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Beaverhead River Channel Migration Mapping

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Abstract

This report contains the results of a Channel Migration Zone (CMZ) mapping effort for approximately 83 miles of the Beaverhead River from its beginning at Clark Canyon Dam, downstream to its confluence with the Big Hole River just north of Twin Bridges MT. The Beaverhead River mapping is part of a larger effort to map approximately 440 miles of rivers in the Missouri River headwaters watershed.

The 83-mile long project reach of the Beaverhead River flows from the outlet of Clark Canyon Dam through Clark Canyon, where it turns northward to traverse the Beaverhead River Valley between Dillon and Twin Bridges. To address this geomorphic variability, the river was broken into 15 reaches based on river pattern, rates of change, geologic controls, etc. For the first 15 miles below Clark Canyon Dam, the river flows through a narrow canyon that is constricted by both volcanic rocks and transportation infrastructure. The combined effects of Interstate 15, a rail line, and frontage road severely confine the naturally narrow stream corridor, in places completely isolating all historic floodplain area. The river exits the canyon at a narrow constriction at Barretts entering a broad valley for most of the remainder of its course to Twin Bridges. Long side channels such as Poindexter Slough create geomorphic complexities and widen the CMZ, as the stream alternates between a single thread meandering and multi-thread anabranching form. A few miles downstream of Dillon, the modern river is perched about 6 feet above a series of channel remnants to the west, including Selway Slough, Murray Gilbert Slough, and Albers Slough.

Clark Canyon reservoir was built between 1961 and 1964 for irrigation and flood control. The hydrologic record for the Beaverhead River records a wide range of annual peaks prior to dam construction, followed by lower flows and less variability with the dam in place. The relatively quiet post-dam flood history was interrupted by one enormous flood in 1984 and persistently low annual peaks since the late 1980s. From a geomorphic perspective, one of the most striking patterns in the flow record is the lack of channel forming flows over recent decades. For example, the 2-year flow, which tends to strongly influence channel form, has been exceed only twice since the late 1980s at the Barretts gaging station south of Dillon.

In addition to flow management, the geomorphology of the Beaverhead River has been impacted by levees, bank armor, channelization, and riparian clearing. A total of 33.4 miles of berms or levees were mapped in the project reach, the majority of which are associated with the transportation network in Clark Canyon. About 3% of the bankline is armored. In lower reaches below Dillon, riparian degradation since 1955 has been severe.

Mean migration rates on the Beaverhead River range from 0.6 feet per year in geologically confined reaches to 1.6 feet per year in more dynamic areas below Dillon. Relative to other rivers in the Upper Missouri Watershed, these rates are notably low, which is to be expected with the marked absence of channel forming flows in recent decades. It should be noted, however, that floodplain development, riparian clearing, and a recent lack of channel-forming flows have probably made the system less resilient to rare floods such as that of 1984.

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Glossary

Alluvial – Relating to unconsolidated sediments and other materials that have been transported, deposited, reworked, or modified by flowing water.

Avulsion – The rapid abandonment of a river channel and formation of a new channel. Avulsions typically occur when floodwaters flow across a floodplain surface at a steeper grade than the main channel, carving a new channel along that steeper, higher energy path. As such, avulsions typically occur during floods. Meander cutoffs are one form of avulsion, as are longer channel relocations that may be miles long.

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. Bankfull discharge is typically between the 1.5- and 2-year flood event, and in the Northern Rockies it tends to occur during spring runoff.

CD – Conservation District.

Channel Migration – The process of a river or stream moving laterally (side to side) across its floodplain. Channel migration is a natural riverine process that is critical for floodplain turnover and regeneration of riparian vegetation on newly created bar deposits such as point bars. Migration rates can vary greatly though time and between different river systems; rates are driven by factors such as flows, bank materials, geology, riparian vegetation density, and channel slope.

Channel Migration Zone (CMZ) – A delineated river corridor that is anticipated to accommodate natural channel migration rates over a given period of time. The CMZ typically accommodates both channel migration and areas prone to avulsion. The result is a mapped "footprint" that defines the natural river corridor that would be active over some time frame, which is commonly 100 years.

DNRC – Department of Natural Resources and Conservation.

Erosion Buffer—The distance beyond an active streambank where a river is likely to erode based on historic rates of movement.

Erosion Hazard Area (EHA)– Area of the CMZ generated by applying the erosion buffer width to the active channel bankline.

Flood frequency – The statistical probability that a flood of a certain magnitude for a given river will occur in any given year. A 1% flood frequency event has a 1% chance of happening in any given year, and is commonly referred to as the 100-year flood.

Floodplain- An area of low-lying ground adjacent to a river, formed mainly of river sediments and subject to flooding.

Fluvial – Stream-related processes, from the Latin word fluvius = river.

Geomorphology - The study of landforms on the Earth's surface, and the processes that create those landforms. "Fluvial Geomorphology" refers more specifically to how river processes shape the Earth's surface.

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

Historic Migration Zone (HMZ) – The historic channel footprint that forms the core of the Channel Migration Zone (CMZ). The HMZ is defined by mapped historic channel locations, typically using historic air photos and maps.

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

Hydraulics – The study of the physical and mechanical properties of flowing liquids (primarily water). This includes elements such as the depth, velocity, and erosive power of moving water.

Large Woody Debris (LWD) – Large pieces of wood that fall into streams, typically trees that are undermined on banks. LWD can influence the flow patterns and the shape of stream channels, and is an important component of fish habitat.

Management Corridor – A mapped stream corridor that integrates CMZ mapping and land use into a practical corridor for river management and outreach.

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, such as on a map.

RDGP - Reclamation and Development Grants Program, DNRC.

Restricted Migration Area (RMA) – Those areas of the CMZ that are isolated from active river migration due to bank armor or other infrastructure.

Return Interval- The likely time interval between floods of a given magnitude. This can be misleading, however, as the flood with a 100-year return interval simply has a 1% chance of occurring in any given year.

Riparian – Of, relating to or situated on the banks of a river. Riparian zones are the interface between land and a river or stream. The word is derived from Latin ripa, meaning river bank. Plant habitats and communities along stream banks are called riparian vegetation, and these vegetation strips are important ecological zones due to their habitat biodiversity and influence on aquatic systems.

Riprap – A type of bank armor made up of rocks placed on a streambank to stop bank erosion. Riprap may be composed of quarried rock, river cobble, or manmade rubble such as concrete slabs.

Sinuosity - The length of a channel relative to its valley length. Sinuosity is calculated as the ratio of channel length to valley length; for example, a straight channel has a sinuosity of 1, whereas a highly tortuous channel may have a sinuosity of over 2.0. Sinuosity can change through time as rivers migrate laterally and occasionally avulse into new channels. Stream channelization results in a rapid reduction in sinuosity.

Stream competency - The ability of a stream to mobilize its sediment load which is proportional to flow velocity.

Terrace – On river systems, terraces form elongated surfaces that flank the sides of floodplains. They represent historic floodplain surfaces that have become perched due to stream downcutting. River terraces are typically elevated above the 100-year flood stage, which distinguishes them from active floodplain areas.

Wetland – Land areas that are either seasonally or permanently saturated with water, which gives them characteristics of a distinct ecosystem.

1 Introduction

The Beaverhead River Channel Migration Zone (CMZ) mapping project developed approximately 83 miles of mapping for the Beaverhead River from its beginning at Clark Canyon Dam, downstream to its confluence with the Big Hole River in Twin Bridges. It is part of a larger effort to create CMZ mapping for approximately 440 miles of river in the Missouri River headwaters. Other rivers in the study include the Beaverhead, Madison, Jefferson, and Gallatin Rivers, revising the 2005 Big Hole River mapping, as well as updating mapping in the Ruby River Valley to include Clear Creek. The main stem of the Ruby River from Ruby Reservoir to Twin Bridges was mapped in 2010 and the Big Hole River in 2005. In total, approximately 493 miles of river in the Missouri River headwaters will have CMZ mapping. Other rivers in Montana that have CMZ significant areas of mapping include the Yellowstone River, sections of the Flathead, Clark Fork, and Bitterroot Rivers, Deep Creek (Broadwater County), and Prickly Pear and Tenmile Creeks (Lewis and Clark County).

The work is being funded through a 2013 Montana Department of Natural Resources and Conservation (DNRC) Reclamation and Development Grants Program (RDGP) titled *Upper Missouri Headwaters River/Flood Hazard Map Development*. The project is administered by the Ruby Valley Conservation District, but includes input and review from stakeholders associated with each of the mapped rivers.

1.1 What is Channel Migration Zone Mapping?

The goal of Channel Migration Zone (CMZ) mapping is to provide a cost-effective and scientifically-based tool to assist land managers, property owners, and other stakeholders in making sound land use decisions along river corridors. Typically, projects constructed in stream environments such as bank stabilization, homes and outbuildings, access roads, pivots, and diversion structures are built without a full consideration of site conditions related to river process and associated risk. As a result, projects commonly require unanticipated and costly maintenance or modification to accommodate river dynamics. CMZ mapping is therefore intended to identify those areas of risk, to reduce the risk of project failure while minimizing the impacts of development on natural river process and associated ecological function. The mapping is also intended to provide an educational tool to show historic stream channel locations and rates of movement in any given area.

CMZ mapping is based on the understanding that rivers are dynamic and move laterally across their floodplains through time. As such, over a given timeframe, rivers occupy a corridor area whose width is dependent on rates of channel shift. The processes associated with channel movement include lateral channel migration and more rapid channel avulsion (Figure 1).

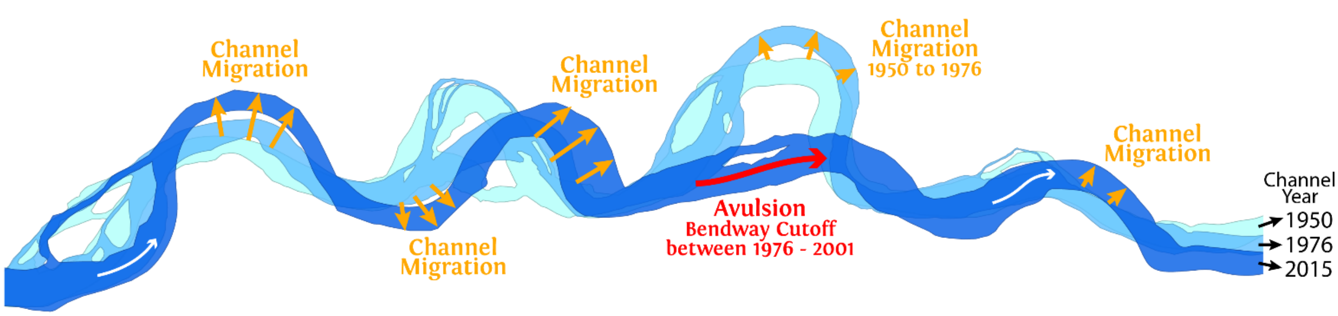

Figure 1. Typical patterns of channel migration and avulsion evaluated in CMZ development.

The fundamental approach to CMZ mapping is to identify the corridor area that a stream channel or series of stream channels can be expected to occupy over a given timeframe – typically 100-years. This is defined by first mapping historic channel locations to define the HMZ (Figure 1). Using those mapped banklines, migration distances are measured between suites of air photos, which allows the calculation of migration rate (feet per year) at any site. The statistical summarization of all migration measurements allows the determination of average rates of movement, and these average annual rates of movement are extended to the life of the CMZ, which in this case is 100 years. This 100-year mean migration distance defines the Erosion Buffer, which is added to the modern bankline to define the Erosion Hazard Area.

Channel migration rates are affected by local geomorphic conditions such as geology, channel type, stream size, flow patterns, slope, bank materials, and land use. For example, a meandering channel with high sediment loads would have higher migration rates than a geologically confined channel flowing through a canyon. To address this natural variability, the study area has been segmented into a series of reaches that are geomorphically similar and can be characterized by average migration rates. Reach breaks can be defined by changes in flow or sediment loads at tributary confluences, changes in geologic confinement, or changes in stream pattern. Reaches are typically on the order of 5-10 miles long. Within any given reach, dozens to hundreds of migration measurements may be collected.

Avulsion-prone areas are mapped where there is evidence of geomorphic conditions that are amenable to new channel formation on the floodplain. This would include meander cores prone to cutoff (Figure 1), historic side channels that may reactivate, and areas where the modern channel is perched above its floodplain.

The following map units collectively define a Channel Migration Zone (Rapp and Abbe, 2003):

- Historic Migration Zone (HMZ) – the area of historic channel occupation, usually defined by the available photographic record.
- Erosion Hazard Area (EHA) – the area outside the HMZ susceptible to channel occupation due to channel migration.
- Avulsion Hazard Zone (AHZ) – floodplain areas geomorphically susceptible to abrupt channel relocation.
- Restricted Migration Area (RMA) – areas of CMZ isolated from the current river channel by constructed bank and floodplain protection features. The RMA has been referred to in other studies as the DMA- Disconnected Migration Area.

The Restricted Migration Area (RMA) is commonly removed from the CMZ to show areas that are “no longer accessible” by the river (Rapp and Abbe, 2003). In our experience, the areas that have become restricted due to human activities provide insight as to the extent of encroachment into the CMZ, and highlight potential restoration sites. These areas may also actively erode in the event of common project failure such as bank armor flanking. For this reason, the areas of the natural CMZ that have become isolated are contained within the overall CMZ boundary and highlighted as “restricted” within the natural CMZ footprint.

The individual map units comprising the CMZ are as follows:

$$CMZ = HMZ + EHA + AHZ$$

Each map unit listed above is individually identified on the maps to show the basis for including any given area in the CMZ footprint (Figure 2).

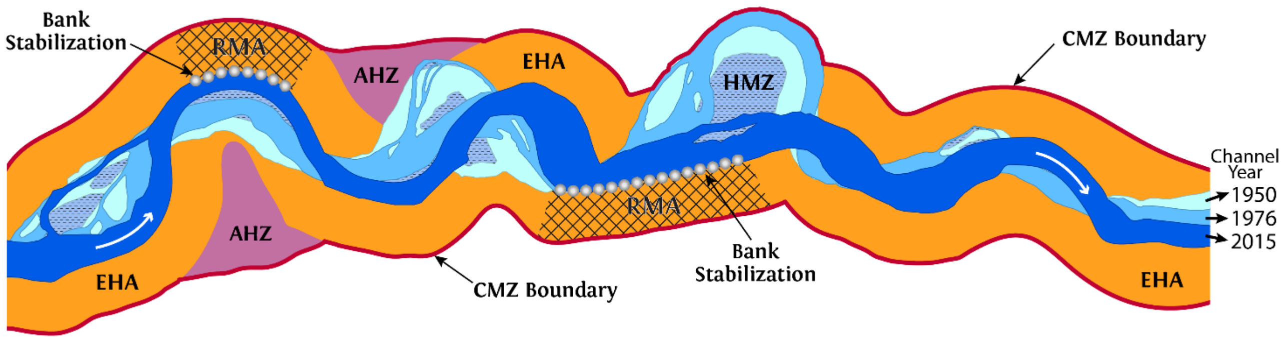

Figure 2. Channel Migration Zone mapping units.

1.2 CMZ Mapping on the Beaverhead River

The Channel Migration Zone (CMZ) developed for Beaverhead River extends 78 river miles from the Clark Canyon Dam approximately 18 miles south west of Dillon, MT to its confluence with the Big Hole River at Twin Bridges, MT.

Although the basic concept is largely the same, Channel Migration Zone mapping efforts performed throughout the country have used different approaches to defining CMZ boundaries. These differences in assessment techniques can be driven by the channel type, different project scales, the type and quality of supporting information, the intended use of the mapping, etc. For this study the CMZ is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations shown in the 1955, 1979, 2013, and 2015 imagery (Historic Migration Zone, or HMZ), and an Erosion Hazard Area (EHA), that is based on reach-scale average migration rates. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Areas or AHZ. This approach generally falls into the minimum standards of practice for Reach Scale, Moderate to High Level of Effort mapping studies as defined by the Washington State Department of Ecology (www.ecy.wa.gov). This approach does not, however, include a geotechnical setback on hillslopes, as these areas would require a more site specific analysis than that presented here.

1.3 Uncertainty

The adoption of a 100-year period to define the migration corridor on a dynamic stream channel requires the acceptance of a certain amount of uncertainty regarding those discrete corridor boundaries. FEMA (1999) noted the following with respect to predicting channel migration:

…uncertainty is greater for long time frames. On the other hand, a very short time frame for which uncertainty is much reduced may be useless for floodplain management because of the minimal erosion expected to occur.

The Beaverhead River shows historic patterns of lateral migration and avulsion, locally within a very broad floodplain surface that has dense networks of historic channels. Downstream of Dillon, the river is slightly perched above the floodplain area to the west. Ice jams are common. With potential contributing factors, such as woody debris jamming, sediment slugs, tectonic deformation, or ice jams, dramatic change could potentially occur virtually anywhere on the floodplain. As the goal of this mapping effort is to highlight those areas most prone to either migration or avulsion based on specific criteria, there is clearly the potential for changes in the river corridor that do not meet those criteria and thus are not predicted as high risk.

Uncertainty also stems from the general paradigm that "the past is the key to the future". As predicted future migration is based on an assessment of historic channel behavior, the drivers of channel migration over the past 50 years are assumed to be relatively consistent over the next century. If conditions change significantly, uncertainty regarding the proposed boundaries will increase. These conditions include system hydrology, sediment delivery rates, climate, valley morphology, riparian vegetation densities and extents, and channel stability. Bank armor and floodplain modifications, such as bridges, dikes, levees, or sand and gravel mining could also affect map boundaries.

1.4 Relative Levels of Risk

The natural processes of streambank migration and channel avulsion both create risk to properties within stream corridors. Although the probability of any area experiencing either migration or an avulsion during the next century has not been quantified, their association with specific river process allows some relative comparison of the type and magnitude of their risk. In general, the Erosion Hazard Area delineates areas that have a demonstrable risk of channel occupation due to channel migration over the next 100 years. Such bank erosion can occur across a wide range of flows. As such, the risk is not solely associated with flood events, as channel migration commonly occurs as a relatively steady process. Avulsion tends to be a flood-driven process, and as such, risks identified by the Avulsion Hazard Zone are typically associated with infrequent, relatively rapid shifts in channel course that are often difficult to predict.

1.5 Other River Hazards

The CMZ maps identify areas where river erosion can be expected to occur over the next century. It is important to note that river erosion is only one of a series of hazards associated with river corridors.

1.5.1 Flooding

The CMZ maps do not delineate areas prone to flooding. The difference between mapped flood boundaries and CMZ boundaries can be substantial. In cases where the floodplain is broad and low, the CMZ tends to be narrower than the flood corridor (Figure 3). In contrast, where erodible terrace units bound the river corridor, the CMZ is commonly wider than the floodplain, because the terraces may be high enough to prevent flooding, but not immune to erosion (Figure 4). This is a common problem in Montana because of the extent of high glacial terraces that are above base flood elevations, but not erosion-resistant. Figure 5 shows a property on the Yellowstone River in Park County that was progressively undermined during the 1996-1997 floods, prompting the owner to burn it down to prevent any liability associated with the structure falling into the river. This has been a chronic problem in river management, as landowners assume that if their home is beyond the mapped floodplain margin, it is removed from all river hazards. After experiencing massive 2005 flood damages in Saint George Utah (Figure 4), several property owners reflected on this issue (www.Utahfloodrelief.com):

> *"We knew the river was there. We were 3 feet above the 100-year flood plain and made sure we were well above the flood plain. It was surveyed and the engineers told us where we had to put it and no, we don't have flood insurance or any kind of insurance that is going to reimburse us for anything."*
>
> *"Our property was not located within the 500-year flood plain or was it adjacent to it. The river simply took a new route that went right through our property."*
>
> *"I knew we were in big trouble. The river was raging and making a sharp "S" turn right behind our home. Our property seemed to take the full force of the river turning against the bank. Large chunks of earth were being swallowed up into the river. We watched 20 feet erode in less than two hours. We knew if it continued at that pace, we'd lose our house. Our contractor contacted an excavation company early that morning, but they said there was nothing they could do for us. We were also informed that our contractor's insurance was not covered for floods."*

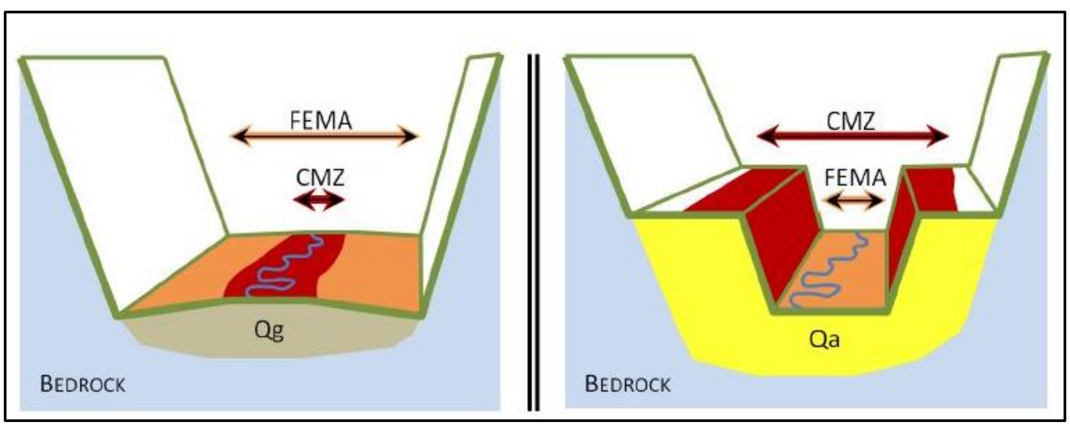

Figure 3. Schematic comparisons between CMZ and flood mapping boundaries (Washington State Department of Ecology).

Figure 4. Photos from a 2005 flood in Saint George Utah, where homes several feet above the mapped floodplain were destroyed by channel migration (www.Utahfloodrelief.com).

Figure 5. Yellowstone River home on high glacial terrace that was burned down in 1997 to prevent its undermining by the river.

