flathead River: http://www.flatheadlakers.org/uploads/pdfs/single_flathead_river_CMZ.pdf
Ruby River: http://www.rvcd.org/links/cmz
Yellowstone River: http://www.yellowstonerivercouncil.org/maps.php

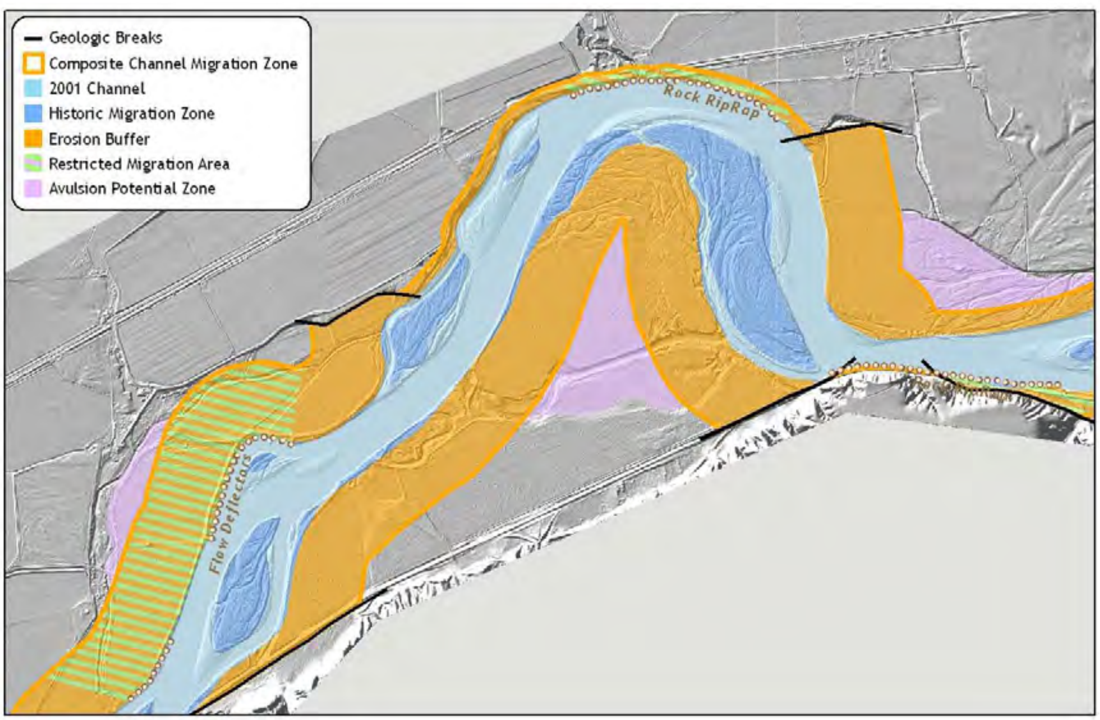

Figure 81. Yellowstone River Channel Migration Zone mapping example (DTM and AGI, 2009).

9.2 Potential Impacts of Future Bank Armor and Floodplain Restrictions

A number of agencies are involved in permitting processes for practices that affect and alter the river channel, banks, and associated wetlands and floodplains. Each agency has its own rules and procedures that it is required to follow. We recommend that as possible, permitting agencies work together to coordinate their response to permit applications. As described in Section 7.2.2, short-term, wide-spread, aggressive armoring of the river corridor in response to the flood is likely to compromise river stability, natural flood recovery, and ecological function for many years. As such the RATT team recommends that bank armor and floodplain projects be carefully considered in terms of local impacts, adjacent impacts, and large scale impacts to the geomorphic stability of the river.

Where possible, we recommend that erosion control strategies consider the process of channel recovery through inset floodplain development described in previous sections, and that bank erosion and channel lengthening is allowed where feasible. Floodplain restrictions such as dikes, roads, elevated canals, etc. should be considered with regard to overall floodplain function, both at and adjacent to the project site. Where the rail berm has been breached, projects designed to plug those breaches should carefully consider the impacts of the berm to channel stability and floodwater storage.

Recommended erosion control strategies are provided in more detail in Section 7.2.

9.3 Rehabilitation Project Performance

Since the flood of spring 2011, numerous projects have been permitted and constructed in the river corridor to address flood damages, such as bank armor installations, dike breach plugs, and infrastructure repair. Many additional projects are in planning stages or in the process of implementation. We strongly recommend that a representative suite of these projects be monitored for performance, cost-effectiveness, and effects on the river, to help landowners identify the best options available, and to assist in the project design and permitting process.

- ***Bank armor:*** Monitoring would include tracking performance relative to cost, assessing both on- and off-site impacts such as accelerated erosion, and monitoring the survival of any vegetation included in the armoring technique.

- ***Floodplain Restrictions:*** Projects that repair or create new floodplain restrictions should be monitored for stability and geomorphic impacts. Breach repairs will re-isolate floodplain area, and the comparison of the impacts of such reconstructed breaches to un-modified breaches would be beneficial to long-term floodplain management. In addition, several recent breach repairs in the railroad berm have been built with coarse rock riprap in contrast to the original fine grained material, creating plugs that are much less erodible than the rest of the berm. These discontinuities may cause accelerated scour and floodplain erosion as they form hard points along the old rail line.