1.5.2 Ice Jams

Another serious river hazard, especially in Montana, is ice jamming. Over 1,470 ice jams have been recorded in Montana, which is the most of any of the lower 48 states (http://dphhs.mt.gov/). The ice jams are most common in February and March. The National Weather Service has identified the Beaverhead River as having 13 reported ice jams (Figure 6). Ice jamming has been a recurring problem around the confluence of the

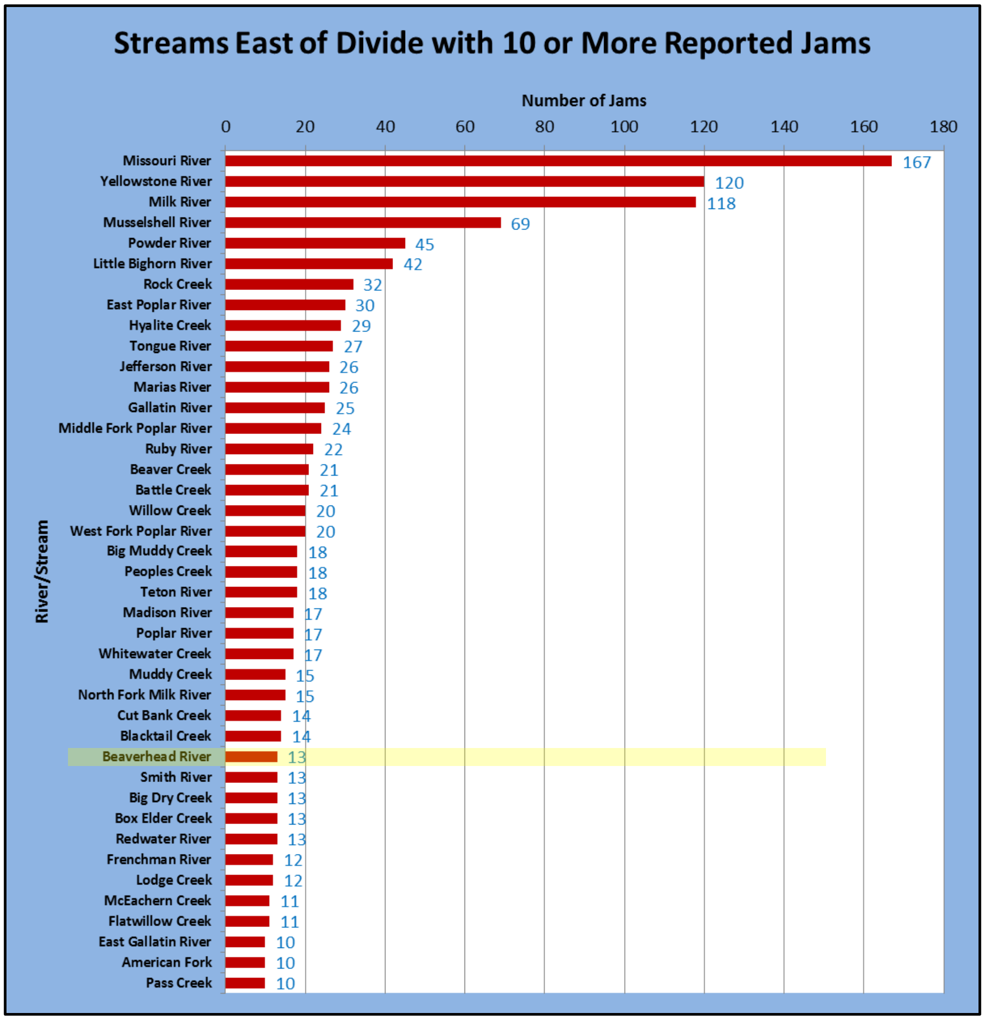

Figure 6. Montana rivers east of the continental divide with 10 or more reported ice jams.

Beaverhead with the Big Hole and Ruby Rivers near Twin Bridges, where in 2011, ice jams caused flooding in town (Figure 7 and Figure 8).

On January 28, 1937, the Dillon Tribune reported the following:

DAMAGING FLOOD AS RESULT OF ICE JAM IN BEAVERHEAD

Four Families Forced to Move as Water and Ice Inundate Large Area North of City.

Beaverhead's own flood situation showed little improvement today, with the water still spreading over a wide area and freezing as rapidly as it spreads.

"Beaverhead's own flood situation showed little improvement today, with the water still spreading over a wide area and freezing as rapidly as it spreads. Cars are passing through the half-mile of ice and water on the Butte-Dillon highway…There appears to be little chance of blasting a new channel for the river and only thawing temperatures can bring the river back to its regular course, it is feared. The main channel now seems to have been diverted by the ice jam through the J.P. Best tourist camp and over the highway. Little or no water is flowing through the natural channel….it has been some thirty years since an ice jam has formed on the Beaverhead River and it is doubtful If ever more widespread damage resulted".

The article above describes how ice jamming can cause flooding as well as avulsions. Ice effects can also accelerate bank migration rates. The massive 1984 flood was reportedly to have been driven by a combination of snowmelt, spring rains, and frequent ice jams (www.dphhs.mt.gov), although ice jamming in the Dillon area is reportedly mainly associated with Blacktail Creek.

Figure 7. Ice jam and flooding at Twin Bridges, MT, January 4, 2011. (Madison County, MT Office of Emergency Management).

Figure 8. Ice jam and flooding at Twin Bridges, MT, January 4, 2011. (Madison County, MT Office of Emergency Management).

1.5.3 Landslides

Clark Canyon hosts several active landslides that impinge into the river corridor (Section 2.2). These landslides have the potential to create river hazards by blocking the channel and potentially diverting or impounding flow. Figure 9 shows an example of a landslide that occurred in February 2014 on the south wall of the Nooksack River Valley near Bellingham, Washington. The landslide originally blocked the channel, and the effect was seen at a gaging station downstream where river flows rapidly dropped from over 2,000 cubic feet per second to about 400 cubic feet per second in the early morning hours of February 21. The river breached the landslide and flows returned to normal, however in some cases impacts have been much worse. Probably the most recently renown landslide into a river system was the 2014 Oso Slide into the North Fork of the Stillaguamish River, which dammed the river causing extensive flooding upstream (Figure 11). Prior to that, the 1959 Quake Lake slide occurred about 72 miles east of Clark Canyon, creating a lake that is 6 miles long and 190 feet deep.

Figure 9. Hillslope failure on Nooksack River near Bellingham Washington on February 21, 2014.

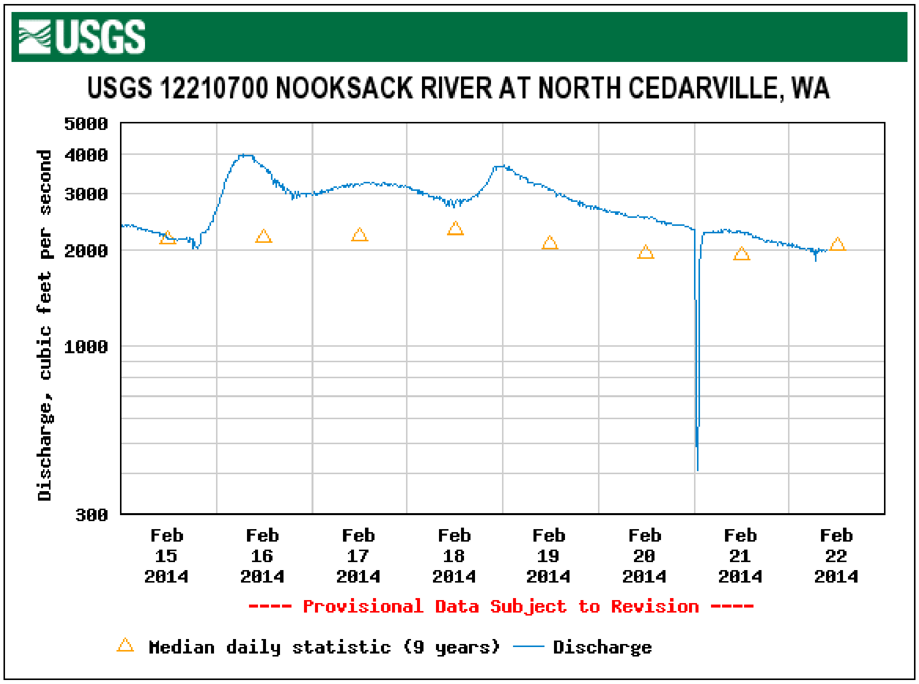

Figure 10. USGS gage data for the Nooksack River in Washington showing rapid drop in river flow following upstream hillslope failure.

Figure 11. Massive mudslide in Oso Washington on March 22, 2014, deflecting the North Fork of the Stilliguamish River (AP Photo/Ted Warren).

1.6 Potential Applications of the CMZ Maps

The CMZ mapping developed for the Beaverhead River is intended to support a myriad of applications and was not developed with the explicit intent of either providing regulatory boundaries or overriding site-specific assessments. Any use of the maps as a regulatory tool should include a careful review of the mapping criteria to ensure that the approach used is appropriate for that application.

Potential applications for the CMZ maps include the following:

- Identify specific problem areas where migration rates are notably high and/or infrastructure is threatened
- Strategically place new infrastructure to avoid costly maintenance or loss of capital
- Strategically place new infrastructure to minimize impacts on channel process and associated ecological function
- Assist in the development of river corridor best management practices
- Improve stakeholder understanding of the risks and benefits of channel movement
- Identify areas where channel migration easements may be appropriate
- Facilitate productive discussion between regulatory, planning, and development interests active within the river corridor
- Help communities and developers integrate dynamic river corridors into land use planning
- Assist long-term residents in conveying their experiences of river process and associated risk to newcomers.

1.7 Disclaimer and Limitations

The boundaries developed on the Channel Migration Zone mapping are intended to provide a basic screening tool to help guide and support management decisions within the mapped stream corridor and were not developed with the explicit intent of providing regulatory boundaries or overriding site-specific assessments. The criteria for developing the boundaries are based on reach scale conditions and average historic rates of change. The boundaries can support river management efforts, but in any application, it is critical that users thoroughly understand the process of the CMZ development and its associated limitations.

Primary limitations of this reach-scale mapping approach include a potential underestimation of migration rates in discrete areas that are eroding especially rapidly, which could result in migration beyond the mapped CMZ boundary. Additionally, site-specific variability in alluvial deposits may affect rates of channel movement. Mapping errors introduced by the horizontal accuracy of the imagery, digitizing accuracy, and air photo interpretation may also introduce small errors in the migration rate calculations. Future shifts in system hydrology, climate, sediment transport, riparian corridor health, land use, or channel stability would also affect the accuracy of results, as these boundaries reflect the extrapolation of historic channel behavior into the future. As such, we recommend that these maps be supplemented by site-specific assessment where near-term migration rates and/or site geology create anomalies in the reach-averaging approach, and that the mapping be revisited in the event that controlling influences *change dramatically. A site-specific assessment would include a thorough analysis of site geomorphology, including a more detailed assessment of bank material erodibility, both within the bank and in adjacent floodplain areas, consideration of the site location with respect to channel planform and hillslope conditions, evaluation of influences such as vegetation and land use on channel migration, and an analysis of the site-specific potential for channel blockage or perching that may drive an avulsion.*

1.8 The Project Team

This project work was performed Tony Thatcher of DTM Consulting and by Karin Boyd of Applied Geomorphology, with support from Chris Boyer of Kestrel Aerial Services. Over the past decade, we have been collaborating to develop CMZ maps for numerous rivers in Montana, in an attempt to provide rational and scientifically sound tools for river management. It is our overall goal to facilitate the understanding of rivers regarding the risks they pose to infrastructure, so that those risks can be managed and hopefully avoided. Furthermore, we hope to stress the benefits of managing rivers as dynamic, deformable systems that provide resilience to flooding, economic benefit through ecological sustainability, and reduced capital costs of engineered solutions.

1.9 Acknowledgements

We would like to extend our gratitude to Rebecca Ramsey of Ruby Watershed Council and Shirley Galovic of Ruby Conservation District for their assistance in contract management and scheduling. The following individuals provided input and review while developing the mapping and report: Rick Hartz (Madison County Planner), Tom Rice (Beaverhead County Commissioner), Samuel Novich (Twin Bridges), Tiffany Lyden (DNRC Floodplain Program), and Jamie Cottom (Beaverhead River Watershed Coordinator). We also appreciate the oblique aerial photography shot by Chris Boyer of Kestrel Aerial Services, as those images provide a perspective of the river that can’t be made with conventional air photos. Photographs of ice jam flooding were provided by the Montana Office of Emergency Management and Doris Fischer.

2 Physical Setting

The following section contains a general description of the geographic, hydrologic, and geologic influences on the Beaverhead River to characterize the general setting and highlight how that setting may affect river process.

2.1 Geography

The Beaverhead, Ruby, and Big Hole Rivers are the three main stream systems that join to form the Jefferson River at Twin Bridges, MT (Figure 14). The Beaverhead River is approximately 83 miles long, flowing northward from the outlet of Clark Canyon Dam to Twin Bridges, MT. Prior to completion of the dam in 1964, the river formed at the confluence of the Red Rock River and Horse Prairie Creek near the historic town of Armstead, MT (Figure 12), which is now submerged by Clark Canyon Reservoir (Figure 13). Construction of the dam reduced the length of the river by several miles by inundating its upper end. The elevation of the contributing watershed reaches 11,000 feet, and the elevation at the outlet of the dam is 5,450 feet. Along its course to Twin Bridges the river drops about 850 feet, reflecting an average slope of approximately 0.2%, which is typical for major rivers of the area. The contributing watershed area of the Beaverhead River is 3,817 square miles, or 27% of the total area of the Missouri Headwaters (Figure 14). Of that 27%, the Red Rock River/Horse Prairie watersheds account for 2,315 square miles (16%) of drainage area, while the Beaverhead watershed below the reservoir accounts for the remaining 1,502 square miles (11%).

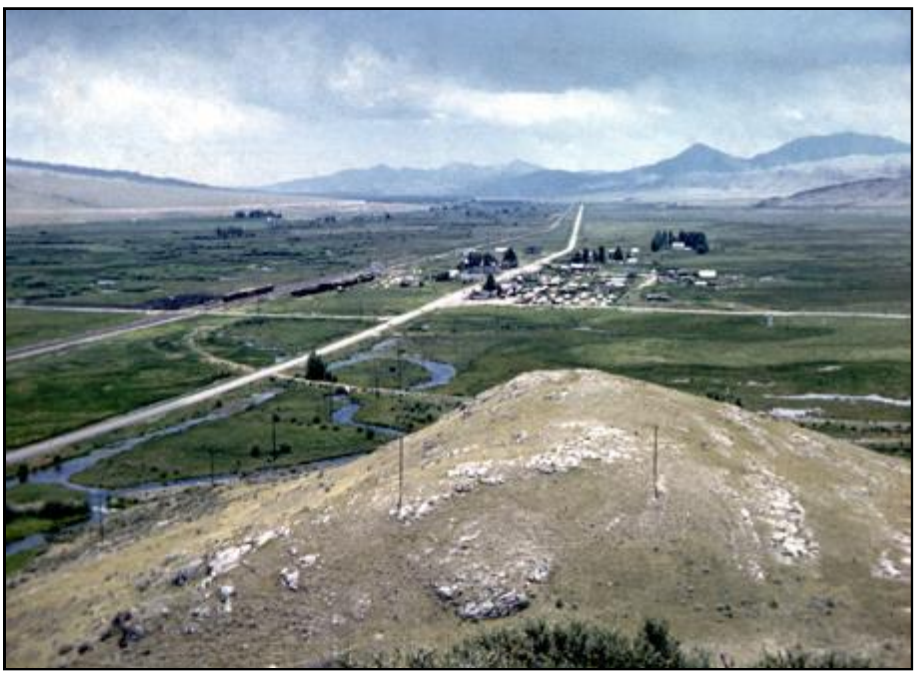

Figure 12. Armstead, MT from the current Armstead Island (c. 1960), prior to construction of Clark Canyon Dam. (www.lewis-clark.org)

Figure 13. Clark Canyon Reservoir looking east showing historic and current features. (www.lewis-clark.org).

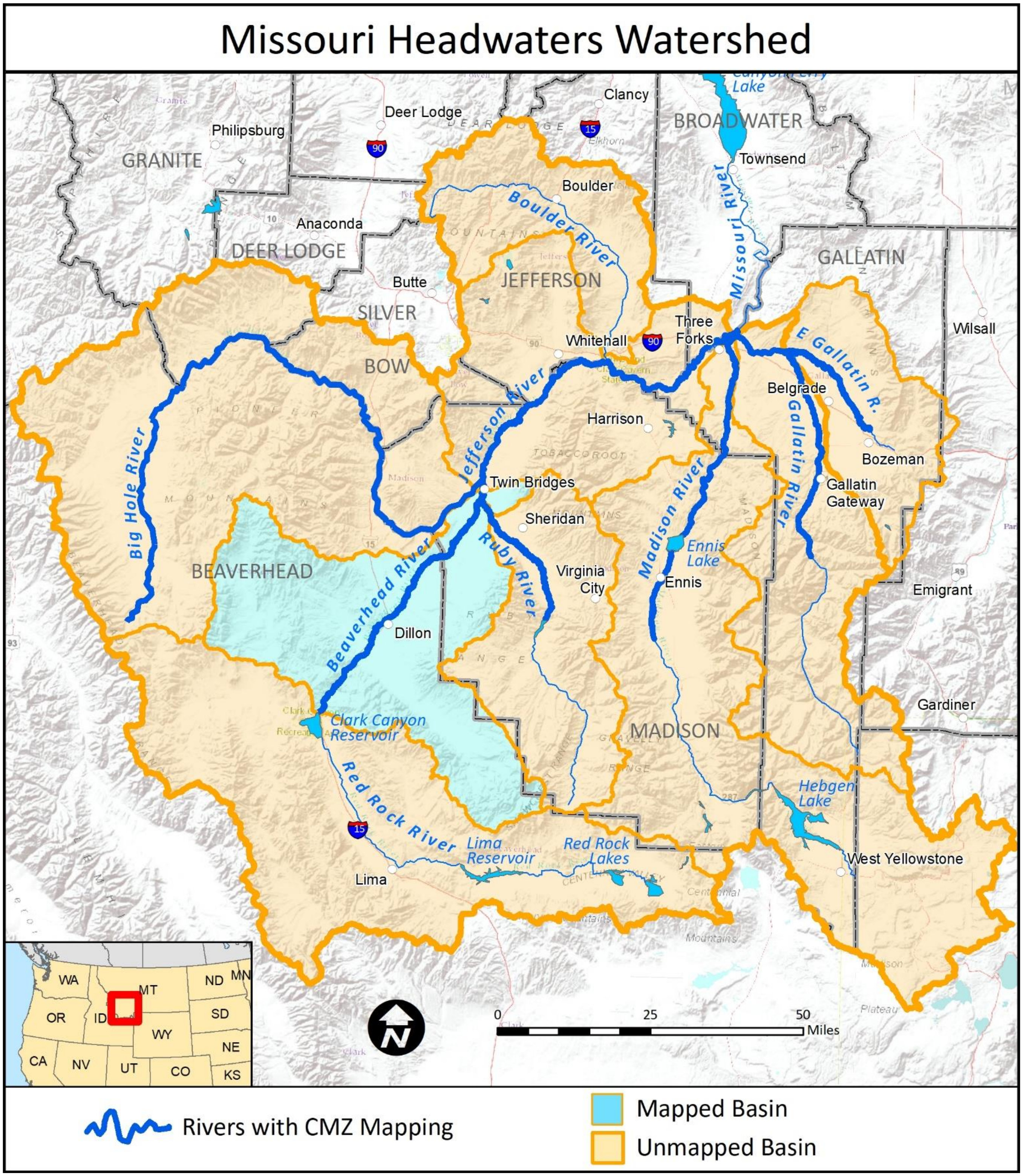

Figure 14. Missouri headwaters watershed showing Beaverhead River subwatershed.

For the first 15 miles below Clark Canyon Dam, the river flows through a narrow canyon that is constricted by both volcanic rocks and transportation infrastructure. The combined effects of Interstate 15, a rail line, and frontage road severely confine the naturally narrow stream corridor, in places completely isolating all historic floodplain area. The river exits the canyon at a narrow constriction at Barretts entering a broad valley for most of the remainder of its course to Twin Bridges. The two main tributaries in the project reach are Grasshopper Creek which enters from the west at river mile 71.1 in Clark Canyon and Blacktail Deer Creek which enters from the east at river mile 53.5 in the City of Dillon.

The upper 52 miles of the Beaverhead River are located in Beaverhead County, with the remaining 31 miles in Madison County. Dillon and Twin Bridges are the only two communities along the river. The 2010 population of Dillon was 4,134 people, while Twin Bridges is an order of magnitude smaller at 375 people.

2.2 Geology and Glacial History

Just below Clark Canyon Dam, the Beaverhead River has incised into a ~600-foot deep canyon as it crosses the Blacktail Range. Within the canyon, several scattered terraces have been mapped above the modern river floodplain. Research has indicated that the canyon formed due to intersecting influences of incision, uplift, and glaciation (Bartholomew et al., 1999). The course of the river across the Blacktail Range was developed by Late Pleistocene time, and as the river cut down through bedrock, it left deposits perched on the valley walls as terrace remnants. Uplift on the active Blacktail Fault, which forms the northern margin of the Blacktail Range, drove some of the incision. However, the highest rates of downcutting occurred during the Pinedale and Bull Lake glaciations, indicating that glacial processes were key in canyon formation.

Landslides have also affected the valley form through the canyon; There is a large slide on the west side of the channel at High Bridge that has confined the corridor (Figure 15). Gradient changes in the river near Grasshopper Creek reflect a lower slope upstream from two active landslides and steeper gradients where the river is constricted by the toes of these landslides (Bartholomew et al., 1999). Landslides have periodically blocked, constricted, or diverted to the river, and Bartholomew and others (1999) indicated this may be associated with major earthquakes. Landslides are most common in mixed volcanic rocks.

At Barretts, the river enters a broad basin near Dillon, crossing the projected trace of the Blacktail Fault almost perpendicularly. Downstream of Barretts, the course and gradient of the river have been described as influenced by Pleistocene age tributaries that delivered large volumes of sediment through the ancestral Rattlesnake and Blacktail Deer Creeks, impeding the flow of the ancient Beaverhead River (Bartholomew et al., 1999). As a result, the upper miles of the valley are underlain by coalescing fan complexes. This has resulted in lower gradients and compressed meanders for several miles below Barretts where the river is confined between these features (Figure 16). This influence is concentrated between Barretts and Poindexter Slough, and is characterized by notably low channel migration rates.

Figure 15. View downstream from near Clark Canyon Dam showing large a landslide deflecting the Beaverhead River to the east at High Bridge (Kestrel).

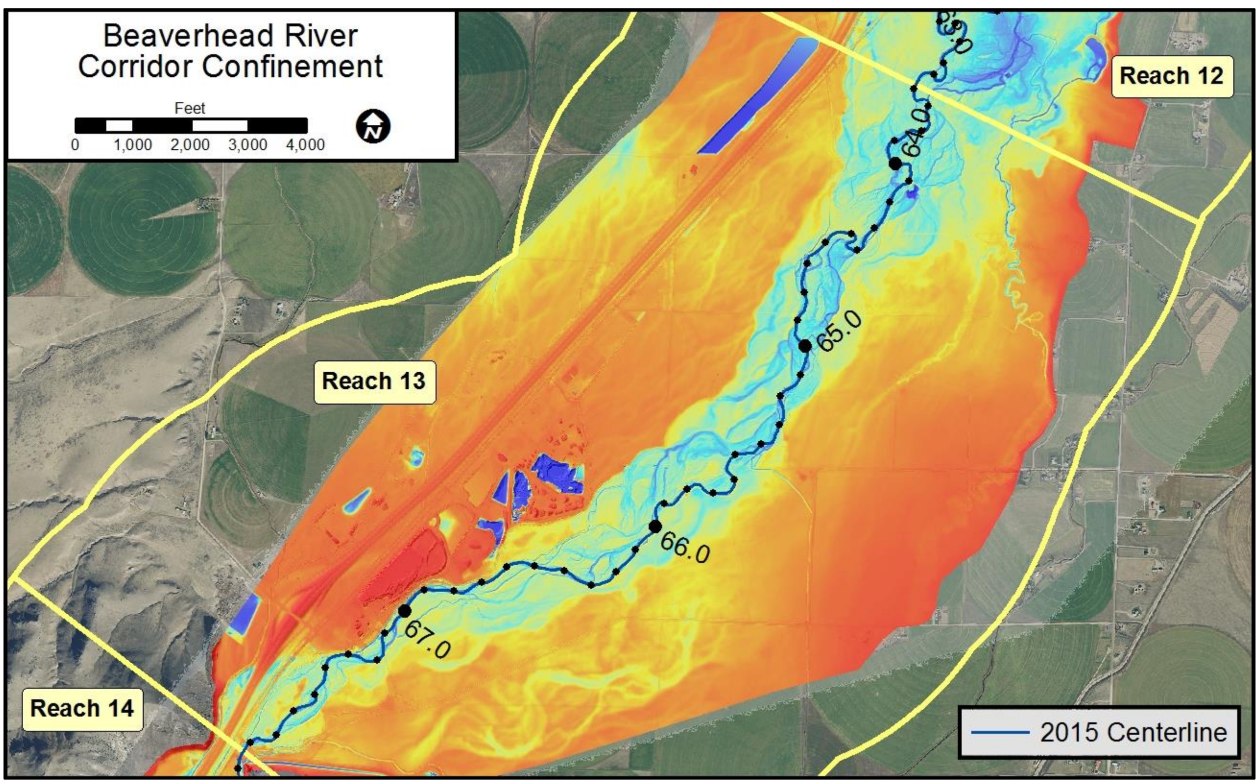

Figure 16. Stream corridor confinement by Pleistocene-age alluvial fans below Barretts Diversion; warmer colors reflect relatively high elevations.

Approaching Dillon, the river valley becomes wider and characterized by long side channels such as Poindexter Slough. The stream alternates between a single thread meandering channel and multi-thread anabranching form. Abandoned channels are common on the floodplain. A few miles downstream of Dillon, the modern river is perched about 6 feet above a series of channel remnants to the west, including Selway Slough, Murray Gilbert Slough, and Albers Slough (Figure 17 and Figure 18).

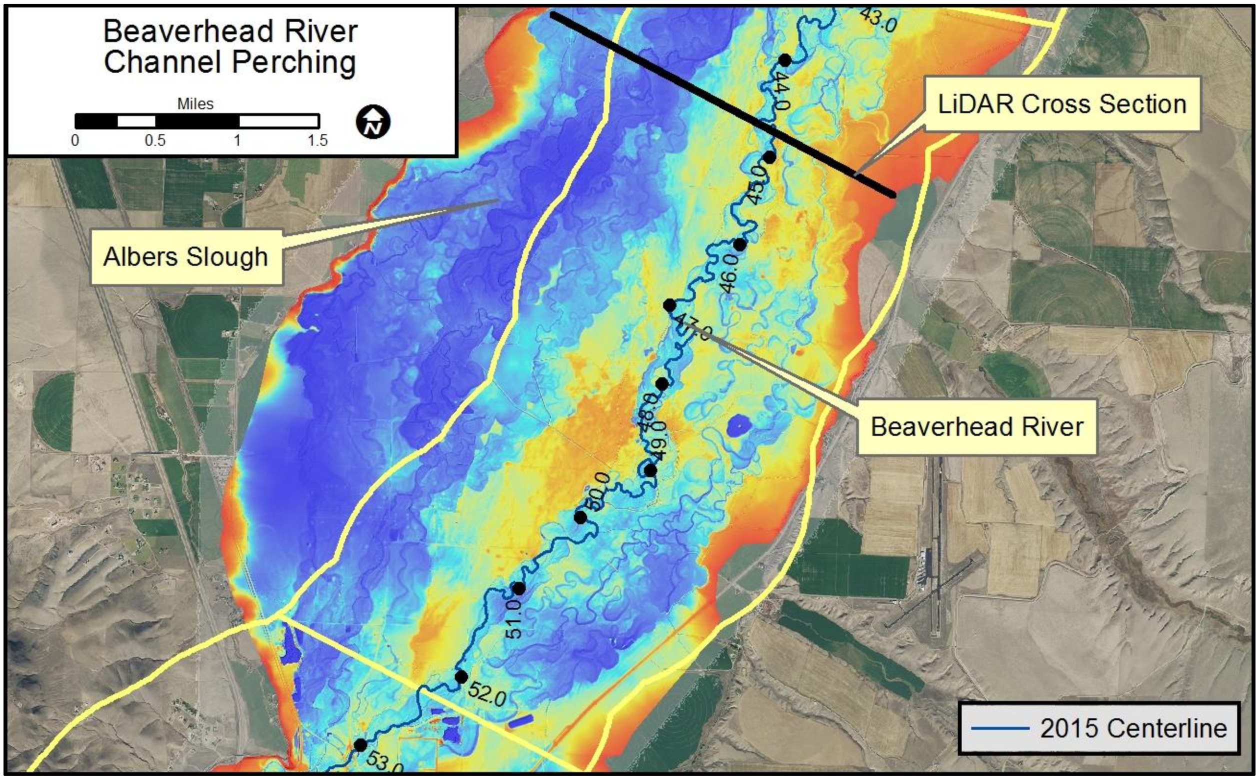

Figure 17. Inundation Modeling showing perching of Beaverhead River above sloughs to west; blue colors reflect relatively low elevations.

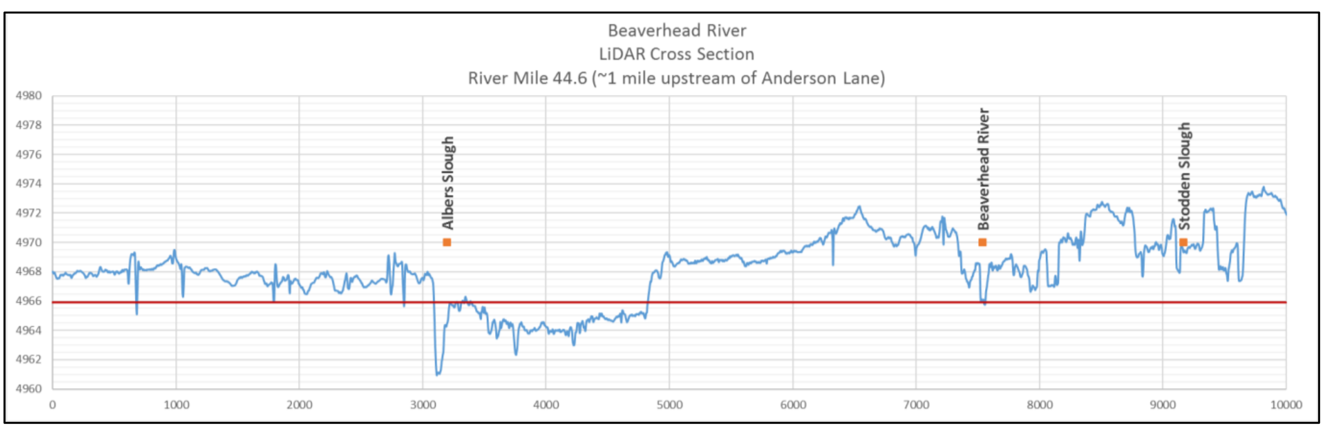

Figure 18. LiDAR cross section from line shown in Figure 17 showing perching of Beaverhead River above Albers Slough; view is downstream (north).

At RM 28, Beaverhead Rock (also known as Point of Rocks) marks a distinct pinch point in the stream corridor (Figure 19). According to Meriwether Lewis, Beaverhead Rock was the first landmark that Sacajawea recognized as the Lewis and Clark expedition approached her homeland. Although the rock is marked as Beaverhead Rock, according to Clark's journals the actual landmark is the outcrop south of Dillon at Barretts. For this study, Beaverhead Rock (Point of Rocks) is the pinch point at RM 28, and it is composed of Madison limestone (Alt and Hyndman, 1997).

Figure 19. View downstream showing corridor constriction at Beaverhead Rock (Point of Rocks)(Kestrel).

2.3 Hydrology and Flow Management

Human development has strongly altered the natural hydrology of the Beaverhead River. Both high and low flow conditions have been impacted, with peak flows reduced due to on-line reservoir storage and low flows affected by irrigation management patterns.

2.3.1 Clark Canyon Dam

The Clark Canyon Dam (Figure 20) is located at the upstream end of the project reach approximately 18 miles south west of Dillon, MT. The mainstem reservoir was built between 1961 and 1964 with the purpose of storing and regulating water for irrigation use downstream as well as providing flood control. The dam is a zoned earthfill dam with a height of 147.5 feet and a width of 2,950 feet. It is currently owned and managed by the Bureau of Reclamation as part of the East Bench Unit irrigation system (Bureau of Reclamation, 2016). The reservoir has an exclusive flood control capacity of over 79,000 acre feet, and includes storage capacity allocated to assist with flood and power operations of the Corps of Engineers Missouri River Main Stem System (CCWSC, 2004).

Figure 20. View downstream over Clark Canyon Dam, Montana. (Kestrel).

Flows in the Beaverhead River are largely regulated by the Clark Fork Dam to support irrigation practices in the Beaverhead Valley. According to the Montana Fish Wildlife and Parks:

> *Clark Canyon Reservoir and irrigation diversions affect the flow pattern of the Beaverhead River. Prior to the construction of the reservoir, much of the lower river was severely dewatered during the summer irrigation season. In general, reservoir management has resulted in higher flows in the lower river during the historically low flow months of May, July, August and September. However, much of the lower 64 miles still suffer from dewatering. In recent years, sections of the lower river have been totally dry. Massive withdrawals of irrigation water have virtually eliminated high water flows in the lower river. During periods of drought, the upper river is now severely affected by low flow releases during the non-irrigation season when water is being stored for the following year. (MTFWP, No Date).*

2.3.2 Major Diversion Structures

The largest diversion structure on the mainstem is Barretts Diversion, which is located at the mouth of Clark Canyon. It was built in conjunction with the Clark Canyon Dam between 1961 and 1964 as part of the East Bench Unit of the Pick-Sloan Missouri Basin Program. Water is diverted through a 44-mile long network of canals, including the East Bench Canal and Canyon Ditch (Bureau of Reclamation, no date), irrigating approximately 49,800 acres. The diversion capacity for the East Bench Canal headworks is 440 cubic feet per second, while the Canyon Ditch headworks is 200 cubic feet per second.

The Dillon Canal is another major diversion system, which leaves Poindexter Slough. This system has been recently rebuilt as part of a major restoration effort on four miles of Poindexter Slough.

The Clark Canyon Water Supply Company (CCWSC), which serves over 28,000 acres of irrigated lands, lists 70 diversion points from the Beaverhead River. Most of the water is used to irrigate alfalfa and grass hay with a smaller fraction of cereal grain, potatoes, and irrigated pasture (CCWSC, 2004). The Montana Department of Natural Resources and Conservation Water Rights data lists approximately 500 claimed Points of Diversion from the Beaverhead River, including 358 headgates. It is unclear the functionality of these "claimed" headgates, or the associated infrastructure such as in-stream diversions that may be associated with them.

2.3.3 Beaverhead River Flood History

The annual peak flow record for the USGS gage at Barretts (06016000) is shown in Figure 21. Prior to the completion of Clark Canyon Reservoir, the median annual peak discharge over 56 years was 1,335 cubic feet per second. Over the 51 years following reservoir completion, the median annual peak flow was 1,060 cubic feet per second. With regard to individual flood events, Figure 21 shows the post-reservoir flood frequency discharges for the gage, to gain some perspective as to how historic flooding patterns have been altered. Prior to the dam, what is now considered a 100-year flood (2,480 cubic feet per second) was exceeded four times, and there has been one event since. Even more striking, floods that are now considered at least a 10-year event (>1,720 cubic feet per second) occurred 15 times prior to the dam completion, or about once every four years. Since 1964, there have been three events exceeding a 10-year event, or once every 17 years.

In addition to a drop in overall flood magnitudes, the variability of peak flows has markedly dropped. Figure 22 shows a box and whisker plot with the pre- and post- dam data summarized separately. The results show the compression of the range of peak flows into a narrow range that is concentrated between about 900 and 1,250 cubic feet per second.

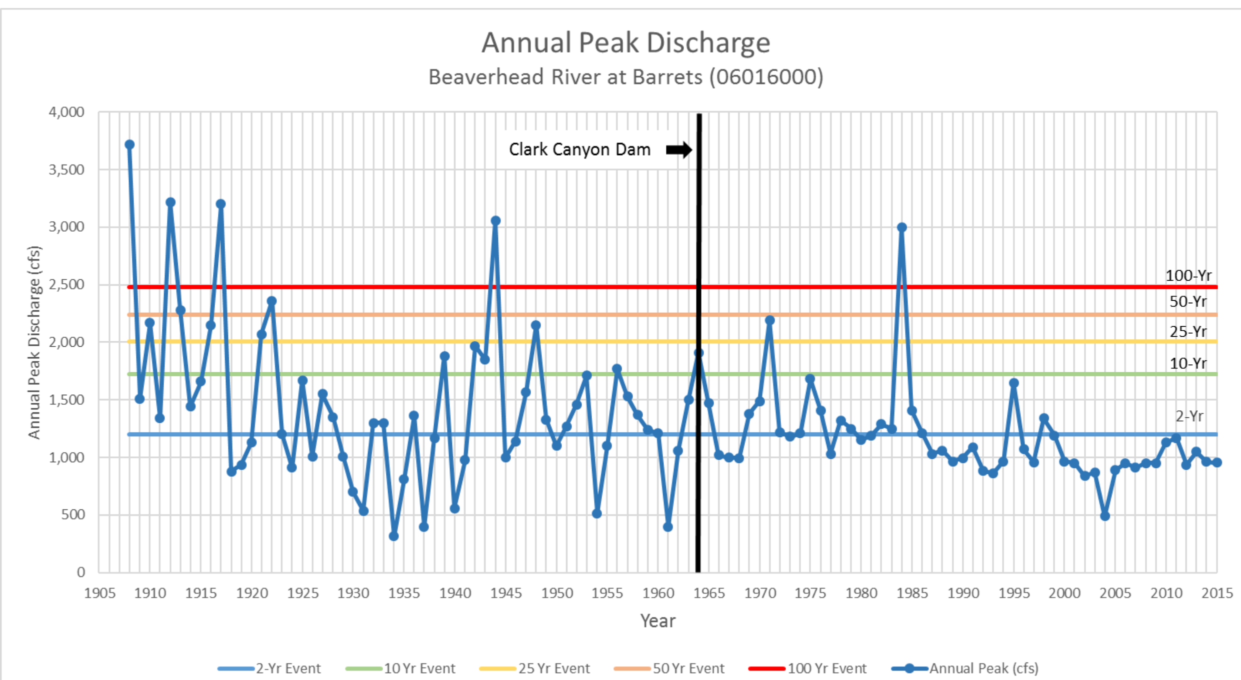

Figure 21. Peak annual discharge for Beaverhead River at Barretts gage (06016000).

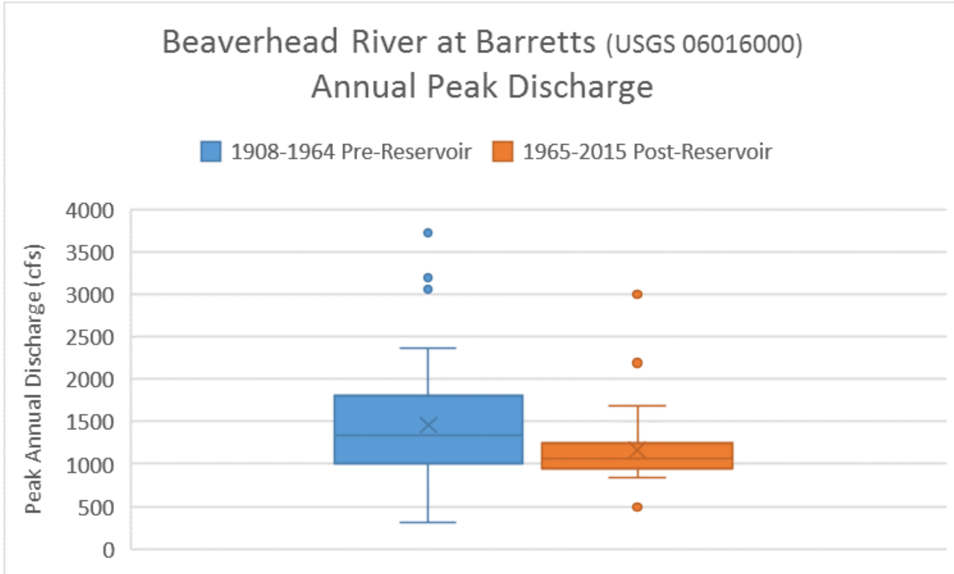

Figure 22. Box and whisker plot showing Peak Annual Discharge values for Beaverhead River at Barretts pre- and post- Clark Canyon Reservoir.

In terms of stream process, large flood events have the potential to drive rapid channel migration and avulsions. Floods are therefore important to consider when evaluating channel change, and the hydrologic record suggests that the geomorphology of the Beaverhead River was much more flood-driven prior to the construction of Clark Canyon Reservoir. Smaller flood events show the same trend, however, which may have a larger cumulative impact on channel migration. The 2-year discharge, is commonly referred to as a "channel forming flow", meaning the flow that fills the channel and largely dictates overall channel form. In the northern Rockies, the channel forming flow typically occurs on the order of 10 days per year during spring runoff (Andrews and Nankervis, 1995). Figure 23 and Figure 24 show how each year's highest flow compares to the 2-year flow at Barretts and near Twin Bridges. Whereas the 2-year flow should occur other year or so, it has been exceeded only twice since the late 1980s at the Barretts gage (Figure 23). A similar trend is evident downstream at the gage near Twin Bridges, where the 2-year discharge is 856 cubic feet per second, and peak flows have commonly been less than half that (-50% on Figure 24).

The century-long hydrologic record for the Beaverhead River reflects a wide range of annual peaks prior to dam construction, with post-dam conditions characterized by a dampened flow range, a huge flood in 1984, and persistently low annual peaks since the late 1980s. The consequences of these changes can probably be described as an increased vulnerability to rare events because of the persistent low flows that can be interrupted by major floods. That means the system is probably more susceptible to dramatic change during relatively rare high water events than pre-1964 when flooding was more common.

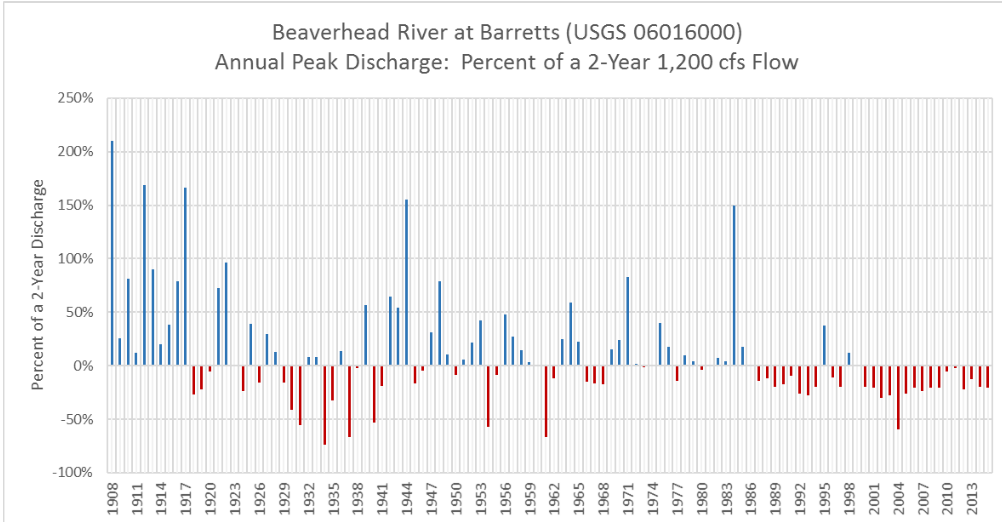

Figure 23. Peak annual flows shown as percentage of a 2-year 1,200 cubic feet per second event, Beaverhead River at Barretts.

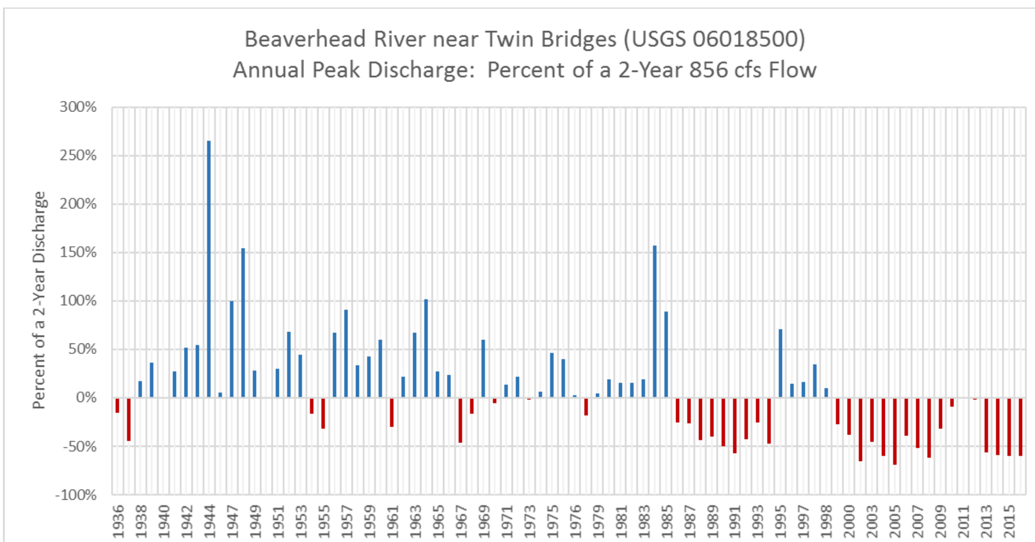

Figure 24. Peak annual flows shown as percentage of a 2-year 856 cubic feet per second event, Beaverhead River near Twin Bridges.

2.4 Dikes and Levees

Floodplain dikes, levees, and channel plugs were mapped using primarily air photos, supplemented with other available data sources such as Google Earth and LiDAR. The LiDAR data extents from Barretts to Beaverhead Rock, which allowed for more detailed mapping in that segment.

A total of 33.4 miles of features that act as berms or levees were mapped on the Beaverhead River. These features were identified remotely using air photos and the LiDAR elevation data, and their influence on flooding and channel migration is unknown. Reportedly, some of these features were illegally installed during the 1984 flood (R. Hartz, pers. comm.). The majority (23.8 miles) of the mapped dikes and levees are associated with the transportation network. The railroad (consisting of an abandoned line and an active line) accounts for 5 miles, almost all of which is in Clark Canyon. Agriculture accounts for 2.9 miles, while the remaining 1.7 miles are attributed to various other land uses such as residential or industrial uses, or as channel plugs in old swales. Figure 25 show an example of the abandoned railroad grade in Clark Canyon which has been partially breached by bank erosion. A typical floodplain dike is shown in Figure 26. Unless these features represent maintained infrastructure or are visibly armored, they are not considered to restrict channel migration.