- ***In-Stream Irrigation Structures:*** If damaged in-stream structures are repaired, we recommend that they be monitored for post-flood channel stability issues that may compromise their performance, such as downcutting that may perch a pump or undermine a dam. The monitoring of overall channel stability in the vicinity of these structures will identify threats to the infrastructure, as well as determine maintenance needs caused by excessive sediment loading.

9.4 Riparian and Land Use Trends

The health and function of the Musselshell River system is closely tied to the presence of vibrant and diverse riparian vegetation along the river corridor. The potential for rejuvenating the Musselshell River riparian corridor was greatly increased by the 2011 flood, as thousands of young cottonwood and willow seedlings have taken root on fresh flood sediment deposited on fields, in old cottonwood stands, as new gravel bars, and in abandoned channels (Figure 82). Most fundamentally, the massive number of seedlings provides an opportunity for survival of a new age class of cottonwoods and willows throughout the river corridor. The 2011 flood has truly created a very rare opportunity for long-term contributions to habitat extent and quality, and system resiliency to future floods. We recommend that trends in riparian vegetation health be monitored following this extreme flood, so that management strategies can be developed to optimize system recovery and ecological function.

The NRCS has developed a process to monitor woody species recovery that is currently being used on the Musselshell River, and local NRCS field offices can be contacted for more information regarding these techniques that include transects and photo points. These approaches, as well as broader scale mapping assessments, are briefly described below.

- ***Riparian Transects:*** The survival rates of riparian seedlings should be monitored by establishing repeatable transects in a range of geomorphic and land use environments. Riparian transects document species occurrence and frequency, canopy cover, and age diversity over time, and would include mapping weeds and invasive woody species such as salt cedar and Russian olive. The results could be used to identify the benefits of riparian recovery with regard to bank stability, floodplain stability, and fish and wildlife habitat.

- ***Photo Points:*** Photo points are an effective, fast, and low-cost way to document changes in riparian vegetation through time. Points are typically established by placing a re-bar or other permanent marker in an appropriate location. The points are then mapped as a GPS waypoint so they can be easily relocated. In taking the photos, the direction of the photo should be recorded as a compass bearing or azimuth, and the photos should be consistently filed to allow comparison over time. More information can be collected at each point; supporting information regarding photo points is available online at:
  http://www.fs.fed.us/eng/rsac/invasivespecies/documents/Photopoint_monitoring.pdf or
  http://www.nm.nrcs.usda.gov/technical/tech-notes/bio/bio61a6_PhotoDocumentation_Protocol.pdf

- ***Riparian and Land Use Mapping:*** Mapping historic trends in riparian vegetation communities and land use can be achieved on a fairly coarse scale using historic and current air photos. The information provides baseline data for historic trends and future monitoring of the system response to the flood and associated management activities. The mapping will help identify the overall susceptibility of cleared agricultural fields to erosion, and would identify the distribution of invasive species such as Russian olive, which can be effectively mapped on air photos.

Figure 82. Cottonwood seedlings at RM 27.5; note RATT team in distance for scale.

9.5 Targeted Fish Monitoring

Fisheries can be affected both negatively and positively by floods. Flooding of hazardous materials such as petroleum products, insecticides, and herbicides can be toxic to aquatic life. Barn yards, corrals, and septic systems can introduce large quantities of readily available nutrients that can cause large algal blooms that depress oxygen levels and alter habitat. Excessive erosion where heavy livestock grazing or field encroachments have removed healthy riparian vegetation can introduce fine sediment and degrade fish habitat. The positive sides of floods typically are natural process such as redistribution of gravels which often enhances fish spawning areas or rearing areas. Redistribution of large woody material provides fish cover and other habitat enhancing qualities. Many structural barriers can be bypassed during high flows which increases short-term habitat connectivity. Flood waters also activate side channels and other habitat types.

Although the flood probably had both positive and negative impacts on the fishery, reports from farmers, ranchers, and anglers indicate that the flood benefited the fish community overall (MTFWP). Fish now have unimpeded access to more river length where structures were flanked or abandoned and passage barriers were consequently removed. Some of these damaged diversion dams may be abandoned and ultimately removed, which will increasing the long-term habitat connectivity on the river. Other structures may be repaired, but in a fashion that will accommodate fish passage. And lastly, discussions have taken place regarding the establishment of fish passage around persistent barriers that survived the flood.

With respect to monitoring, MTFWP staff anticipates a redirection of effort to evaluate the condition of game species as well as other native and nonnative fish in several sections of river over the next two or more years. Results of the effort will be compared to previous studies conducted from 1977 through 1984. These monitoring results could help guide the following:

- Identification of irrigation structures that either block fish passage or entrain fish into canals or ditches
- Design of fish passage structures that are specific to the targeted fish community
- Identification of optimal areas of habitat restoration for targeted species
- Identification of optimal areas for stocking to improve native fish distribution and sport fish availability
- Continued assessment of the relationship between in-stream flows and fish populations (See Appendix B for FWP summary of minimum flow recommendations on Musselshell River).

We recommend that MWC work with MTFWP to secure sufficient resources for comprehensive monitoring and evaluation of the Musselshell River fishery.