Figure 25. A historic rail grade in Clark Canyon showing a breach in the abandoned rail grade, July 12, 2016. (Kestrel)

Figure 26. A 1.4 mile levee below Beaverhead Rock, July 12, 2016. (Kestrel)

2.5 Bank Armor

Bank armor such as rip rap and wood revetments were mapped where visible in aerial photographs, Google Earth, or oblique photographs. Since there was no ground inventory, the mapping probably captures a conservative estimate of the extent of bank armor on current and historic channels. A total of 4.9 miles of bank armor were mapped in the river corridor, which reflects approximately 3% of the total bankline. About 1.5 miles of that armor is associated with transportation features (bridges, bridge approaches, and roads), 1.4 miles is protecting agricultural land uses including irrigation infrastructure, 1.2 miles is along the railroad line, with the remaining 0.6 miles of armor associated with other land uses (Clark Canyon Dam, industrial, etc.).

2.6 Transportation Infrastructure

The transportation network has a large impact on the Beaverhead River CMZ, especially in Clark Canyon. Between Clark Canyon Dam and Barretts, the river is paralleled by Interstate 15, the Union Pacific rail line, and local frontage roads. These features cross the river multiple times and the crossings are typically if not always armored. Below Barretts the river flows through the broad Beaverhead Valley, with occasional bridge crossings for ranch or county roads, along with numerous diversions into local irrigation canals.

There are 47 bridges that span the entire river channel within the project area; Appendix B contains oblique photos of the major crossings.

The greatest concentration of bridges occurs in the 30 miles from Clark Canyon Dam through Dillon, where there are 38 river crossings. The remaining nine crossings are distributed throughout the remaining 48 miles of river below Dillon. Interstate 15 crosses the river seven times, each with two separate bridges, accounting for 14 total crossings. The Union Pacific rail line has four crossings. There are 14 bridges on unnamed roads that access ranch or farm land. The remaining 15 bridges are for local roads and state highways.

Though the construction of I-15 in Montana started in 1958 with a 5-mile section between Monida and Lima, the canyon section of the Interstate below Clark Canyon was not completed until 1988 (Montana Standard, 2013).

The Union Pacific Railroad largely follows the eastern valley edge through Clark Canyon, crossing to the west side of the valley at river mile 69.2 (Figure 80). The rail line crosses back to the east side of river at river mile 62, where it crosses the river's main channel, a side channel, as well as Poindexter Slough (Figure 83). A final crossing back to the west side occurs at river mile 53.5 where it parallels Highway 91 on the north side of Dillon (Figure 90).

3 Methods

The development of the Beaverhead River Channel Migration Zone mapping is based on established methods in Washington, as well as closely following similar efforts on a variety of Montana's rivers.

3.1 Aerial Photography

Imagery from 1955, 1979, 2013 and 2015 were used to develop the CMZ maps (Table 1). These suites were selected due to their dates, quality, and overall coverage. This 60-year long span from 1955-2015 includes one extreme flood event in 1984 that exceeded the 100-year discharge, one event in 1971 that approached a 50-year flood, and three events that met or exceeded a 10-year event (1956, 1964, and 1995).

Table 1. Imagery suites used in this study.

Date	Source	Scale	Notes
1955	USDA APFO	1:20,000	75 frames, orthorectified by Aerial Services, Inc.
1979	USDA APFO	1:40,000	39 frames, orthorectified by Aerial Services, Inc.
2013 NAIP	NRIS	~ 1 meter resolution	Digital Download
2015 NAIP	NRIS	~ 1 meter resolution	Digital Download

The 1955 and 1979 flights were ordered from the USDA Aerial Photography Field Office (APFO). The 1955 flight has 75 black and white frames, providing complete stereographic coverage of the project area at a scale of 1:20,000. The 1979 flight also has full coverage with 39 frames at 1:40,000. These were orthorectified by Aerial Services, Inc. of Cedar Rapids, Iowa. The resulting mosaic provides spatially accurate (estimated 3 meter accuracy) seamless coverage of the project area. The dataset was assessed after delivery and determined to meet or exceed National Map Accuracy standards for horizontal position (USGS).

3.2 GIS Project Development

All project data was compiled using ESRI's ArcMap Geographic Information System (GIS) utilizing a common coordinate system - Montana State Plane NAD83 Feet (HARN). The Ruby River CMZ Study utilized this coordinate system as it was the recommended best practice at the time. So, to be consistent with that study, the Beaverhead mapping utilizes this reference system. The orthorectified air photos provide the basis for CMZ mapping. In addition to the specific project data created for this study, other data included in the GIS project LiDAR elevation data (Point of Rocks to Beaverhead Rock), roads, railroads, stream courses as depicted in the National Hydrography Dataset, scanned General Land Office Survey Maps which were obtained from Bureau of Land Management, and geologic maps produced by the United States Geological Survey.

3.3 Bankline Mapping

Banklines representing bankfull margins were digitized for each year of imagery at a scale of 1:2,000. A tablet computer running ArcGIS and using a pen stylus was used to trace the banklines using stream mode digitizing. This methodology allowed us to capture a much more detailed bankline than using a mouse. Bankfull is defined as the stage above which discharge commences to flow out onto the floodplain. Although that boundary can be identified using approaches such as field indicators or modeling (Riley, 1972), digitizing banklines for CMZ development requires the interpretation of historic imagery. Therefore, we typically rely on the extent of the lower limit of perennial, woody vegetation to define channel banks (Mount & Louis, 2005). This is based on the generally accepted concept that bankfull channels are inhospitable to woody vegetation establishment. Fortunately, shrubs, trees, terraces, and bedrock generally show distinct signatures on both older black-and-white as well as newer color photography. These signatures, coupled with an understanding of riparian processes, allow for consistent bankline mapping through time and across different types of imagery. Figure 27 shows an example of bankline mapping for the project.

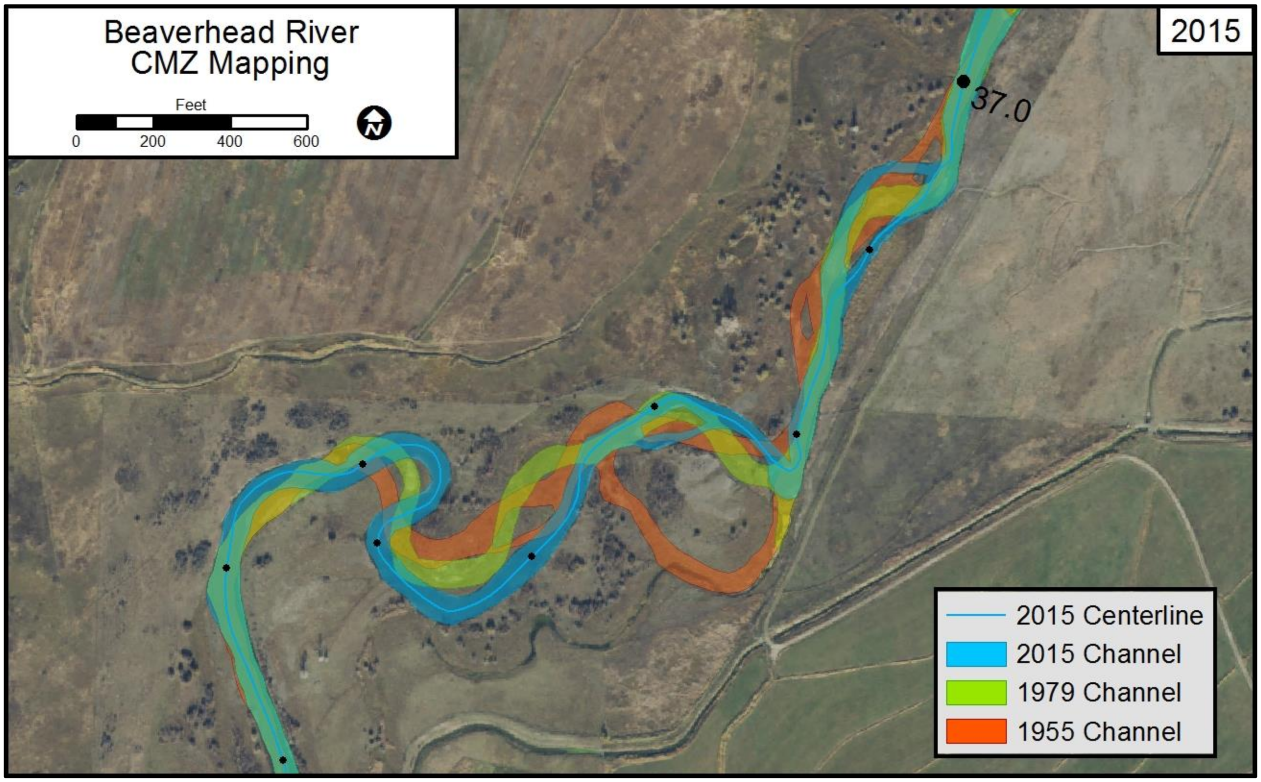

Figure 27. Bankline mapping on 2015 NAIP imagery.

3.4 Migration Rate Measurements

Once the banklines were digitized, they were evaluated in terms of discernable channel migration since 1955. Where migration was clear, vectors (arrows with orientation and length) were drawn in the GIS to record that change. At each site of bankline migration, measurements were collected at approximately 30 foot intervals (Figure 28). A total of 1,959 migration vectors were generated for the Beaverhead River. These measurements were then summarized by reach. The results were then used to define a reach-scale erosion buffer width to allow for likely future erosion. Results of this analysis are summarized in Section 4.2 .

Each location of channel migration was assigned a Migration Site ID based on the river mile location of the site. Each site may have anywhere from 1 to 11 migration vectors, depending on the length of the site. A total of 507 migration sites were identified throughout the study area. An accounting of the site-based statistics can be found in Appendix A.

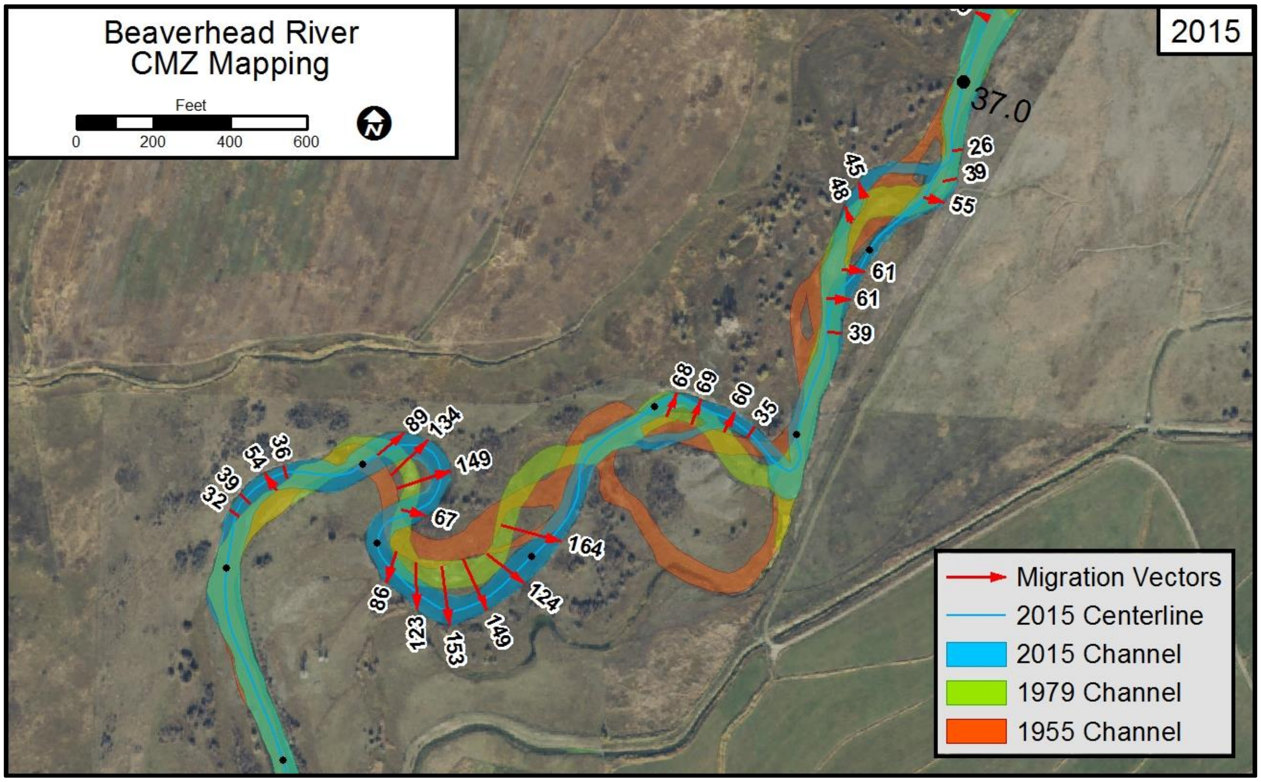

Figure 28. Example of migration measurements (migration distance in feet).

3.5 Inundation Modeling

Inundation Modeling, also known as Relative Elevation Modeling (REM), is an effective way to visually compare floodplain elevations to channel elevations, and is useful in identifying floodplain features such as historic channels that are prone to frequent flooding and/or avulsion (Figure 29).

Inundation modeling is a static model of relative elevations based upon Digital Elevation Model (DEM) data. The general goal of the modeling is to identify areas that may be prone to flooding as the water surface of the stream is raised. The general technique involves using cross sections to create a water surface profile down the stream corridor. This profile is then transformed into a series of ramped planes down the stream corridor that match the down-valley slope of the water surface. The ground surface is then subtracted from this planar water surface, so that a relative depth can be assigned at each LiDAR data point. The resulting surface coarsely represents relative inundation potential based on relative elevation. This can be used to approximate flood prone areas, but it also is a useful tool for identifying low topographic features or channels that may pose an avulsion risk.

It is important to note that this modeling does not consider flood water routing or backwater effects, but only elevation. As such, low areas may not be flood prone if the overflow paths are blocked by physical features such as dikes or road prisms.

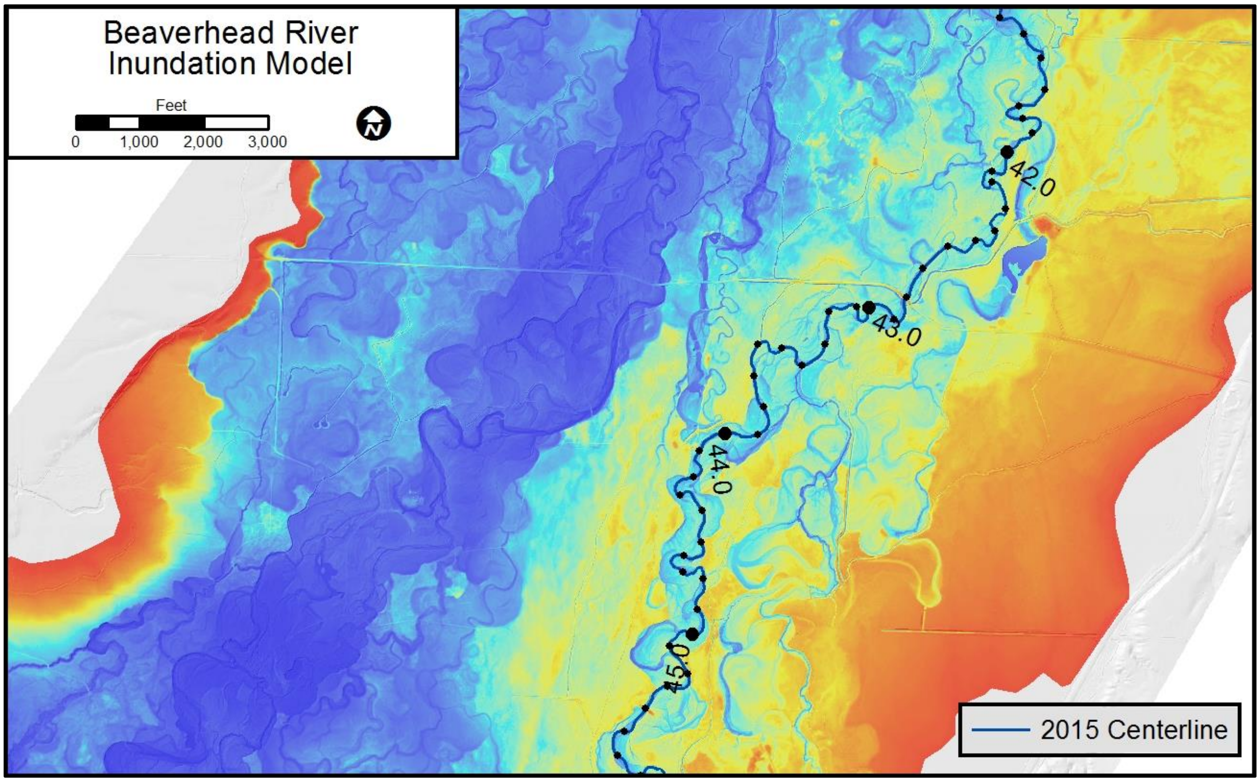

Figure 29. Example Inundation Modeling results. Colors represent elevations relative to the elevation of the main channel. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

3.6 Avulsion Hazard Mapping

Avulsion hazards can be difficult to identify on broad floodplains, because an avulsion could occur virtually anywhere on the entire floodplain if the right conditions were to occur. Avulsion pathways were identified and mapped using criteria that identify a relatively high propensity for such an event. These criteria usually include the identification of high slope ratios between the floodplain and channel, perched channel segments, and the presence of relic channels that concentrate flow during floods. These features were identified for the Beaverhead River project reach using aerial photos and inundation modeling results.

Features that can help determine avulsion hazard areas include (WSDE, 2010):

- Low, frequently flooded floodplain areas with relic channels
- Past meander-bend cutoffs
- Main channel aggradation, particularly medial bar formation or growth, in the upstream limb of a bend
- Lower elevation of relict channel than active channel bed
- Present and former distributary channels on alluvial fans, deltas, and estuaries
- Channels that diverge from the main channel in a downstream direction
- Creeks that run somewhat parallel to main channel

Where available, the GIS-based inundation model discussed in Section 3.5 was used to help identify potential avulsion pathways. These pathways were identified as low continuous swales with connectivity to the river (Figure 30). Additional information used in mapping avulsion paths included oblique photos from Kestrel Aerial Services and air photos.

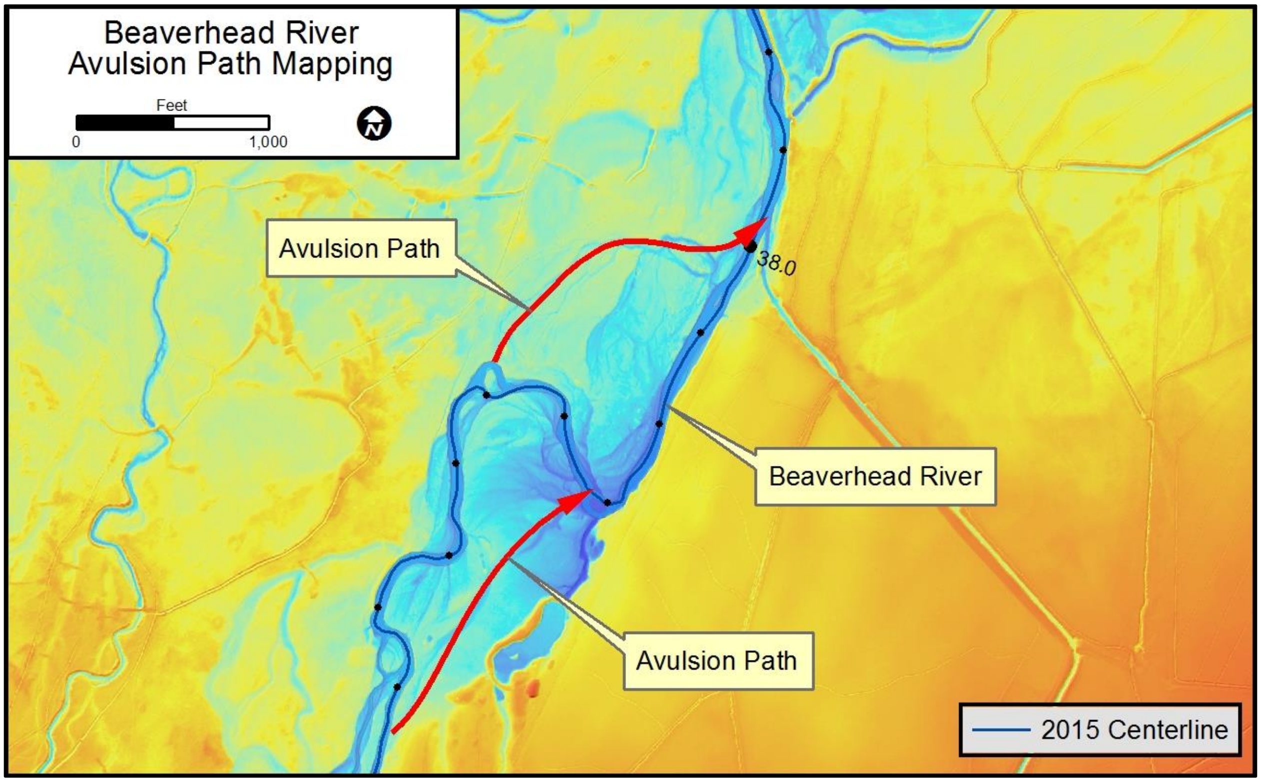

Figure 30. Example use of LiDAR to map avulsion pathways.

4 Results

The Channel Migration Zone (CMZ) developed for the Beaverhead River is defined as a composite area made up of the existing channel, the historic channel since 1955 (Historic Migration Zone, or HMZ), and an Erosion Hazard Area (EHA) that encompasses areas prone to channel erosion over the next 100 years. Areas beyond the EHA that pose risks of channel avulsion comprise the Avulsion Hazard Zone (AHZ). Lastly, those areas where migration has been restricted are highlighted as Restricted Migration Area (RMA).

4.1 Project Reaches

As described in Section1.1, the approach to CMZ mapping used here includes a reach-scale evaluation of channel migration rates. For the 83 miles of project length, the river was broken into 15 reaches based on geomorphic character such as river pattern, rates of change, geologic controls, etc. (Figure 32). The reaches range in length from 1.0 to 12.7 miles (Table 2).

Table 2. Beaverhead River reaches.

Reach	Start RM	End RM	Length
Reach 1	0	2.2	2.8
Reach 2	2.2	5	2.8
Reach 3	5	10.6	5.6
Reach 4	10.6	12.0	1.4
Reach 5	12.0	14.7	2.7
Reach 6	14.7	15.7	1.0
Reach 7	15.7	28.4	12.7
Reach 8	28.4	36.2	7.8
Reach 9	36.2	42.8	6.6
Reach 10	42.8	52.4	9.6
Reach 11	52.4	56.75	4.35
Reach 12	56.75	63.6	6.85
Reach 13	63.6	67.85	4.25
Reach 14	67.85	72.6	4.75
Reach 15	72.6	83.3	10.7

4.1 The Historic Migration Zone (HMZ)

The Historic Migration Zone (HMZ) is created by combining the bankfull polygons for each time series into a single HMZ polygon. The bankfull channel boundaries are the boundary between open channel and off-stream areas, including woody vegetation stands, vegetated floodplains, terrace margins, or bedrock valley walls. Thus, the HMZ contains all unvegetated channel threads that are interpreted to convey water under bankfull conditions (typical spring runoff), and as such, the zone has split flow segments and islands. Many of the larger islands have not had any active river channels since 1955, yet are included in the historic footprint of the HMZ. This inclusion of islands reflects the fact that the HMZ incorporates the entire river corridor area occupied by the Beaverhead River from 1955-2013. In some settings, where island areas are non-erodible, it may be appropriate to exclude these features from the CMZ. In the case of the Beaverhead River, these areas are comprised of young alluvial deposits in the active stream corridor that are prone to reworking and avulsion; hence, they have been retained in the CMZ.

Any side channels that have not shown unrestricted connectivity to the main channel since 1955 were not mapped as active channels hence are not included in the HMZ. This includes Poindexter Slough, which was manually reconnected to the river on its upper end and has a headgate at its inlet.

For this study, the Historic Migration Zone is comprised of the total area occupied by Beaverhead River channel locations in 1955, 1979, 2013 and 2015 (Figure 31). The resulting area reflects 60 years of channel occupation.

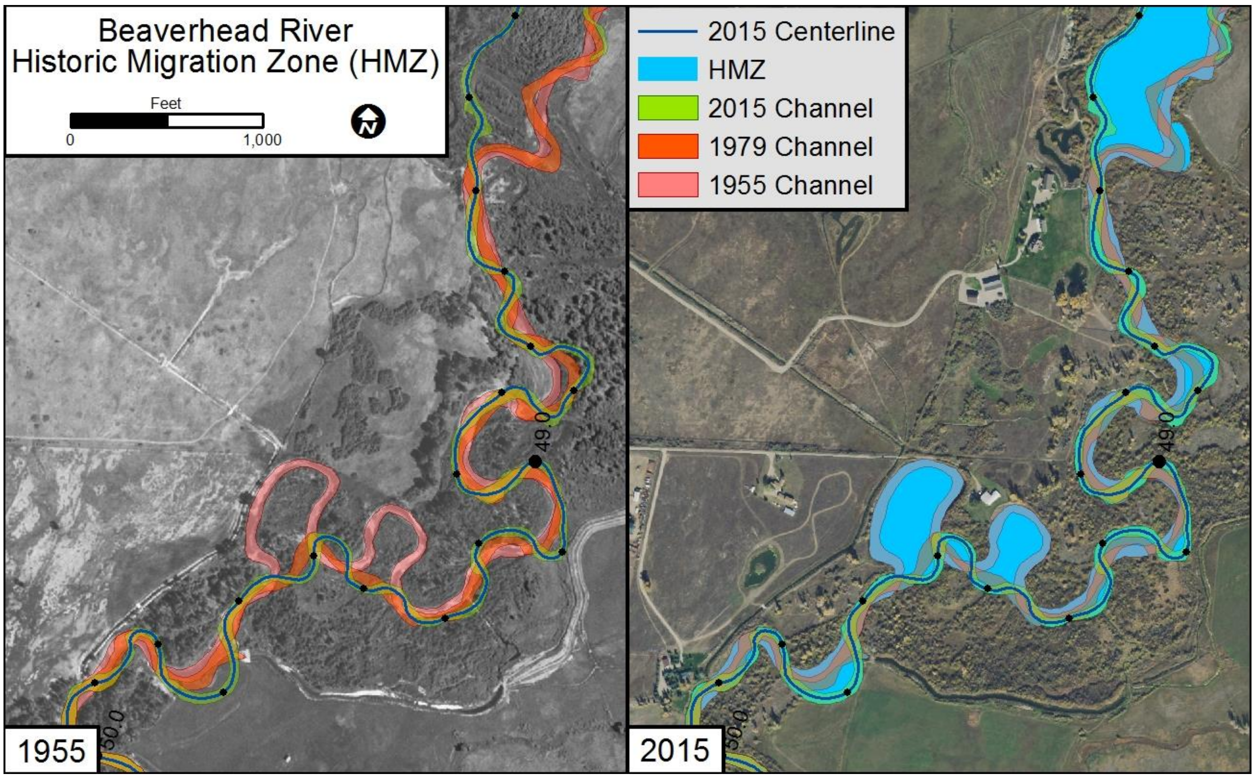

Figure 31. The Historic Migration Zone (HMZ) is the combined footprint of all mapped channel banklines.

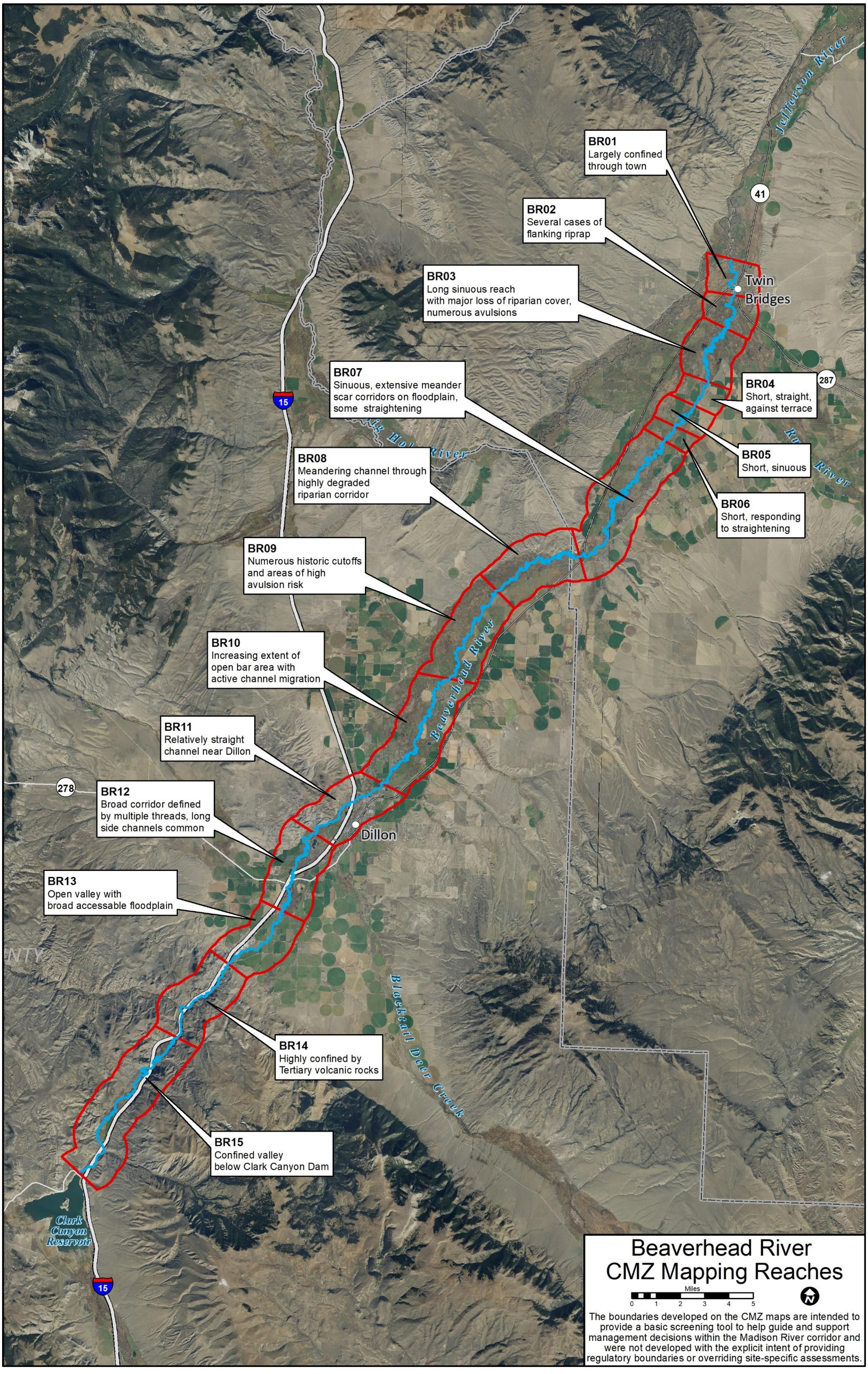

Figure 32. Reaches

4.2 The Erosion Hazard Area (EHA)

The EHA is based on measured migration rates. Within the GIS, migration distances were measured where it was clear that the migration was progressive lateral movement versus an avulsion. A total of 1,953 measurements were made through the project length where a bank had migrated at least 20 feet since 1955. The 20-foot minimum was selected as an easily measurable distance that was not compromised by the resolution of the data. The migration distances vary substantially both within and between reaches, with several reaches showing over 150 feet of bank migration since 1956 (Figure 34).

The mean migration distances were used to generate a mean annual migration rate for each reach (Table 3). This in turn defined the erosion buffer width, which allows for 100 years of continual bank movement at the mean annual rate. The erosion buffer widths assigned to each reach are shown in Figure 35, and range from 64 to 163 feet in width. The erosion buffer width, when applied to the 2015 bankline, defines the Erosion Hazard Area (EHA). This area is considered prone to channel occupation over the life of the CMZ (100 years).

This reach-scale assessment acknowledges that predicting movement at single sites over the next century is at best difficult due to the non-linear nature of channel migration. As such, the erosion buffer is assigned to all banks, even those not currently eroding, to allow future bank movement at any given location. This is consistent with the Reach Scale approach outlined by the Washington State Department of Ecology (WSDE, 2010).

The general approach to determining the Erosion Buffer (using the annual migration rate to do define a 100 year migration distance) is similar to that used in Park County (Dalby, 2006), on the Tolt River and Raging River in King County, Washington (FEMA, 1999), and as part of the Forestry Practices of Washington State (Washington DNR, 2004).

An example of EHA mapping is shown in Figure 33. If the EHA extends into the Historic Migration Zone, it is masked by the HMZ so that areas of historic channel locations are prioritized in the mapping hierarchy. As a result, the EHA is typically discontinuous along the river.

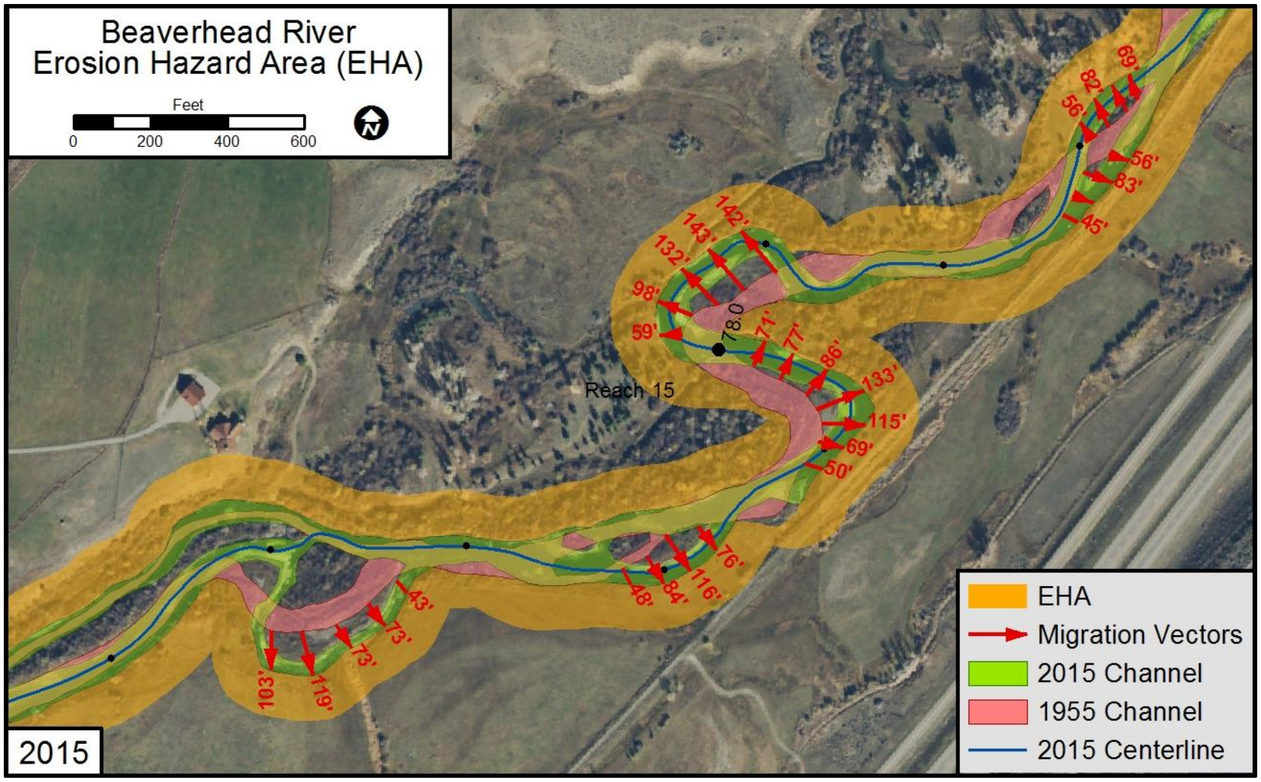

Figure 33. The Erosion Hazard Area (EHA) is a buffer placed on the 2015 banklines based on 100 years of channel migration for the reach.

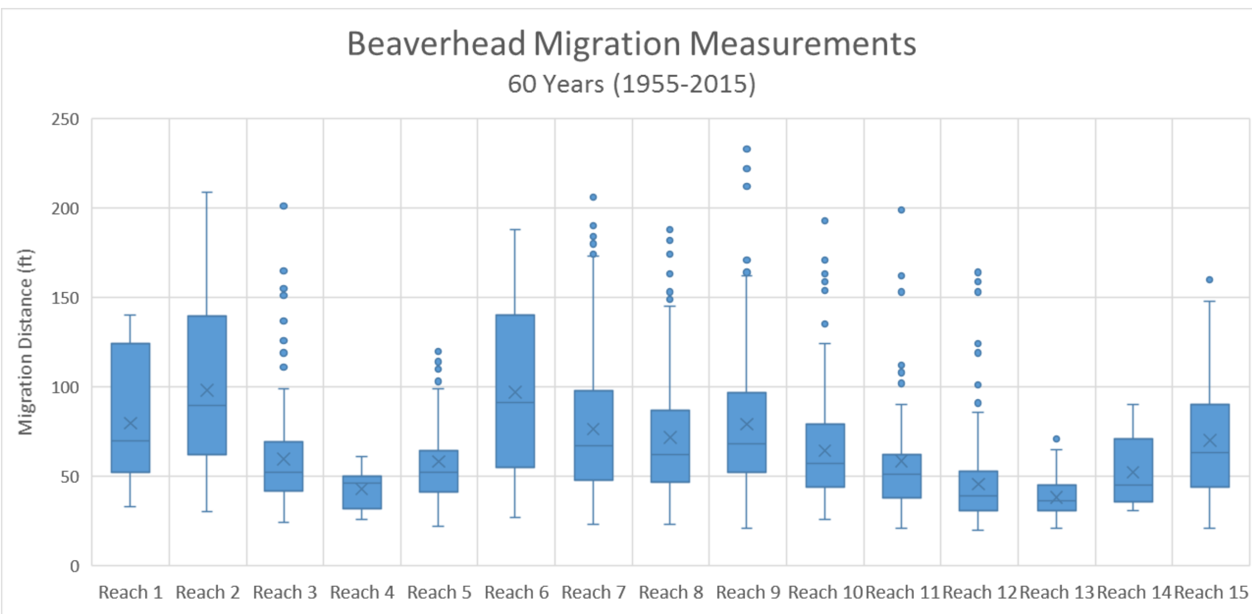

Figure 34. Distribution of migration measurements by reach.

Table 3. Reach-based summary of migration measurements.

Reach	Number of Measurements	Average Length (ft) (1955-15)	Minimum Length (ft)	Maximum Length (ft)	Average Annual Migration Rate (ft/yr)	100 Year Buffer (ft)
Reach 1	23	79.6	33	140	1.3	133
Reach 2	72	98.1	30	209	1.6	163
Reach 3	168	59.7	24	201	1.0	99
Reach 4	14	43.0	26	61	0.7	72
Reach 5	94	58.2	22	120	1.0	97
Reach 6	42	97.0	27	188	1.6	162
Reach 7	340	76.3	23	209	1.3	127
Reach 8	214	71.8	23	188	1.2	120
Reach 9	140	79.1	21	233	1.3	132
Reach 10	254	64.3	26	193	1.1	107
Reach 11	66	58.7	21	199	1.0	98
Reach 12	206	45.7	20	164	0.8	76
Reach 13	58	38.2	21	71	0.6	64
Reach 14	23	52.2	31	90	0.9	87
Reach 15	239	70.2	21	162	1.2	117

The 100-year buffer distance was calculated as 100 times the annual mean migration rate for each entire reach (Table 3). Table 3 shows that in several reaches, the 100-year erosion buffer is less than the maximum migration distance. This shows that there are areas where very rapid bank migration has occurred, and that the Erosion Hazard Area may be locally eroded through over the next 100 years. Typically, however, these areas of rapid bankline movement are within the Historic Migration Zone, and thereby captured in the CMZ. In a broader sense, it shows that the Erosion Hazard Area is a relatively conservative estimate of erosion risk.

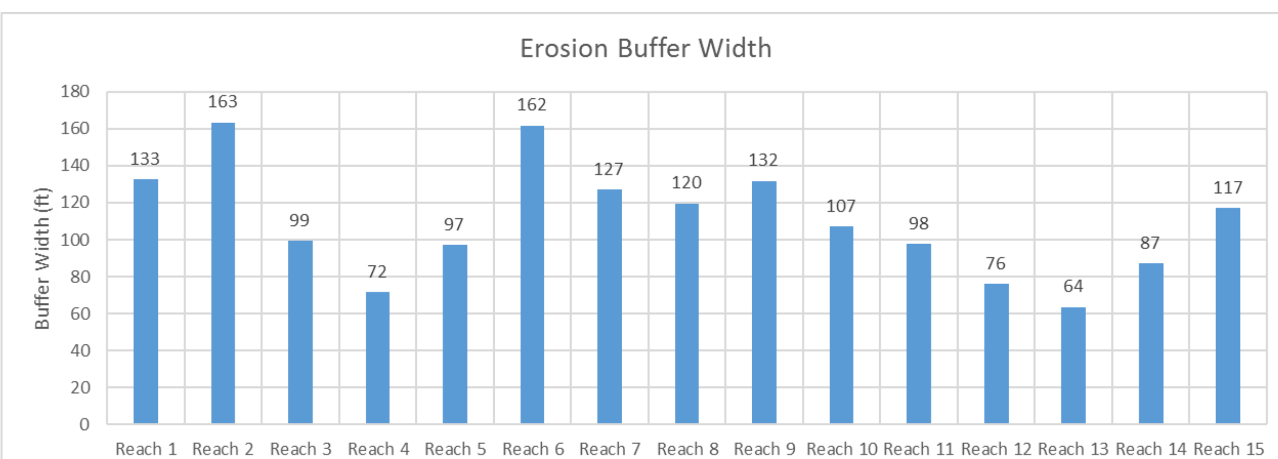

Figure 35. Erosion buffer widths assigned to 2015 bankline margins to define Erosion Hazard Area (EHA).

4.3 The Avulsion Hazard Area (AHZ)

The Avulsion Hazard Zone (AHZ) includes the areas of the river landscape, such as secondary channels, relic channels, and swales that are at risk of channel occupation outside of the Historic Migration Zone (HMZ).

Avulsions are common on the Beaverhead River, especially as bendway cutoffs (Figure 36). Though there are several locations where the river has avulsed into a former channel, abandoning the original river course (Figure 37). As such, the scale of avulsions can range from tens of feet to thousands of feet. The historic avulsions are clearly defined by the bankline mapping, and are an important component of the Historic Migration Zone. The patterns of the historic avulsions were also used to help identify areas where future avulsions are most likely.

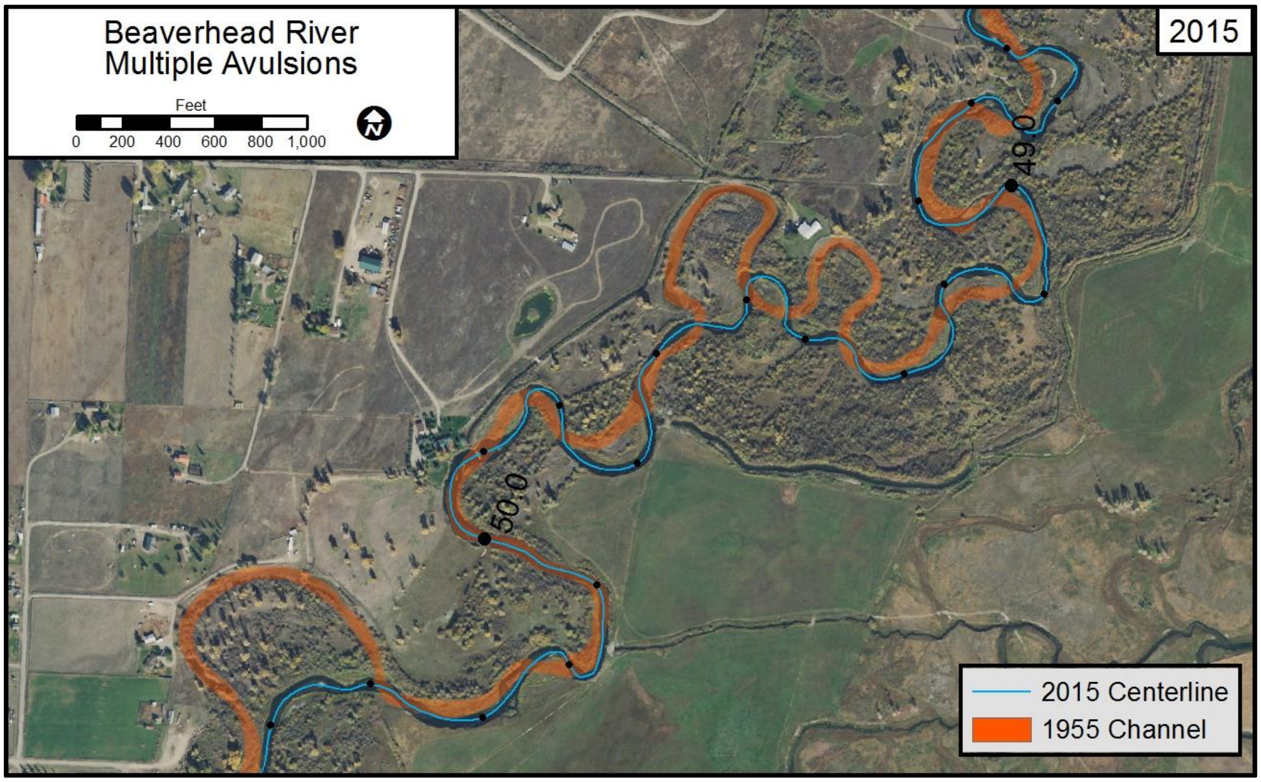

Figure 36. Multiple bendway cutoff avulsions in Reach 10.