9.6 Water Use

Sustainable water use is one of the most constant, pressing concerns of the Musselshell River basin community. To that end, the MWC has long worked to improve collaboration among irrigators to improve water use efficiencies. There is concern, however that the 2011 flood may have changed the rates and patterns of natural water storage and passage through the basin. For example, the shortened river is steeper than before the flood, which increases velocities, reduces the residence time of water in the basin, and lowers the overall wetted area of the channel. Runoff patterns and groundwater recharge may be impacted as a result. Irrigators are actively changing points of diversion, and in some cases, types of use. Keeping track of both natural shifts in flow conditions, and shifts in irrigator's uses will be important for the MWC and their partners in their long-term efforts to optimize both water use and system sustainability. Flow conditions are also critically important in sustaining fish and riparian communities (Appendix B).

To that end, the RATT team recommends the following:

- ***Hydrologic Investigation:*** Whether or not the channel changes will affect recharge rates and water availability is unclear; we recommend that necessary resources are secured to help evaluate these changes and their potential impacts. The results would help identify restoration projects that maximize recharge and improve late season flow conditions, and would also help determine means of meeting the needs of irrigators while supporting the fishery (Appendix B).

- ***State Water Supply Initiative:*** Basin-wide water planning in the Musselshell basin will be carried out by the DNRC Water Resources Division. This initiative integrates well with the objectives and activities of MWC. We therefore recommend that MWC actively participates in this process to ensure that their interests are represented.

- ***Gaging Stations:*** Water measuring devices are absolutely critical in tracking water use and availability, to ensure that sustainable practices evolve as necessary. The RATT team recommends that MWC continues to press for operational USGS gaging stations on the Musselshell River, especially in light of flood impacts. Also, salinity is an issue for irrigators, especially during low flows. We would therefore recommend that real-time salinity meters be installed at the gages, and that the information be available on-line so that producers can adjust their uses as they see fit.

- ***Physical Features Inventory:*** In support of water management, we recommend that a complete physical features inventory be performed between the North and South Fork confluence and Fort Peck Reservoir. This would build on the ongoing web information template development to create a complete inventory of all in-stream structures such as irrigation pump sites, irrigation diversions, bank armoring, bridges, floodplain dikes etc. The inventory would provide a baseline for tracking the types and impacts of river corridor features. A physical features inventory would also support large scale impact assessment and Channel Migration Zone mapping.

9.7 Outreach and Education

Persistent and targeted outreach and education can be an effective means of creating a grass roots understanding of the impacts of a major event such as the 2011 Musselshell River flood, as well as associated opportunities for collaborative and strategic response. The development of an Outreach and Education Plan can help guide that process with regard to targeted audience, content, and schedule. In the event that the MWC develops a plan, we recommend that the following approaches and content be considered:

- ***Outreach and Education Workshops:*** Develop a workshop or series of workshops with field trips that present the following:

    - The nature of the 2011 flood and its impacts
    - Challenges and opportunities created by the flood
    - Appropriate Best Management Practices (BMPs)
    - Grazing management in riparian areas
    - Applicable programs for technical or financial assistance
    - Monitoring strategies

  - Invasive species extent and control strategies
  - The status of the Musselshell River fishery
  - Demonstration projects with field trips
  - Volunteer opportunities

- ***Sponsor DNRC Winter Grazing Seminars and/or a Governor's Range Tour***

- ***Present Experiences at State Level Conferences:*** The 2011 Musselshell River Flood has been a major topic of discussion among water resource managers throughout the state. There as several annual meetings attended by these professionals where the event, its impacts, its opportunities, and its challenges could be presented, including the following:
  - Montana Association of Water Resources
  - Montana Watershed Coordination Council
  - Montana Association of Floodplain Managers
  - Montana Association of Conservation Districts

- ***Involve Local Schools:*** Individual sites and rehabilitation projects can provide excellent opportunities for local schools to become involved in restoration programs as outdoor classrooms to study stream processes and riparian community development over time. One of the RATT team's primary goals is to provide a summary of the magnitude and implications of this event, in support of the long term stewardship of the Musselshell River corridor by its people. As the young generation of Montanan's in the corridor will forever remember the flood of 2011, their involvement in tracking system recovery would be a worthwhile endeavor.

10 Programs to Assist with Flood Recovery

There are a number of federal, state, and local programs that are available to government entities and private landowners to assist them with flood recovery efforts. The number and diversity of technical and financial assistance programs can be somewhat bewildering at first glance. Many programs change from year to year or with each new Farm Bill, so it is best to check with the appropriate agencies to determine which program best suits a particular restoration need and the applicable timelines. The Montana Department of Natural Resources and Conservation maintains a list of current contacts for various flood recovery assistance programs at:
http://dnrc.mt.gov/PublicInterest/Flood/GuideToFloodResponseFunding.pdf.

To assist with flood damage specifically on privately owned farms and ranches, the USDA Natural Resources Conservation Service (NRCS) and the USDA Farm Service Agency (FSA, and Montana Fish, Wildlife and Parks (FWP) each have programs that provide financial and technical assistance. Program assistance can help to restore damaged conservation practices such as rebuilding fences and irrigation structures, or to apply new, needed practices. Information is available at each agency's website as noted below.