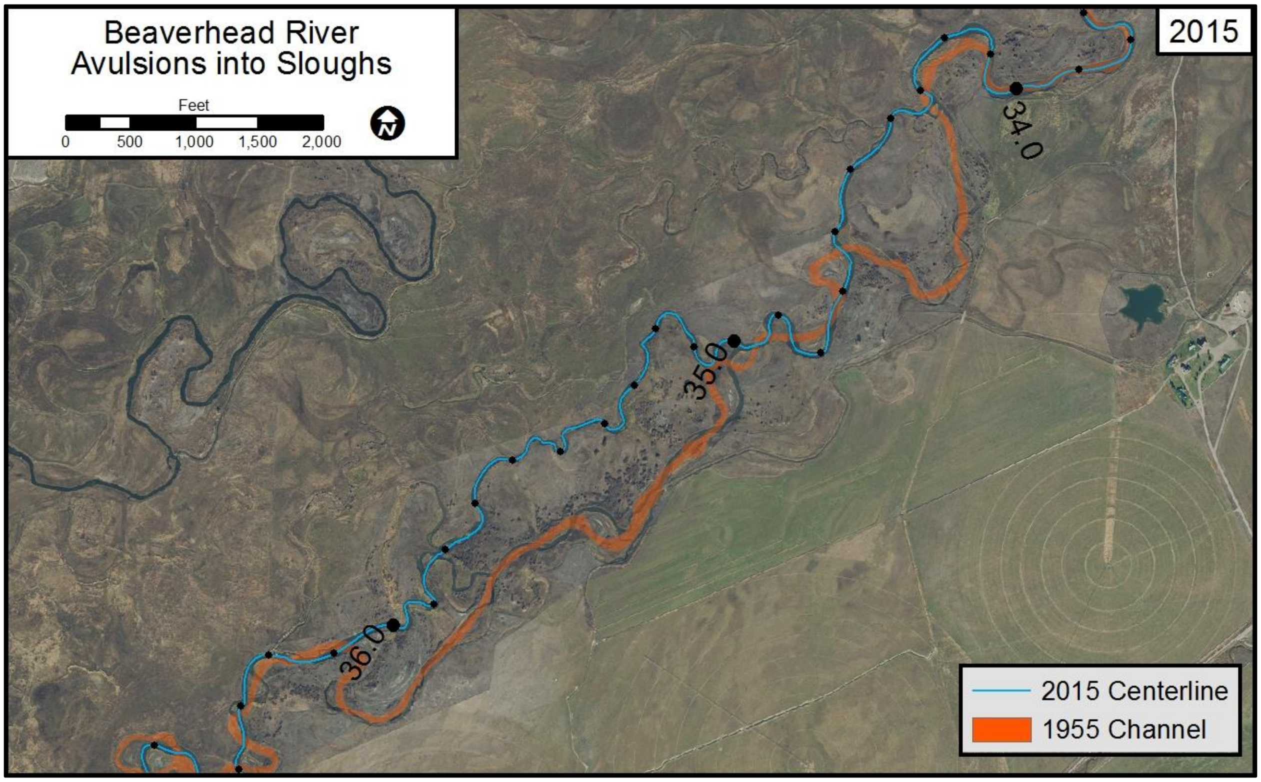

Figure 37. Multiple avulsions into historic channels in Reach 8.

The results of the avulsion hazard mapping can be seen on individual map sheets. In many locations, the AHZ creates a relatively smooth belt width corridor for the CMZ, and in others it extends out well beyond the core of the active meander belt.

4.4 The Restricted Migration Area (RMA)

The extent of migration area that is restricted by physical features is largely dependent on the proximity of transportation infrastructure to the channel. The highway and railroad embankments locally encroach well into the CMZ, especially in Clark Canyon (Figure 38). By comparison, bank armor restricts a fairly small portion of the CMZ.

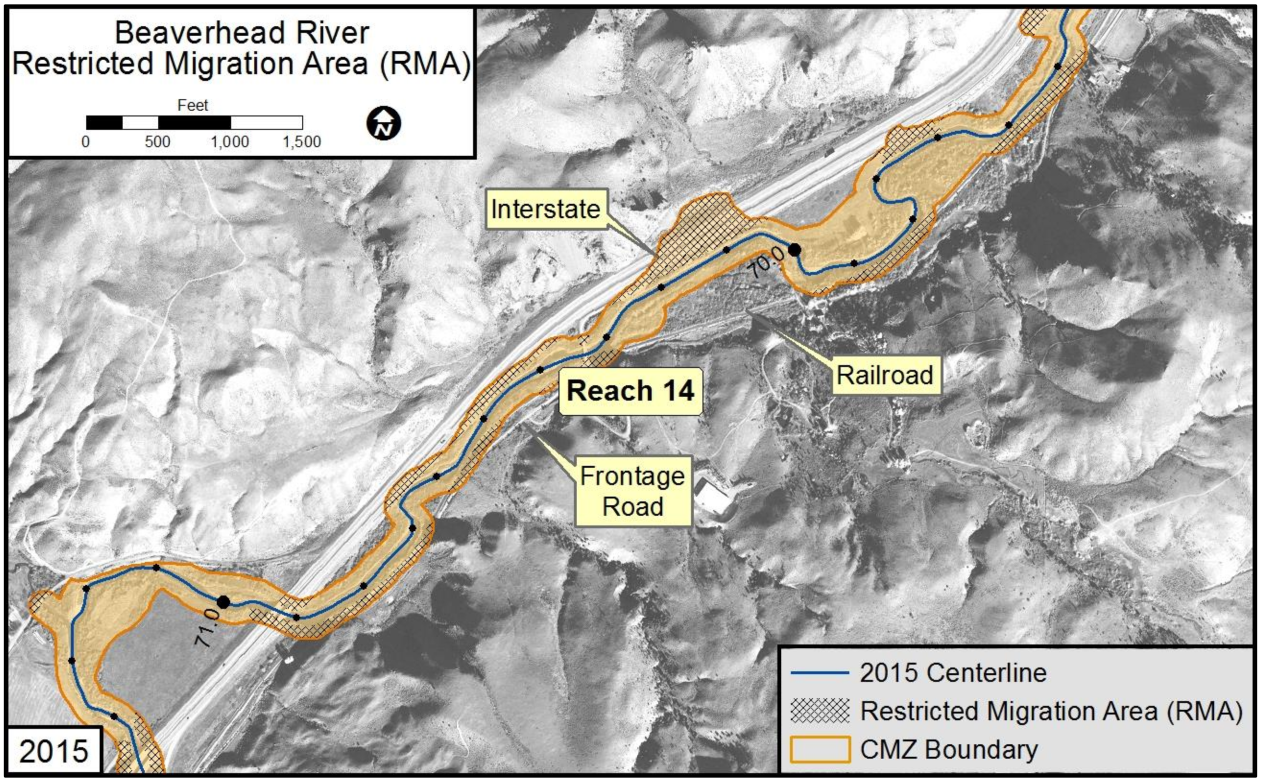

Figure 38. Restricted Migration Areas in Clark Canyon.

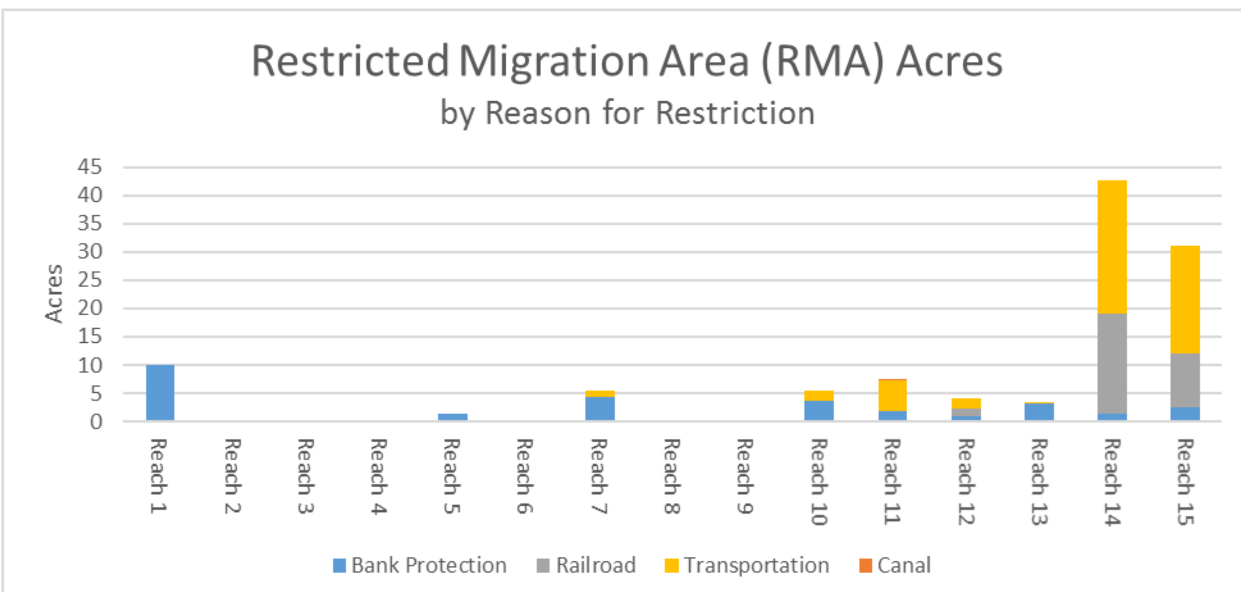

Figure 39. Acres of the CMZ mapped as restricted by reach.

Figure 40 shows that the extent of banks that were mapped as armored ranges from 0% to 15% of the total bankline in any given reach. Four reaches contained no visible armor. The densest armor is in Reach 14 in Clark Canyon, where about 15% of the total bankline is armored to largely protect transportation infrastructure.

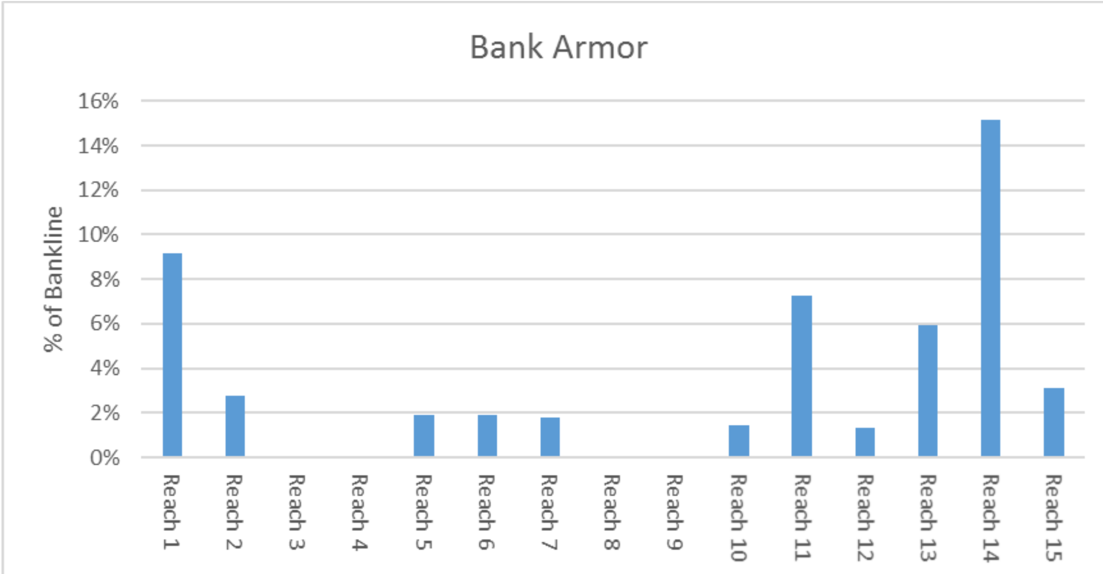

Figure 40. Percentage of bankline protected by armor by reach.

4.5 Composite Map

An example portion of a composite CMZ map for a section of the Beaverhead River project reach is shown in Figure 41.

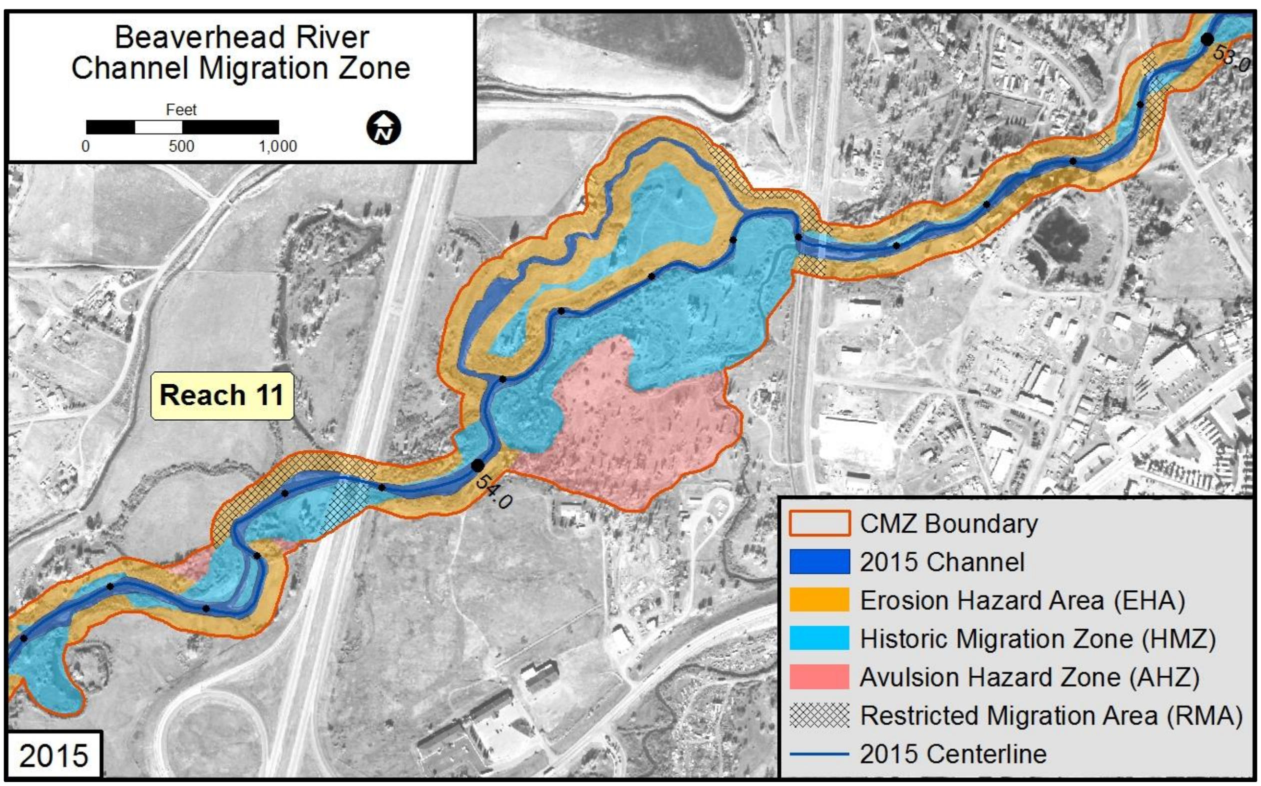

Figure 41. Composite Channel Migration Zone map.

4.1 Geologic Controls on Migration Rate

Many CMZ mapping efforts incorporate a Geotechnical Setback on valley walls, which is an area of expanded EHA against geologic units that may be prone to geotechnical failure. In Clark Canyon, the presence of active landslides on the valley edge and floor indicate that the CMZ could indeed be altered by hillslope failure. That said, defining an appropriate setback for these processes is difficult at best and may reflect more stochastic processes than have been used to develop the CMZ. As a result, Geotechnical Setbacks have not been incorporated into the EHA, and incorporating the potential for mass failure on hillslopes was considered beyond the scope of this effort.

5 CMZ Mapping Results by Reach

The following sections summarize the mapping results for each reach of the Beaverhead River. The reaches are numbered sequentially from downstream to upstream to allow the potential extension of the mapping above Clark Canyon Reservoir in the future. To best describe the downstream trends in geomorphology and mapping results, they are described below in the opposite order, starting with Reach 15 at Clark Canyon Dam and ending with Reach 1 at Twin Bridges. The maps can be found in Appendix D.

Note: Many of the reach descriptions, below, reference River Miles (RMs), which refer to the distance upstream from Twin Bridges along the 2015 channel centerline. River Miles are labeled on the maps in Appendix D

5.1 Reach 15

Reach 15 extends approximately 10.7 miles downstream from the Clark Canyon Dam. The valley bottom width ranges from about 200 feet to over half a mile, depending on geologic controls and transportation infrastructure encroachment. The valley walls consist of Tkb conglomerates (Beaverhead Group), with some local landslides. One large landslide is located across from the mouth of Canyon Creek at RM 81.7, deflecting the stream corridor to the east (Figure 42). Canyon Creek is known to deliver high volumes of fine sediment from a landslide-ridden volcanic watershed; when it is running high and turbid, it creates a major concern for the Beaverhead fishery, especially when the Beaverhead is running low.

The river is relatively dynamic in less confined areas of Reach 15, with meander development and cutoffs common. Immediately below the dam, the river is confined by coarse colluvial deposits and river terraces, and there has been some relocation/straightening of the historic channel, such as at RM 82.2, where a large meander visible in the 1955 imagery was cut off by Interstate construction (Figure 42). At RM 79, an avulsion over a half-mile long that occurred sometime between 1979 and 2013, and active bendway cutoffs can be seen on the photos and imagery (Figure 43). The natural floodplain of the river is bisected by the old railroad grade that forms a defacto floodplain levee through much of Reach 15. Since the river is eroding into the abandoned railroad berm, it remains within the CMZ. Just upstream of Pipe Organ, two very large and mature bendways have generated a wide avulsion hazard area due to their configuration and the potential for major channel shortening. From Pipe Organ to the lower end of the reach, avulsions have been relatively common.

	Reach 15
Downstream/Upstream RM	72.6/83.3
Length	10.7 miles
General Location	Clark Canyon Dam outlet to confined canyon reach.
Mean 60-year Migration Distance	70.2
Max 60-year Migration Distance	162
100-year Buffer	117

Figure 42. View downstream below Clark Canyon Dam showing 1955 meander isolated by interstate bridge and major landslide crossing river valley just downstream. (Kestrel)

Figure 43. View downstream from RM 80 showing an active avulsion/cutoff on the near meander and a pre-2013 avulsion in the distance. (Kestrel)

5.2 Reach 14

Reach 14 is a highly confined ~8-mile long river segment that extends from about 1.5 miles upstream of Grasshopper Creek to Barretts Diversion. From Grasshopper Creek down to Barretts, the valley is bound entirely by Tertiary volcanic rocks; upstream of that there are some older sedimentary rocks exposed in the west valley wall. In this area upstream of Grasshopper Creek, the right valley wall has been terraced and the left valley wall excavated to make room for transportation infrastructure (Figure 44). The 1955 channel was relocated in three places to accommodate the interstate (RM 69.3, 69.6, and 70.1). At one of these locations (RM 69.6), riprap protecting the Interstate embankment appears to be flanking on its upstream end. Bartholomew and others (1999) mapped active landslides on both sides of the river near Grasshopper Creek, and in their work concluded that landslides in Clark Canyon have periodically blocked, constricted, or diverted to the river.

	Reach 14
Downstream/Upstream RM	67.85/72.6
Length	4.75 miles
General Location	Confined canyon upstream of Barretts diversion.
Mean 60-year Migration Distance	52.2
Max 60-year Migration Distance	90
100-year Buffer	87

Because of the geologic controls, only 23 migration measurements were made in Reach 14. The 100-year buffer width, which is 87 feet, was largely clipped out as restricted migration area or geologic control. At Barretts Diversion, the river crosses over the projected trace of the Blacktail Fault, entering the main Beaverhead River Valley. This distinct transition is marked by a prominent outcropping of Tertiary volcanic rocks, which some identify as the actual Beaverhead Rock described by Lewis and Clark (Alt and Hyndman, 1997).

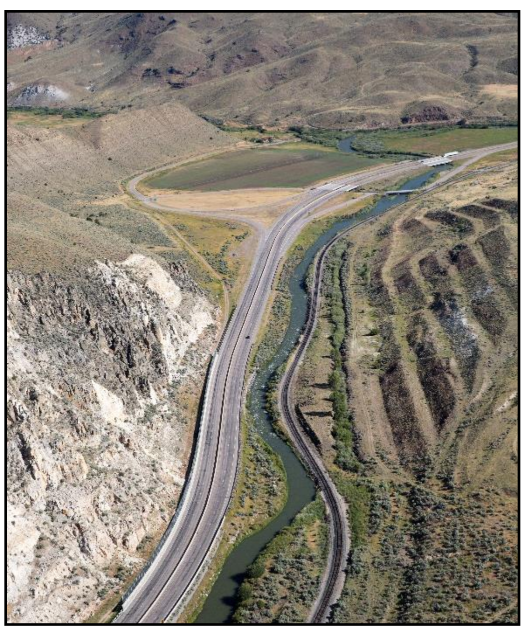

Figure 44. View downstream towards Grasshopper Creek showing Paleozoic-age sandstones on left valley wall, terraced right valley wall; an active landslide can be seen in distance at mouth of Grasshopper Creek (hummock ground surface).

Figure 45. View downstream of Barretts diversion and location of projected trace of Blacktail Fault. (Kestrel)

5.3 Reach 13

Just downstream of Barretts Diversion, Reach 13 marks the entrance of the Beaverhead River into the Beaverhead River Valley. Although this emergence from the canyon includes an abrupt loss of confinement, Reach 13 is somewhat unique in that it is geologically controlled by Pleistocene-age alluvial fans formed on Rattlesnake and Blacktail Deer Creeks (Section 2.2; Figure 16). As a result, the reach is less dynamic than reaches downstream. The reach is also affected by land uses adjacent to the channel; in upper Reach 13, Barretts Minerals operates a talc plant on the left bank of the river at RM 67. The site is used to process the talc that has been mined from open pits in marbles of the Ruby Mountains, and prepare it for shipping. The talc is then shipped by rail. With the talc plant on the left bank and irrigated land on the right bank, the river is moderately confined in the upper portion of Reach 13 (Figure 46).

	Reach 13
Downstream/Upstream RM	63.6/67.85
Length	4.25 miles
General Location	Barretts Diversion to Poindexter Slough
Mean 60-year Migration Distance	38.2
Max 60-year Migration Distance	71
100-year Buffer	64

Further downstream, the confinement is reduced and overflow channels are common, creating some broader avulsion hazard areas. The riparian corridor consists of scattered, low density stands of mature cottonwoods; there appears to be minimal cottonwood regeneration through the reach. In some areas, the loss in density and complexity of riparian vegetation since 1955 is striking (Figure 47).

Because of the geologic controls and low sinuosity in Reach 13, the CMZ is quite narrow with an erosion buffer width of 64 feet. The CMZ widens out locally in the lower portion of the reach where mappable overflow channels create potential avulsion sites. Reach 13 appears to have dampened rates of geomorphic change, likely due to the combined effects of alluvial fan encroachment, floodplain land uses, reduced peak flows from Clark Canyon Reservoir, and lost coarse sediment loads due to trapping at the reservoir.