10.1 United States Department of Agriculture (NRCS and FSA)

The USDA often creates unique programs to address specific resource concerns within a particular area such as in a flood-affected watershed. It is always best to check with the local USDA Service Center to find what programs are available and which program will work best for you. The USDA agricultural assistance programs most commonly used in response to floods impacts are described as follows:

10.1.1 NRCS Emergency Watershed Protection Program (EWP)

The NRCS Emergency Watershed Protection (EWP) Program may be available for local sponsors (units of government and irrigation districts only) to aid in recovery work on private and public property following a natural disaster. NRCS provides technical and financial assistance (fifty percent matching funds are required) to install measures that reduce post-flood and fire damage. The measures are intended to reduce threats to life or property, retard runoff, restore capacity of waterways, prevent flooding and/or soil erosion and reduce damage from sediment and debris. The removal of debris deposited by the disaster that is a health or safety hazard can be a part of such measures as well. Information regarding the application process and contacts is at http://www.mt.nrcs.usda.gov/technical/eng/ewp/index.html.

10.1.2 NRCS Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program (EQIP) is a voluntary conservation program, administered by NRCS, for farmers and ranchers who face serious threats to soil, water, and related natural resources. EQIP provides technical and financial assistance to deal with significant conservation needs in targeted areas. Areas with severe damage to the floodplain are targeted. Conservation practices such as fences, access control, watering facilities, critical area plantings, riparian area recovery, and weed control are typically offered to allow for the recovery of the floodplain.
http://www.mt.nrcs.usda.gov/programs/index.html.

10.1.3 NRCS Wetlands Reserve Program (WRP)

The Wetlands Reserve Program (WRP), administered by NRCS, is a voluntary conservation program that offers landowners the means to restore, enhance, and protect wetlands on their property through permanent easements. The NRCS is looking for sites on agricultural land where former wetlands have been drained, altered, or manipulated. The landowner must be interested in restoring the wetland and then protecting the site. Once under an easement or a contract, the land can no longer be cropped. Haying and grazing may be used through a wetland management plan determined by NRCS to maintain riparian functions. http://www.mt.nrcs.usda.gov/programs/index.html.

10.1.4 FSA Continuous Conservation Reserve Program (CCRP)

The Continuous Conservation Reserve Program (CCRP), administered by FSA, is a voluntary program for eligible, agricultural landowners. CCRP protects millions of acres of topsoil from erosion and is designed to safeguard the Nation's natural resources. Through CCRP, a landowner can receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. Environmentally desirable land devoted to certain conservation practices may be enrolled at any time under CCRP continuous sign-up. Certain eligibility requirements still apply, but offers are not subject to competitive bidding. Cropland, including field margins, planted or considered planted to an agricultural commodity or marginal pastureland that is suitable for use as a riparian buffer (the vegetated area next to a river or stream) or for similar water quality purposes, may be eligible.

More information can be found at http://www.fsa.usda.gov/mt.

10.1.5 FSA Emergency Conservation Program (ECP)

The USDA Farm Service Agency's (FSA) Emergency Conservation Program (ECP) provides emergency funding and technical assistance for farmers and ranchers to rehabilitate farmland damaged by natural disasters and for carrying out emergency water conservation measures in periods of severe drought. Funding for ECP is appropriated by Congress. More information can be found at http://www.fsa.usda.gov/FSA/ .

10.1.6 To Apply

Producers interested in applying for any of these USDA programs must submit applications through their local USDA Service Center, which can be located through the Montana NRCS Web site at www.mt.nrcs.usda.gov/contact/offices/index.html or the Montana FSA Web site at www.fsa.usda.gov/mt. As applications periods may have a deadline, it's best to check early following the damaging flood event.

10.2 Montana Fish Wildlife and Parks

With nearly 65 percent of the State's lands held in private ownership, landowners are central to the work of conserving Montana's wildlife, fish and important habitats. Landowners help strengthen Montana's traditions by providing public hunting and fishing access to their lands and by helping to preserve key recreational and historical sites. Montana Fish, Wildlife & Parks is committed to working with Montana's landowners through a variety of programs that acknowledge and support their role in maintaining Montana's rich conservation legacy. For a more comprehensive list of available MTFWP programs available for landowners please visit http://fwp.mt.gov/fishAndWildlife/habitat/wildlife/programs/landownersGuide.html

10.2.1 Future Fisheries Improvement Program (FFIP)

For more than a decade, FWP's Future Fisheries Improvement Program (FFIP) has worked to restore rivers, streams and lakes to improve and restore Montana's wild fish habitats. About $750,000 are available each year for projects that revitalize wild fish populations. Future Fisheries applications are considered every year in June and December. An independent review panel recommends Future Fisheries projects to fund to the Montana Fish, Wildlife & Parks Commission. Applicants are strongly urged to contact their local fisheries biologist prior to submitting an application. Floods can both help and hinder efforts to restore and recover native fisheries. The local biologist typically understands the limiting factors associated with fish populations in their management area and is likely familiar with the impacts of a particular flood event. Information for FFIP applicants is available online at http://fwp.mt.gov/fishAndWildlife/habitat/fish/futureFisheries/application.html.

10.2.2 Habitat Montana

The goal of the Habitat Montana program is to preserve and restore important habitat for fish and wildlife. FWP offers incentives to landowners to conserve habitat on private land, including, in some cases, the purchase of a conservation easement. Landowners interested in using a conservation easement to protect traditional farm and ranch land, and to preserve natural resources such as wildlife habitat, may partner with FWP. A variety of funding sources enable FWP to protect seriously threatened habitats and provide recreational opportunities through purchased or donated conservation easements and purchases of land. Annually, about $4 million from several sources goes to fund projects selected by the Montana Fish, Wildlife & Parks Commission from among those recommended by the FWP staff. In addition to monetary compensation, landowners may: realize tax benefits from a conservation easement; gain help in pursuing habitat-friendly agricultural practices; and ensure the protection of scenic and open spaces. For more information contact Montana Fish Wildlife and Parks, Wildlife Bureau at (406) 444-2612 or contact regional offices in Billings 406-247-2940 or Great Falls 406-454-5840.

10.2.3 Montana Wetlands Legacy Program

The goal of the Montana Wetlands Legacy Program is to create and protect wetlands. Through the Wetlands Legacy Program, FWP helps provide landowners who own wetlands and riparian areas with technical support to help preserve and identify potential project funding sources. Working with FWP and the Wetlands Legacy Program, landowners may develop projects to protect, conserve and develop wetlands on their property. The projects can increase the land's value, while creating healthy, functional wetlands. Landowners may also receive direct funding for the project, materials or construction work, or technical assistance in identifying funding sources, depending on the situation. The program is a partnership between FWP and national, state, and local conservation organizations and agencies, and interested landowners and land managers. For more information contact the MTFWP Montana Wetlands Legacy Coordinator at 406-994-7889 or contact regional offices in Billings 406-247-2940 or Great Falls 406-454-5840. http://www.wetlandslegacy.org/

10.2.5 Montana's Upland Game Bird Habitat Enhancement Program

In the Musselshell River corridor, landowners may be interested in linking riparian land management with that of larger upland areas adjacent to the river. These adjacent upland areas may provide opportunities to enhance habitat for upland game birds such as turkeys, pheasant, sharp tail grouse and/or sage grouse. Under Montana's Upland Game Bird Habitat Enhancement Program, Montana Fish, Wildlife & Parks works directly with landowners-and other individuals, groups and organizations-to improve private and public lands for Montana's native sharp-tailed grouse, sage grouse, and mountain grouse, as well as the state's adopted game birds-ring-necked pheasants, Hungarian Partridge, and wild turkeys. Landowners can apply to enroll in the updated cost-share program to develop, enhance, and conserve Montana's upland game bird habitats if the land in the project area remains open to a reasonable level of public hunting. Up to 75 percent of the cost of the Landowner's Upland Game Bird Habitat Enhancement project can be reimbursed. Projects eligible for funding under the Upland Game Bird Habitat Enhancement Program should comprise at least 100 contiguous acres of land, with some exceptions. The local FWP wildlife biologist should be contacted to determine if any specific land can be improved to provide habitat components such as winter cover, food plots, nesting cover, and shelterbelts. Range management, conservation easements, and wetland restoration can also benefit upland game bird populations. For more information, contact regional offices in Billings 406-247-2940 or Great Falls 406-454-5840. An application for this program can be downloaded from http://fwp.mt.gov/fwpDoc.html?id=43413.

10.2.4 Montana Fishing Access Site Program (FAS)

There are currently two established public fishing access sites on the Musselshell River; one at Harlowton, and one upstream at Selkirk. The overall poor public access to the Musselshell River potentially makes it an excellent area for the creation of additional public fishing access sites. The overall goal of the Montana Fishing Access Site Program is to increase public access to Montana waters by providing compensation to landowners for working with FWP to provide public fishing access. Lands identified as suitable for a FAS may be either purchased or leased under a contractual agreement. Funds for the Fishing Access Site Program are generated by fishing license sales and through other means under Montana law. The program's aim is to acquire sites within a four-hour float distance of each other on Montana's larger rivers and to increase fishing access to smaller streams. For more information contact Montana Fish Wildlife and Parks, Fisheries Bureau at (406) 444-2449 or contact regional offices in Billings 406-247-2940 or Great Falls 406-454-5840.

10.3 DNRC—Reclamation and Development Grants, Renewable Resource Grants and Loans

The Montana Department of Natural Resources and Conservation has several programs that may be applicable to landowners in the Musselshell River Valley.

10.3.1 Reclamation and Development Grants Program (RDGP):

The ***Reclamation and Development Grants Program*** is funded by the State of Montana and funds projects that either compensates Montana citizens for the effects of exploration and mining on Montana lands. Or serve the public interest and the state of Montana. The funding is from interest income from the Resource Indemnity Trust fund, which receives proceeds from mineral production taxes. The 2011 legislature allocated $5.8 million to this program, and this amount is subject to legislative change each biennium. Eligible applicants are cities, counties, or other political subdivision Tribal governments in Montana, and divisions of state government.

RDG Program information and application forms can be accessed at:

http://dnrc.mt.gov/cardd/ResourceDevelopment/rdgp/ReclamationDevelopmentGrantsProgram.asp

10.3.2 Renewable Resource Grant and Loan Program (RRGL)

The ***Renewable Resource Grant Program*** was established by the Montana Legislature to fund the conservation, management, development, and preservation of Montana's renewable resources. Types of projects that have been funded by this program include public drinking water improvements, irrigation structure rehabilitation, dam repair, and soil and water conservation. Eligible applicants include state, local, and tribal government entities. Grants are limited to $100,000 per project. Applications are due on or before May 15th of even-numbered years.