Figure 46. View downstream (north) showing channel confinement between Barrett Talc Plant and armored irrigated fields. (Kestrel)

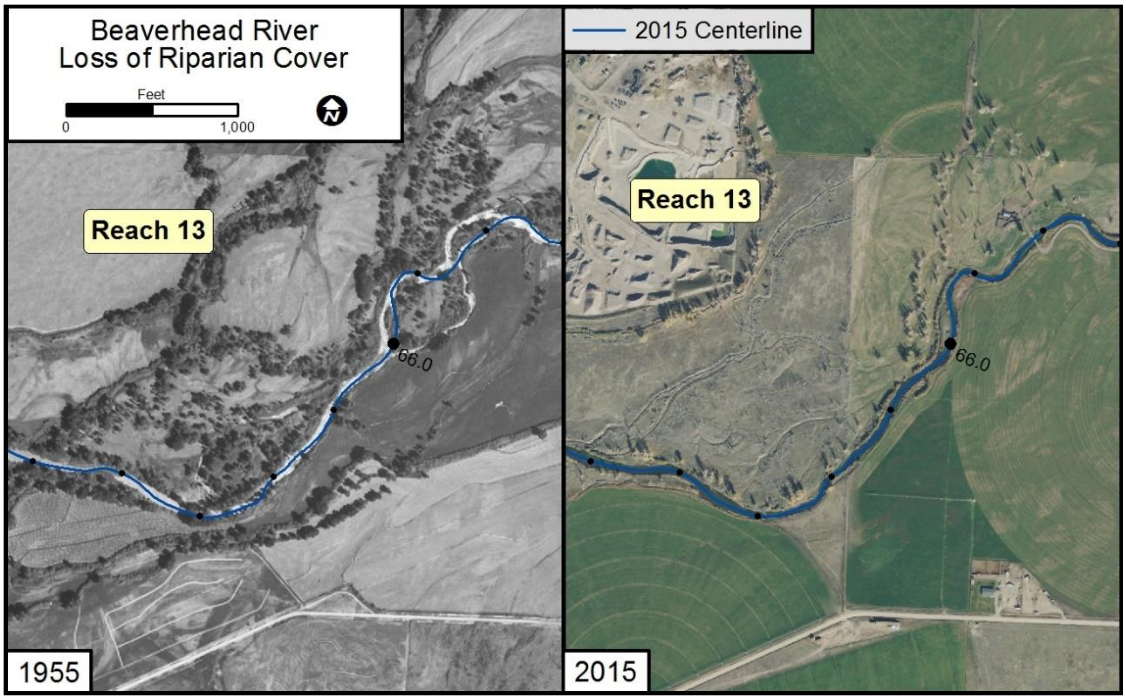

Figure 47. Loss of riparian cvover in Reach 13 from 1955 (left) to 2015 (right)

5.4 Reach 12

Reach 12 is located south of Dillon and consists of a broad river corridor with multiple channel threads. It includes Poindexter Slough, the upper end of which was artificially connected to the Beaverhead River between 1975 and 1995 to convey water through the a headgate, into an old side channel for several miles, and ultimately into the Dillon Canal. Poindexter Slough has recently undergone major restoration, with a new headgate constructed at its entrance to allow controlled flushing flows into the Slough. Because of the artificial excavation and the headgate control, Poindexter Slough was not mapped as a connected Beaverhead channel but rather treated essentially as an avulsion hazard. At RM 62.4, for example, a floodplain sliver that is about 30 feet wide separates the river from the slough (Figure 48); the right bank of the Beaverhead is armored at this site, but large flooding could potentially overtop into the slough and headcut back to the main river. Poindexter Slough adds over 350 acres to the CMZ.

	Reach 12
Downstream/Upstream RM	56.75/63.6
Length	6.85 miles
General Location	Poindexter Slough to Dillon.
Mean 60-year Migration Distance	45.7
Max 60-year Migration Distance	164
100-year Buffer	76

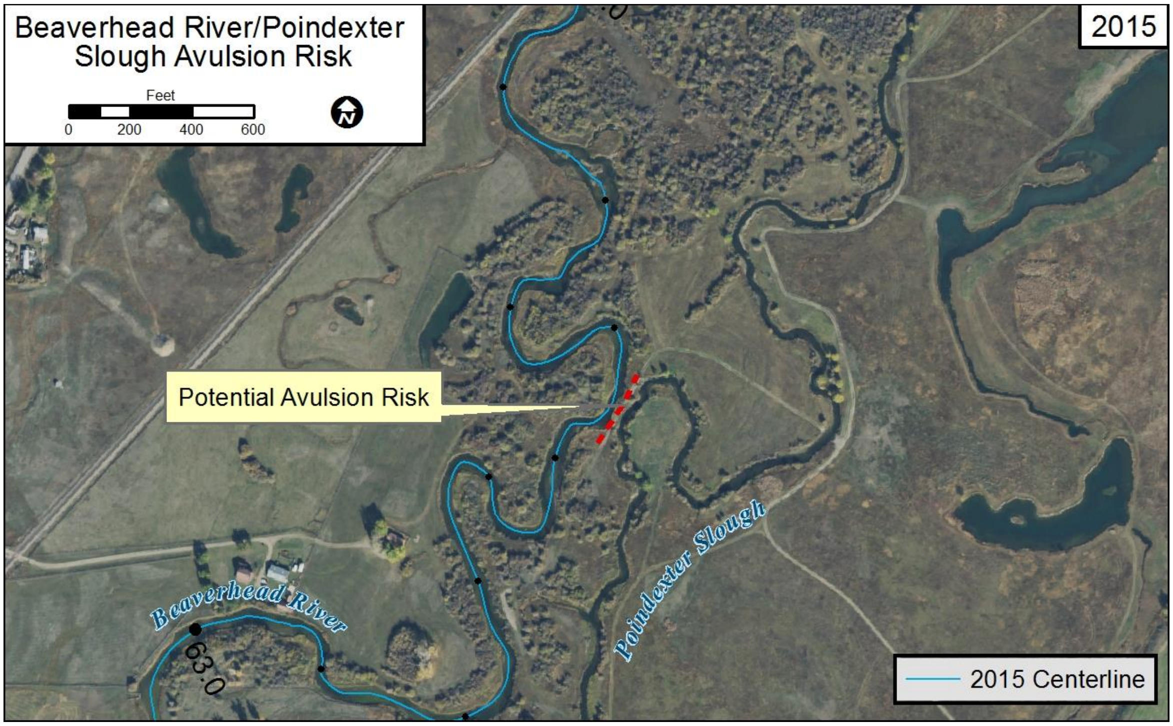

Figure 48. Area of potential avulsion risk of Beaverhead River into Poindexter slough, RM 62.4.

Figure 49. View downstream showing potential avulsion site between Beaverhead River (left) and Poindexter Slough (right). (Kestrel)

5.5 Reach 11

Reach 11 is located due west of Dillon, and within this reach the channel is notably straight, following volcanic rock exposures on the west valley wall (Figure 50). The reach is relatively straight with meander scars suggesting a long history of manipulation due to its proximity to town. Currently, the reach is most distinctly characterized by exurban development. There are several ponds adjacent to the river at RM 55 that pose some avulsion risk. Downstream of the I-15 Bridge, the CMZ widens substantially as the river enters a split flow reach that has an avulsion hazard area to the south at the mouth of Blacktail Deer Creek. The lowermost ~900 feet of Blacktail Deer Creek was an active side channel of the Beaverhead River in 1955. Just south of this old side channel, there are additional channels that are lower than the main thread and thus prone to capture.

	Reach 11
Downstream/Upstream RM	52.4/56.75
Length	4.35 miles
General Location	West of Dillon
Mean 60-year Migration Distance	58.7
Max 60-year Migration Distance	199
100-year Buffer	98

Figure 50. View downstream of Reach 11 showing exurban development and geologic control. (Kestrel)

5.6 Reach 10

Reach 10 starts just downstream of the Stodden Ditch Diversion and extends downstream to Anderson Lane Bridge. Being close to Dillon, it supports substantial exurban development, however it also has a locally broad and dense riparian corridor and active channel movement. There are numerous homes in the CMZ around RM 51. The HMZ in Reach 10 documents numerous bendway cutoffs and avulsions in the reach, which have markedly reduced channel length around RM 50 (Figure 52). The cutoffs commonly drive erosion on downstream meanders due to sediment delivery from the cutoffs. Several bendways have a high risk of avulsion in the near term, and a ~1,400 foot long avulsion occurred at RM 48.3 between 1979 and 2015 (perhaps during the 1984 flood). The floodplain complexity in Reach 10 is enhanced by 1955 channel remnants that form prominent swales on the floodplain (Figure 52). The erosion buffer width in Reach 10 is 107 feet, which the average for the project reach.

One striking aspect of Reach 10 is its perching above Albers Slough and other sloughs to the west. This perching is described in Section 2.2, and is especially evident in the inundation modeling output (Figure 17). At RM 44.1, a major historic channel historically connected the Beaverhead River to the sloughs to the west. This channel has been converted to a series of ponds, and a house has been recently constructed at its junction with the Beaverhead River (Figure 54).

Just downstream at RM 43.6, and irrigation structure is at risk of abandonment due to meander cutoff, as a chute channel is visible through the core of the meander (Figure 55). This situation is not uncommon on the river.

	Reach 10
Downstream/Upstream RM	42.8/52.4
Length	9.6 miles
General Location	Dillon to Anderson Lane bridge
Mean 60-year Migration Distance	64.3
Max 60-year Migration Distance	193
100-year Buffer	107

Figure 51. View downstream showing left bank development near Webster Lane. (Kestrel)

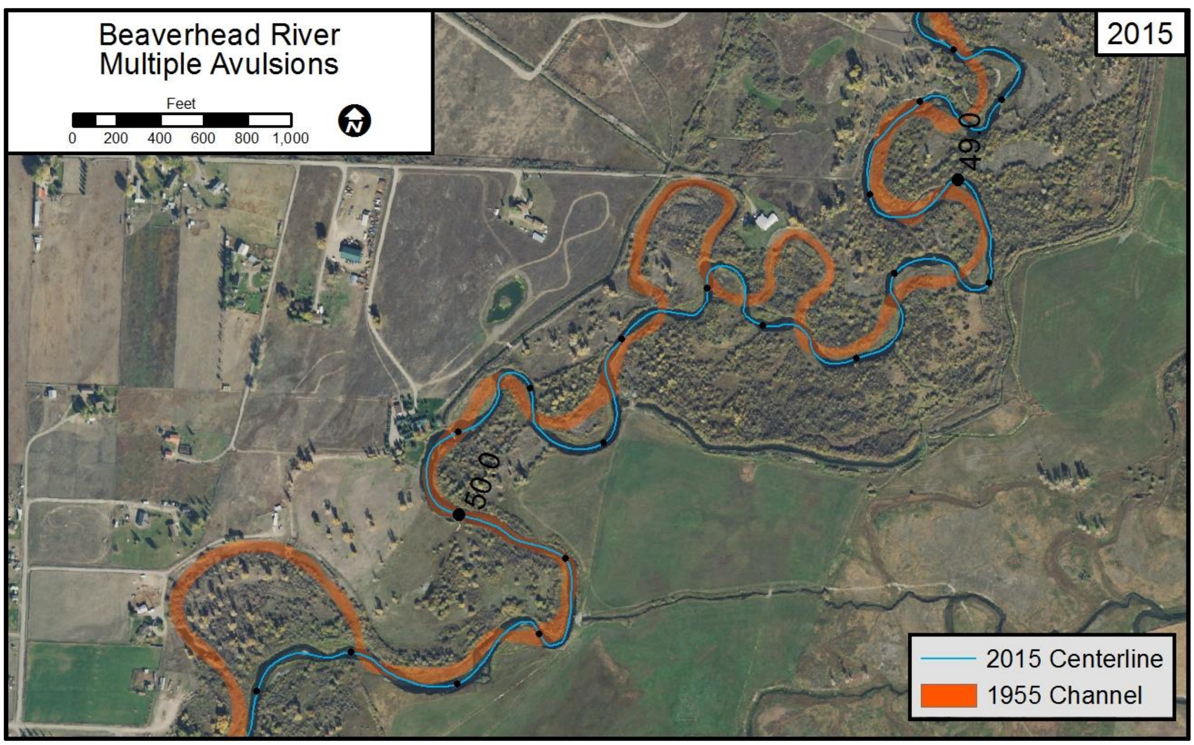

Figure 52. Series of meander cutoffs in Reach 10 between 1955 and 2015.

Figure 53. View downstream showing two 1955 oxbows, RM 49.4. (Kestrel)

Figure 54. View north showing new home and ponds in historic channel trace that connected the Beaverhead River to Albers Slough. (Kestrel)

Figure 55. View downstream at RM 43.6 showing diversion structure at risk of abandonment by bendway cutoff. (Kestrel)

5.7 Reach 9

Reach 9 consists of the 6.6 miles of river downstream of Anderson Lane Bridge, ending near Staudaher East Side Ditch. Immediately below the bridge the channel appears to have been straightened prior to 1955. The river locally flows against a low terrace on the east valley wall, but otherwise occupies a wide, broad floodplain. In general, Reach 9 hosts a meandering channel through a cottonwood corridor with variable tree densities. There are numerous historic cutoffs, avulsions, and areas of high avulsion risk (Figure 56). The entire reach shows a major loss of riparian cover since 1955 and 1979 (Figure 57).

	Reach 9
Downstream/Upstream RM	36.2/42.8
Length	6.6 miles
General Location	Anderson Lane Bridge to near Staudaher East Side Ditch
Mean 60-year Migration Distance	79.1
Max 60-year Migration Distance	233
100-year Buffer	132

Figure 56. View downstream showing area of 1979-2013 avulsion and active chute channel cutoff just beyond, RM 40.9. (Kestrel)

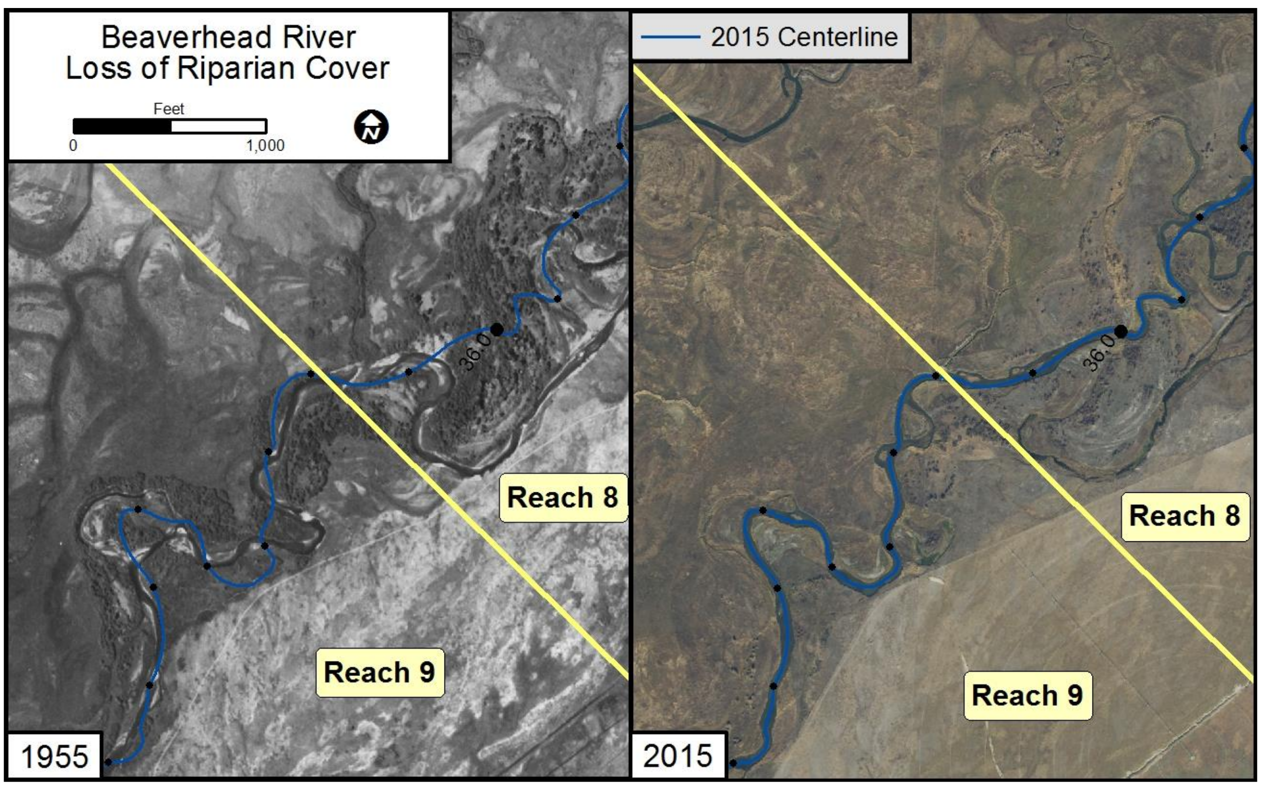

Figure 57. Loss of riparian cover in Reach 8 from 1955 (left) to 2015 (right).

5.8 Reach 8

Reach 8 extends from Staudaher East Side Ditch to Beaverhead Rock. It consists of a meandering channel that flows through a highly degraded riparian corridor. Albers Slough runs along the west valley wall. The reach hosts numerous large avulsions post-1979 that probably occurred during the 1984 flood (Figure 58 through Figure 60). The avulsion shown in may result in the abandonment of a point of diversion if the original channel is abandoned (Figure 59).

	Reach 8
Downstream/Upstream RM	28.4/36.2
Length	7.8 miles
General Location	Staudaher East Side Ditch to Beaverhead Rock
Mean 60-year Migration Distance	71.8
Max 60-year Migration Distance	188
100-year Buffer	120

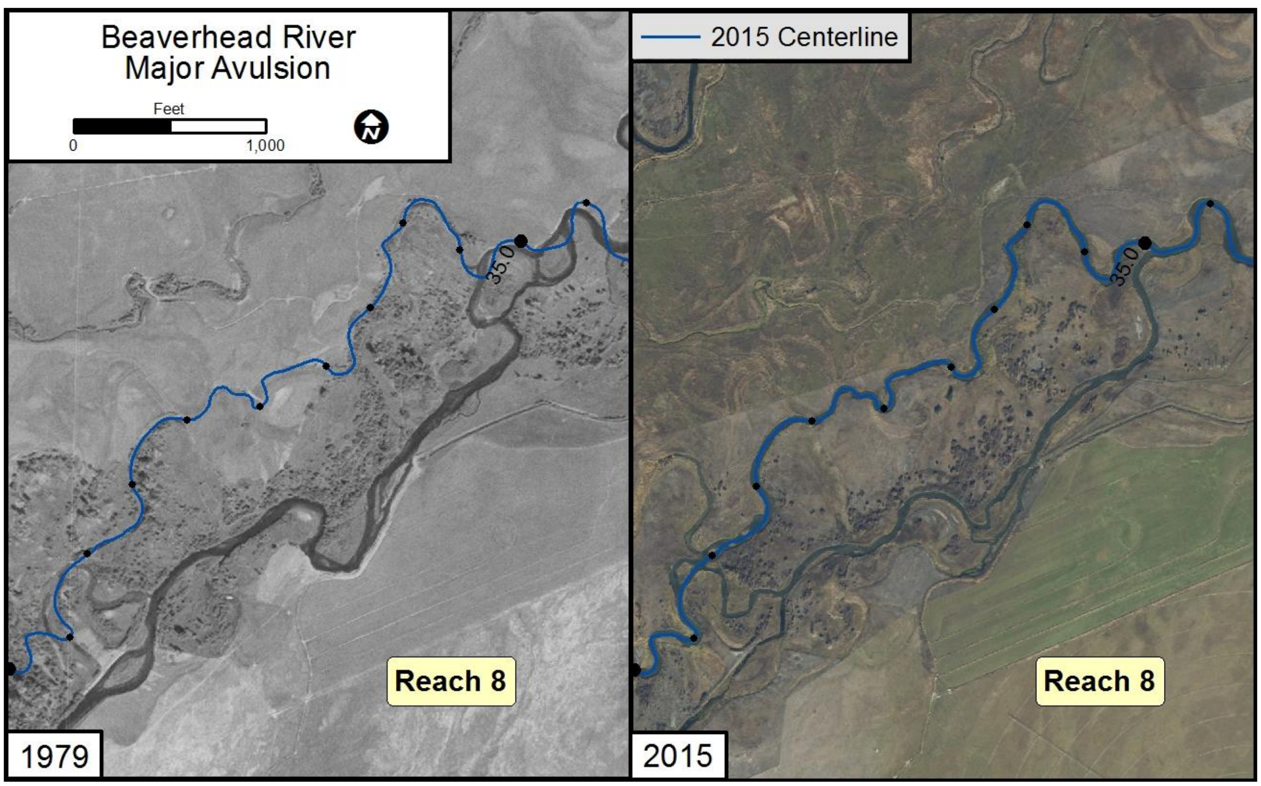

Figure 58. Reach 8 RM 35.8 avulsion site showing pre-avulsion on left (1979) and post-avulsion on right (2015).

Figure 59. View downstream showing area of 1979-2013 avulsion RM 35.8; new channel is to left. (Kestrel)

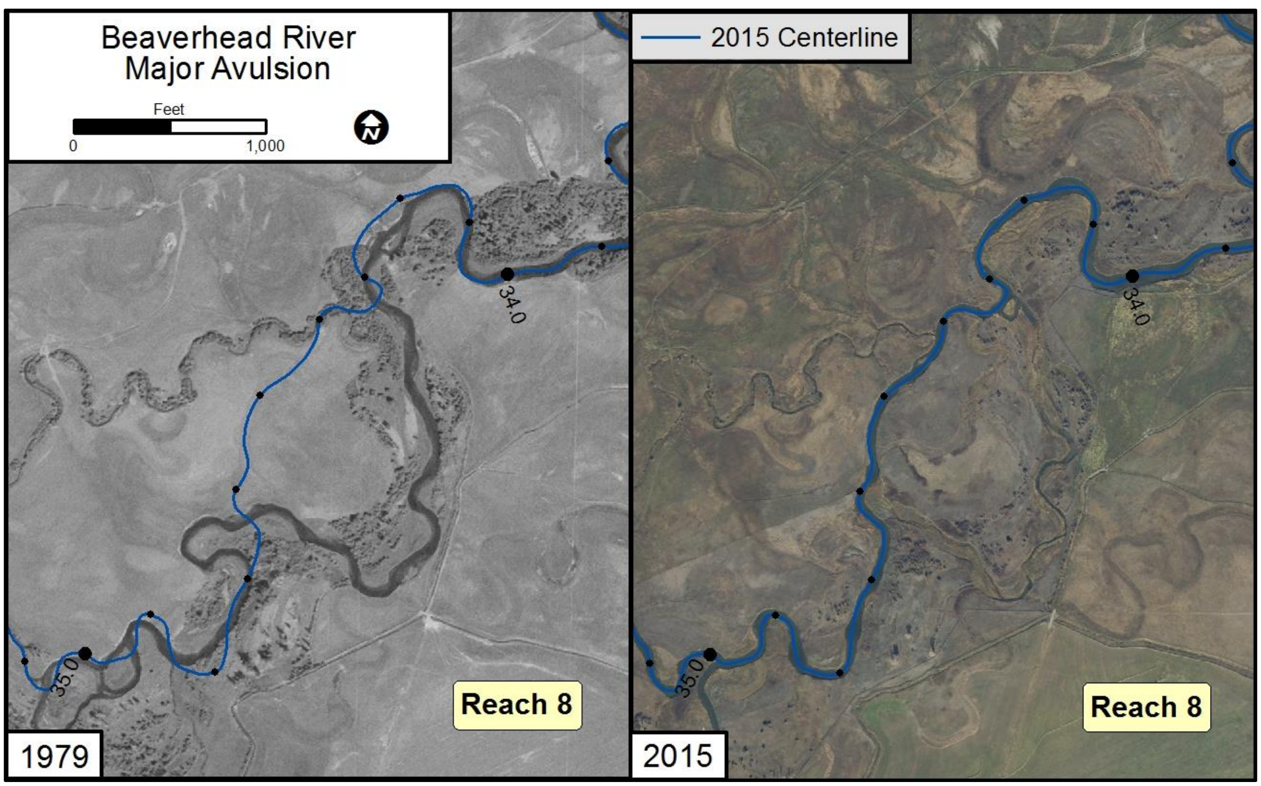

Figure 60. Reach 8 RM 34.6 avulsion site showing pre-avulsion on left (1979) and post-avulsion on right (2015).