RRGL Grant Program information and access forms can be accessed at:

http://dnrc.mt.gov/cardd/ResourceDevelopment/rrgp/RenewableGrantProgram.asp

10.4 DEQ 319

The Montana Department of Environmental Quality (DEQ) 319 grant program funds projects related to watershed restoration and education/outreach. DEQ issues a Call for Grant Applications every year under Section 319(h) of the Federal Clean Water Act (CWA). Applicants must be either a governmental entity or a nonprofit organization. Project proposals for 2012 are due to DEQ on July 27, 2012.

Information regarding the DEQ 319 Grant Program can be accessed at:

http://www.deq.mt.gov/wqinfo/nonpoint/319GrantInfo.mcpx

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Appendix A: Glossary of Terms

Acre-foot – The volume of water that will cover one acre of surface area to a depth of one foot. One acre foot is equivalent to approximately 326,000 gallons.

Avulsion - A sudden cutting off or separation of land by a flood or by abrupt change in the course of a stream, as by a stream breaking through a meander or by a sudden change in current whereby the stream deserts its old channel for a new one. The result is often the formation of a straighter channel pattern characterized by an increase in channel bed slope and decrease in channel length.

Bankfull Depth - refers to the maximum depth of flow measured from the channel thalweg to the estimated bankfull elevation.

Bankfull Discharge - the discharge corresponding to the stage at which flow is contained within the limits of the river channel, and does not spill out onto the floodplain. The stage just before over bank flow begins.

Belt width - the linear distance, perpendicular to the valley's axis, within the floodplain, and including the width of the channel(s), where channel shifting and/or lateral migration forms a bare or sparsely vegetated depositional or eroded surface that may be estimated from aerial photographs.

Bendway translation - a geomorphic process where a river channel bend migrates down-valley.

Flood frequency – The statistical probability that a flood of a certain magnitude for a given river will occur in a certain period of time.

Floodplain- a flat or nearly flat land adjacent a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge

Floodplain swales - depressions in the floodplain, which are often remnant channels that have partially filled in with sediment and/or vegetation.

Fluvial - formed or produced by the action of flowing water; of, pertaining to, or inhabiting a river or stream.

Geomorphic threshold - the threshold or sudden change of landform stability that is exceeded either by intrinsic change of the landform itself, or by a progressive change of an external variable. In this context, threshold refers to the point where episodic change in river course, form, or pattern occurs.

Geomorphology - the study of landscape evolution including shape, form and process through space and over time. It is the earth science that focuses on understanding the processes of erosion, weathering, transport, and deposition, with measuring the rates at which such processes operate, and with quantitative analysis of the forms of the ground surface and the materials of which they are composed (Goudie et. al. 1994).

GIS – Geographic Information Systems: A system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data.

Hydrology: The study of properties, movement, distribution, and effects of water on the Earth's surface.

Lacustrine - of or pertaining to lakes**.**

Large Woody Debris (LWD) - Functional wood in streams is called *large woody debris*. The definition of large woody debris has evolved in the scientific, regulatory and political arenas to include wood as small as four inches in diameter and six feet in length. However, the typical size of LWD are 18-36 inches in diameter and 12 – 32 feet in length.

Meander - One of a series of regular freely developing sinuous curves, bends, loops, turns, or windings in the course of a stream.

Morphology - of or pertaining to shape.

NAIP – National Agriculture Imagery Program: A United States Department of Agriculture program that acquires aerial imagery during the agricultural growing seasons in the continental U.S.

Planform - the configuration of a river channel system as viewed from above.

Prograding - the advancing or growth of a bar deposit**.**

Riparian: Relating to or inhabiting the banks of a natural course of water. Riparian zones are ecologically diverse and contribute to the health of other aquatic ecosystems by filtering out pollutants and preventing erosion.

Return Interval- The likely time interval between floods of a given magnitude.

Rosgen classification - a system of river channel classification developed by Rosgen (1994) that uses a letter and number system (i.e., B4, C3) as nomenclature to describe the geomorphic character of the stream channel, floodplain, and surrounding valley. Physical variables used in a morphological description Level II Rosgen classification include channel gradient, bed material type and size, channel pattern, and channel geometry.

Sediment continuity - where sediment input equals sediment output**.**

Seral-stage - of or pertaining to plant succession its relation to disturbance mechanisms such as floods or fires over time. A particular plant community type or dominant species may represent a *seral*-stage along a temporal scale; a *climax* stage represents the most mature and stable state prior to disturbance.

Sinuosity - the measurement of a channel's relative straightness or curving configuration. It is the ratio of channel length to downward valley length; for example, a value of one 1.0 is a straight channel pattern, whereas a sinuosity of 1.5 is considered meandering.

Stream competency - the ability of a stream to mobilize its sediment load; refers to the maximum size of particles of given specific gravity, which, at a given velocity, the stream will move.

Stream power - a concept that relates fluvial energy to sediment transport. To transport sediment, work (defined as the product of force and distance) must be performed. Power is the rate of doing that work, and stream power per unit length of stream. It is expressed as the product of the specific weight of water, discharge, and water surface slope.

Subaqueous return flow - existing or situated under water, as in the movement of shallow groundwater through riverbank materials to open channel flow.

Terrace - A step-like surface, bordering a valley floor or shoreline, that represents the former position of a flood plain, or lake or sea shore. The term is usually applied to both the relatively flat summit surface (tread), cut or built by stream or wave action, and the steeper descending slope (scarp, riser),graded to a lower base level of erosion. Compare - stream terrace, flood-plain step. HP. [soil survey] Practically, terraces are considered to be generally flat alluvial areas above the 100 yr. flood stage.

Appendix B: Minimum Flow Recommendations

The following section summarizes the results of wetted perimeter analyses provided by Montana Fish Wildlife and Parks that identify flow conditions necessary to sustain the Musselshell River fishery.

Cold water zone

Based on a wetted perimeter analysis, a minimum flow of approximately 80 cfs is considered necessary to sustain a consistent high quality wild brown trout fishery in the cold water section above Harlowton (Montana Fish and Game Commission 1979). Field observations indicate that at 42.8 cfs, many riffles become exposed and fish habitat along the banks is dewatered forcing fish to seek cover in limited pools. As far as higher flows go, bankfull flows near Martinsdale have been approximated at a 2 year frequency of 1,060 cfs which typically occurs in June (USGS 1978) and the 1.25 year frequency flow was reported as 514 cfs. Wiedenheft recommended that a flow of 1,060 be allowed to occur for at least 24 hours in June with the remainder of June at 514 cfs to maintain suitable channel habitat for trout production.

Table 5 shows a summary of mean monthly discharge measurements made between 1907 and 2011 at the Harlowton gauging station (USGS 06120500). A Count of Monthly Report valued of 104 reflects 100% reporting. Every reported month exceeded 43 cfs on average, which has been inferred as a minimum fisheries flow for connectivity. Although 43cfs was exceeded as an average flow, no month consistently maintained this minimum discharge. For example, in September, 43cfs was exceeded only 57% of the time. In contrast, June monthly mean average was 506 cfs and 43 cfs was exceeded 96% of the time. The data also show that achieving the preferred minimum flow for supporting a quality and consistent fishery of 80 cfs is unlikely to happen on a regular basis. April, May, June, and July provided this flow 67%, 88%, 88%, and 67%, respectively. The remaining months have provided this flow in a range from 13% to 49% of the time.

Wiedenheft (1979) reported that additional withdrawal of water in the winter months of December, January, and February and the summer months of August and September could negatively influence resident fish populations in this zone. In the winter, flows of 80 cfs are not necessary to sustain a quality fishery and the lower flow target of 43 cfs is probably more appropriate from December to February. Lower winter flows in this zone would affect brown and brook trout redds by reducing spawning areas and degrading available spawning habitats. Additional losses of water in September, in particular, and October have the potential to disrupt spawning by limiting fish migration to suitable spawning locations and degrading spawning sites with increased deposition of silts and increased temperatures.

Table 5. Summary of Harlowton, MT gauge monthly mean discharge from August 1907 through September 2011.

Harlowton, MT USGS Gauge 06120500 August1907 through September 2011												
Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Mean	58	64	108	169	401	506	161	76	62	72	76	66
Monthly Maximum	250	190	500	632	1957	2467	751	292	290	226	176	206
Monthly Minimum	0	10	20	22	12	28	1	0	0	0	0	0
Count of Monthly report	100	101	102	104	104	104	104	104	104	103	102	100
Count exceeding 80 cfs	13	22	50	70	91	92	70	45	34	42	40	24
Count exceeding 43 cfs	73	76	93	94	98	100	87	64	59	80	82	80
Count less than 10 cfs	1	0	0	0	0	0	7	18	16	8	1	1
Count equal 0 cfs	1	0	0	0	0	0	0	3	5	1	1	1
Percent greater than 80	13%	22%	49%	67%	88%	88%	67%	43%	33%	41%	39%	24%
Percent greater than 43	73%	75%	91%	90%	94%	96%	84%	62%	57%	78%	80%	80%
Percent less than 10	1%	0%	0%	0%	0%	0%	7%	17%	15%	8%	1%	1%
Percent equal 0 cfs	1%	0%	0%	0%	0%	0%	0%	3%	5%	1%	1%	1%

Transition Zone

The results of a Wetted Perimeter analysis just downstream from Roundup near the county fairgrounds identified 50 cfs as the low inflection point for providing minimum fisheries conditions with 100 cfs and above providing adequate fisheries flows. A flow of 80 cfs is recommended yearly. Exposed gravel bars have been reported in this area at 76.7 cfs but still provided moderate fish habitat. The 2 year and 1.25 year flows were not reported for this zone. These values are important to determine flows that typically maintain habitat and transport and redistribute silts and other sediments.

A review of mean monthly discharge from 1947 through September 2011 at Roundup gage (USGS 06126500) is summarized in Table 6. A count of 65 reflects 100% reporting; the only months missing in the dataset are from water year 2012, October through December 2011. The monthly mean average exceeds 50 cfs for each month however the only the time period 80 cfs is meet or exceeded is from March through July. During August, September, and October, flows greater than 80 cfs were met 82%, 58%, and 39% respectively. Flows exceeding 50 cfs from October to February range from 40% to 62% of the time. Winter flows are important to allow fish to move into suitable winter habitat and to maintain water quality in pools. During September and January, 11% of the months had flows less than 10 cfs. It should be noted the drought in the 1930's showed months with mean flows of 0 at Harlowton and

Mosby gauges and the Roundup gage was not in place to record discharge during that time period. In general this section has flows that could not maintain more than a limited fishery due to probable fragmentation of habitats in the winter and frequent low water conditions in late summer and fall.

Table 6 Summary of Roundup, MT gauge 06126500 monthly mean discharge from January 1947 through September 2011.

Roundup MT USGS Gauge 06126500 January1947 through September 2011												
Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Mean	58	64	108	169	401	506	161	76	62	72	76	66
Monthly Maximum	222	415	1281	788	2809	5095	1308	563	504	335	242	283
Monthly Minimum	5	6	7	2	30	37	15	2	0	1	4	4
Count of Monthly report	65	65	65	65	65	65	65	65	65	64	64	64
Count exceeding 80 cfs	22	28	40	35	62	61	60	53	38	25	21	17
Count exceeding 50 cfs	26	39	48	43	63	63	62	56	51	39	33	30
Count less than 10 cfs	7	6	2	3	0	0	0	3	7	3	3	6
Count equal 0 cfs	0	0	0	0	0	0	0	0	0	0	0	0
Percent greater than 80	34%	43%	62%	54%	95%	94%	92%	82%	58%	39%	33%	27%
Percent greater than 50	40%	60%	74%	66%	97%	97%	95%	86%	78%	61%	52%	47%
Percent less than 10	11%	9%	3%	5%	0%	0%	0%	5%	11%	5%	5%	9%
Percent equal 0 cfs	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Water temperature data reported by Weidenheft indicated temperatures at Roundup ranged from 32^0 to 82^0 Fahrenheit.

Warm Water Zone

Based on a Wetted perimeter analysis at the Mosby Bridge, between 60 to 100 cfs is estimated as necessary for fish with a recommendation of 70 cfs to be met year round. Bankfull discharge for the 2-year flood was estimated at 4,080 cfs, and 1.25 year flood was estimated at 1,860. These flows were recommended for annual runoff with 4,080 cfs for 24 hours and 1,860 cfs for several weeks after the high flow. This flow would help maintain fish habitat. Table 7 provides results of an assessment of the Mosby gage data (USGS 06130500) which operated from January 1931 through September 2011. A monthly count of 81 is equivalent to 100% reporting. Results show that the average monthly discharge exceeded 70 cfs every month but didn't exceed 100 cfs from October through January. Flows of 60 cfs were met about 50% of the time during this period from August through February and 70% to 88% of the time from March through July. June was the only month in the period that didn't record a monthly minimum of 0 cfs. During September through January, minimum flow of 0 cfs documented over 8% of the time. Dewatering in the late summer and fall 10% of the time is likely detrimental to many fish unless they find suitable larger pools for refuge. During August, an average monthly flow of less than 10cfs was reported 21% of the time.

Table 7. Summary of Mosby, MT gauge 06130500 monthly mean discharges from August 1907 through September 2011.

Mosby MT USGS Gauge 06130500 January1931 through September 2011												
Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Mean	73	169	440	277	591	956	321	113	113	79	77	68
Monthly Maximum	376	1858	4658	1917	7638	9877	2153	870	787	478	337	278
Monthly Minimum	0	0	0	0	0	2	0	0	0	0	0	0
Count of Monthly report	80	81	81	81	81	81	81	81	81	78	78	78
Count exceeding 100 cfs	20	37	60	52	58	65	49	33	30	25	22	20
Count exceeding 60 cfs	37	50	68	61	67	71	57	43	45	41	42	35
Count less than 10 cfs	14	10	3	6	5	2	13	17	15	16	12	12
Count equal 0 cfs	6	3	1	1	1	0	2	4	9	6	7	6
Percent greater than 100	25%	46%	74%	64%	72%	80%	60%	41%	37%	32%	28%	26%
Percent greater than 60	46%	62%	84%	75%	83%	88%	70%	53%	56%	53%	54%	45%
Percent less than 10	18%	12%	4%	7%	6%	2%	16%	21%	19%	21%	15%	15%
Percent equal 0 cfs	8%	4%	1%	1%	1%	0%	2%	5%	11%	8%	9%	8%

Water temperatures at Mosby have been documented from 32^0 to 82^0 (Wiedeheft 1979) but was documented as high as 85^0 in 2001-2003 at the USGS gauging state at Mosby.

Water quality issues were reported to be more acute in this zone than in the other zones with high increased suspended sediment, salts, and fecal coliform during much of the year (Wiedenheft 1979, unknown Report). Combined with frequent dewatering and high temperatures this reach likely is very dependent on instream pools for fish refuge as well as regular recolonization by fish originating from the Missouri River.

Appendix C: RATT Site Reports

A series of River Assessment Triage Team (RATT) site reports are included on DVD.

Appendix D: GIS Project 2011 Air Photos Showing Mapped Flood Impacts

A series of 23 maps have been put on DVD and accompany this report. The map index is shown below.