5.9 Reach 7

Reach 7 extends downstream from Beaverhead Rock to Big Dry Gulch. Like Reach 8 upstream, it hosts a meandering channel within a highly degraded riparian corridor. The channel is markedly sinuous with extensive meander scars on the floodplain. At RM 24.7 a large meander/island complex is close to cutting off which will abandon two channels, each of which is over 1,000 feet long (Figure 61). Further downstream, there is a good example of an avulsion hazard at RM 17.7 where an older side channel provides a flow route that would shorten the main river by about 1,700 feet (Figure 62).

	Reach 7
Downstream/Upstream RM	15.7/28.4
Length	12.7 miles
General Location	Beaverhead Rock to Big Dry Gulch
Mean 60-year Migration Distance	76.3
Max 60-year Migration Distance	209
100-year Buffer	127

Figure 61. View downstream showing area of imminent cutoff (center of photo), RM 24.7. (Kestrel)

Figure 62. View downstream showing potential avulsion path through abandoned channel (right foreground), RM 17.7. (Kestrel)

5.10 Reach 6

Reach 6 is the shortest reach in the project area. It has been defined as a reach because it was historically straightened, and has since responded to that straightening by gaining length. The straightening occurred prior to 1955, as the 1955 air photo shows long channel remnants that appear to have been recently active. The 1955 channel course cuts straight through the old meander cores, and the 2015 banklines show active channel migration and recovery of channel length since. The 100-year buffer in Reach 6 is 162 feet which is very close to the maximum calculated in any reach (163 feet in Reach 2).

	Reach 6
Downstream/Upstream RM	14.7/15.7
Length	1.0 miles
General Location	Short reach below Big Dry Gulch (2.7 miles above Silver Bow Lane bridge) that is responding to channel straitening.
Mean 60-year Migration Distance	97.0
Max 60-year Migration Distance	188
100-year Buffer	162

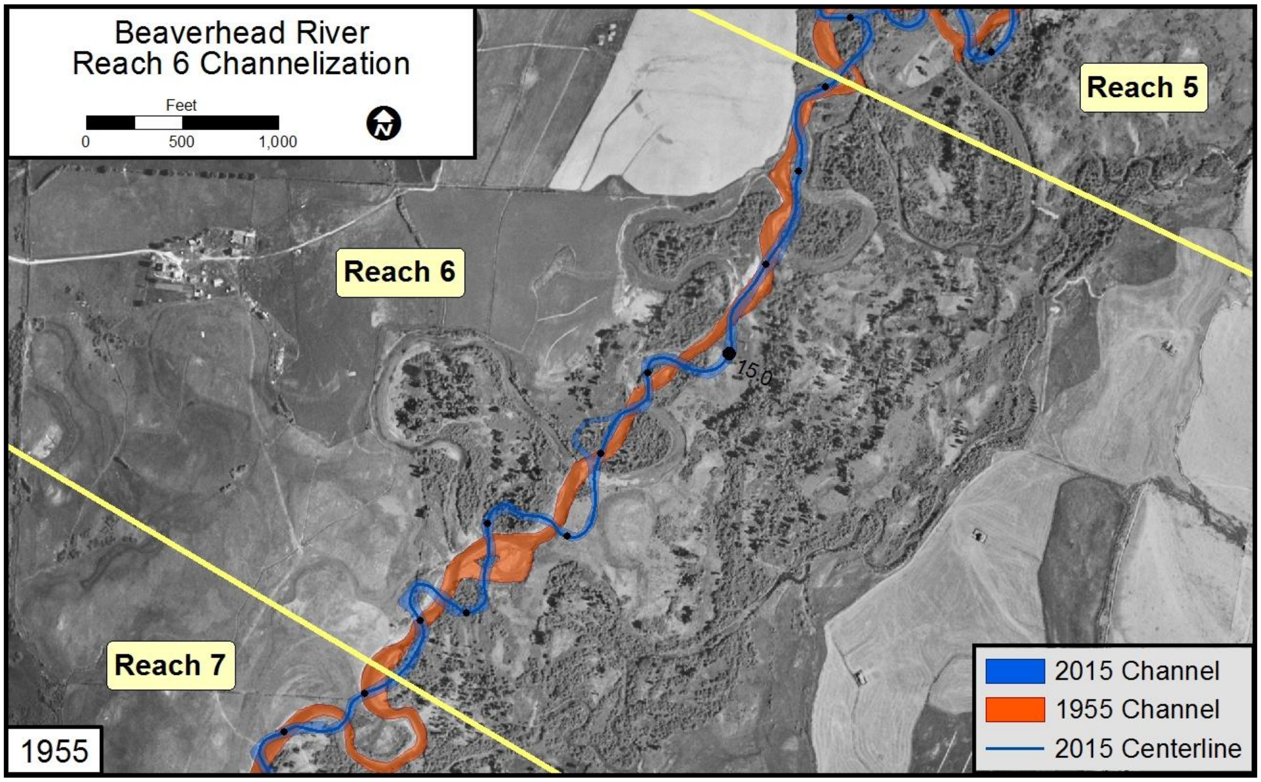

Figure 63. Pre-1955 channelization and subsequent migration, Reach 6 at RM 15.2. (Kestrel)

5.11 Reach 5

Reach 5 is less than 3 miles long and is located upstream of Silver Bow Lane. Like many other sections of the lower Beaverhead, there has been a dramatic loss of the riparian corridor since 1955. There is a very high avulsion risk at RM 13.5 that will shorten the channel by about a mile. On the lower end of the reach the channel is partially confined by a terrace on the east valley margin which has been clipped out of the CMZ (Figure 64).

	Reach 5
Downstream/Upstream RM	12.0/14.7
Length	2.7 miles
General Location	Silver Bow Lane bridge.
Mean 60-year Migration Distance	58.2
Max 60-year Migration Distance	120
100-year Buffer	97

Figure 64. View downstream of active erosion into low terrace on right bank (in distance), RM 12.3. (Kestrel)

5.12 Reach 4

Reach 4 is downstream of Silver Bow Lane Bridge. This channel segment closely follows the east terrace margin, such that migration rates are low and the CMZ is narrow (Figure 65).

	Reach 4
Downstream/Upstream RM	10.6/12.0
Length	1.4 miles
General Location	Below Silver Bow Lane bridge.
Mean 60-year Migration Distance	43.0
Max 60-year Migration Distance	61
100-year Buffer	72

Figure 65. View downstream of low terrace defining CMZ margin, Reach 4. (Kestrel)

5.13 Reach 3

Reach 3 extends from below Nye Road to the mouth of the Ruby River. The reach is unconfined and marks the coalescence of the Beaverhead River floodplain with those of the Big Hole and Ruby Rivers. It is a fairly long and sinuous reach with meander amplitudes that commonly reach 1,000 feet (Figure 66). At RM 9.5, the 1955 imagery shows an excellent example of an engineered bendway cutoff (Figure 67), which was probably undertaken to intentionally narrow the meanderbelt. Like other reaches, this area has experienced a major loss of riparian cover since 1955, with much of that loss occurring since 1979. Numerous avulsions were mapped in Reach 3 and several more avulsions are likely in the coming decades. At RM 5.0, the Beaverhead River is migrating eastward such that it will potentially capture the lower half mile of the Ruby River.

	Reach 3
Downstream/Upstream RM	5.0/10.6
Length	5.6 miles
General Location	Ruby River confluence to where the river leaves the terrace confinement on eastern valley margin.
Mean 60-year Migration Distance	59.7
Max 60-year Migration Distance	201
100-year Buffer	99

Figure 66. View downstream of Reach 3 high amplitude meander bends. (Kestrel)

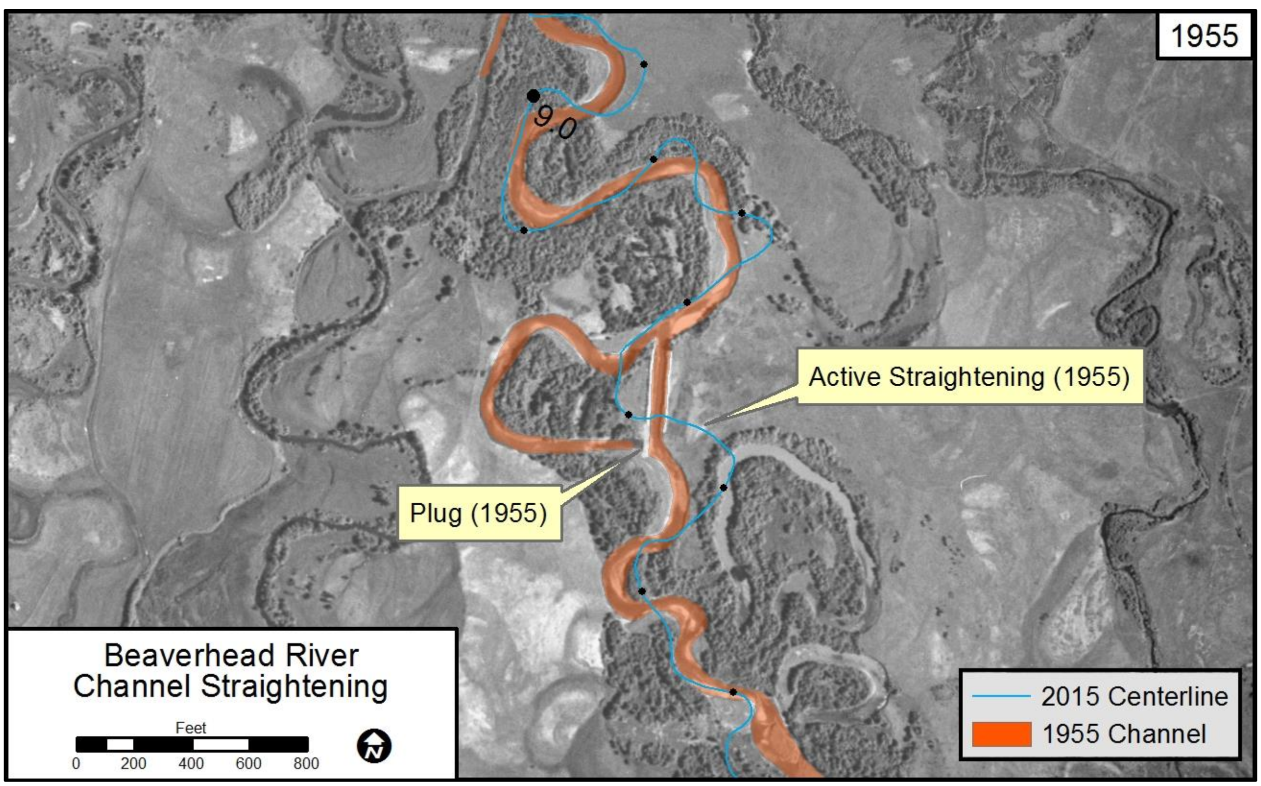

Figure 67. Engineered bendway cutoff around 1955, RM 9.5; note riparian vigor.

5.14 Reach 2

Reach 2 is located just upstream of Twin Bridges. It is an unconfined river segment that crosses broad coalescing floodplains of the Beaverhead, Big Hole, and Ruby Rivers. The riparian corridor becomes more robust downstream of the mouth of the Ruby, which may reflect increasing sediment inputs at that point (Figure 68). At RM 3.4, a long ditch on the edge of a pivot field creates a demonstrable avulsion risk (Figure 69). This reach, as well as lower Reach 3, is located about one half mile east of the route shown in the 1870 General Land Office (GLO) maps (Figure 70). This is common in this area; miles of the lower Ruby River have dramatically relocated as well. Reach 2 has the highest mean migration rate in the project reach, and the erosion buffer width is therefore the largest, at 163 feet.

	Reach 2
Downstream/Upstream RM	2.2/5.0
Length	2.8 miles
General Location	Ruby River confluence to Twin Bridges
Mean 60-year Migration Distance	98.1
Max 60-year Migration Distance	209
100-year Buffer	163

Figure 68. View downstream showing the Ruby River confluence and increased riparian cover downstream. (Kestrel)

Figure 69. View downstream showing potential avulsion route through ditch, RM 3.4. (Kestrel)

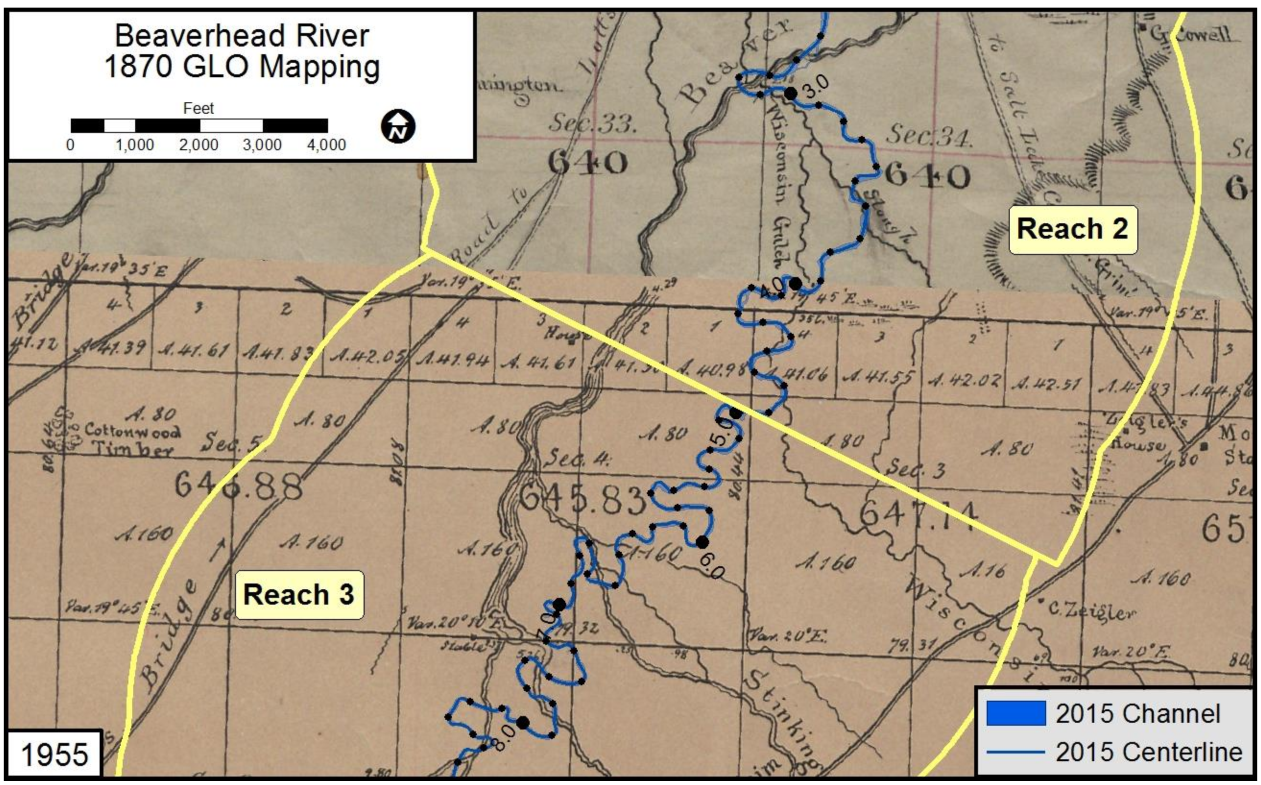

Figure 70. 1870 GLO map showing the location of the Beaverhead River relative to the 2015 mapped channel.

5.15 Reach 1

Reach 1 extends through Twin Bridges to the confluence of the Beaverhead River with the Big Hole River. It is largely confined through town (Figure 71). The confluence with the Big Hole River is characterized by a dramatic increase in open bar area on the Big Hole, which highlights the overall lack of sediment delivery down the Beaverhead (Figure 72).

	Reach 1
Downstream/Upstream RM	0.0/2.2
Length	2.2 miles
General Location	Big Hole confluence through Twin Bridges.
Mean 60-year Migration Distance	79.6
Max 60-year Migration Distance	140
100-year Buffer	133

Figure 71. View downstream showing the Beaverhead River in Twin Bridges. (Kestrel)

Figure 72. View downstream showing the confluence of the Beaverhead River and the sediment-laden Big Hole River. (Kestrel)

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Appendix A: Site Migration Statistics

The Channel Migration Zone Mapping for the Beaverhead River resulted in 1,959 individual measurements of channel movement between 1955 and 2015. These measurements were taken at approximately 30 foot intervals where notable movement has occurred. Each grouping of migration measurements, such as a bendway, was assigned a Migration Site ID (MSID) that includes the river mile as part of the ID. The statistics for each site are presented in the table below.

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
Reach 1				
MSID-BR-0.46	10	109	45	140
MSID-BR-0.98	5	52	33	62
MSID-BR-1.1	4	51	48	55
MSID-BR-1.35	4	69	52	82
Reach 2				
MSID-BR-2.76	7	85	69	106
MSID-BR-2.9	2	67	62	71
MSID-BR-2.95	3	67	59	79
MSID-BR-3.42	2	54	44	63
MSID-BR-3.49	6	118	47	197
MSID-BR-3.61	4	127	96	155
MSID-BR-3.76	2	48	46	50
MSID-BR-3.92	6	122	60	161
MSID-BR-4.1	4	146	91	189
MSID-BR-4.21	8	74	63	99
MSID-BR-4.31	3	35	33	39
MSID-BR-4.41	6	37	30	45
MSID-BR-4.52	5	102	62	160
MSID-BR-4.64	5	136	91	177
MSID-BR-4.84	9	144	42	209
Reach 3				
MSID-BR-5.07	5	53	37	82
MSID-BR-5.2	8	101	46	155
MSID-BR-5.32	7	39	30	47
MSID-BR-5.44	5	54	36	73
MSID-BR-5.6	3	50	37	60
MSID-BR-5.65	3	45	37	58
MSID-BR-5.91	7	66	53	76
MSID-BR-6.01	2	42	42	42
MSID-BR-6.1	4	49	36	63
MSID-BR-6.19	3	56	41	70
MSID-BR-6.31	5	52	34	61
MSID-BR-6.47	7	55	36	75
MSID-BR-6.59	3	69	56	86
MSID-BR-6.65	2	37	29	45
MSID-BR-6.74	4	47	39	52
MSID-BR-6.83	2	27	24	29
MSID-BR-6.89	2	41	34	47

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-6.93	2	34	32	36
MSID-BR-6.97	2	47	42	52
MSID-BR-7.04	3	48	45	51
MSID-BR-7.09	3	60	44	70
MSID-BR-7.28	4	58	34	70
MSID-BR-7.4	6	79	42	126
MSID-BR-7.49	3	36	34	38
MSID-BR-7.62	3	29	26	32
MSID-BR-7.72	2	43	42	43
MSID-BR-7.79	4	50	42	54
MSID-BR-7.9	8	61	38	88
MSID-BR-8.05	3	66	48	76
MSID-BR-8.22	3	38	26	47
MSID-BR-8.3	2	37	36	37
MSID-BR-8.35	2	37	35	39
MSID-BR-8.4	1	42	42	42
MSID-BR-8.56	2	50	40	60
MSID-BR-8.77	3	41	31	49
MSID-BR-8.88	9	67	52	86
MSID-BR-8.99	4	74	58	89
MSID-BR-9.09	5	46	39	53
MSID-BR-9.17	1	35	35	35
MSID-BR-9.23	3	63	55	72
MSID-BR-9.27	2	59	56	62
MSID-BR-9.31	4	90	46	137
MSID-BR-9.59	5	154	111	201
MSID-BR-10.04	3	60	58	64
MSID-BR-10.1	4	77	59	98
Reach 4				
MSID-BR-10.76	3	53	48	61
MSID-BR-10.87	2	45	39	51
MSID-BR-11.5	3	43	31	52
MSID-BR-11.55	3	30	26	32
MSID-BR-11.83	3	45	38	50
Reach 5				
MSID-BR-12.07	8	43	22	66
MSID-BR-12.17	3	40	30	46
MSID-BR-12.23	4	75	49	94
MSID-BR-12.29	3	39	36	41
MSID-BR-12.59	5	50	40	61
MSID-BR-12.76	9	47	39	54
MSID-BR-13.05	6	49	26	63
MSID-BR-13.16	5	55	32	82
MSID-BR-13.3	1	47	47	47
MSID-BR-13.6	2	51	48	54
MSID-BR-13.69	6	47	39	53
MSID-BR-13.8	3	49	42	59
MSID-BR-13.89	10	62	29	96
MSID-BR-13.99	4	48	40	60
MSID-BR-14.23	3	51	46	57
MSID-BR-14.29	6	95	60	117
MSID-BR-14.38	5	103	73	114
MSID-BR-14.45	4	91	53	120
MSID-BR-14.53	7	51	33	73
Reach 6				

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-14.82	11	52	27	85
MSID-BR-15.01	7	116	40	160
MSID-BR-15.09	4	76	48	94
MSID-BR-15.26	6	110	40	148
MSID-BR-15.36	5	127	101	161
MSID-BR-15.49	3	158	129	188
MSID-BR-15.57	3	135	95	162
MSID-BR-15.64	3	72	52	85
Reach 7				
MSID-BR-15.77	2	91	64	117
MSID-BR-15.89	5	99	62	135
MSID-BR-16.02	10	61	38	87
MSID-BR-16.17	4	65	42	86
MSID-BR-16.39	3	38	33	46
MSID-BR-16.47	7	95	81	104
MSID-BR-16.61	8	67	53	81
MSID-BR-16.8	3	52	45	61
MSID-BR-16.88	4	48	44	55
MSID-BR-17.23	4	80	58	105
MSID-BR-17.34	7	73	43	99
MSID-BR-17.55	5	78	55	102
MSID-BR-17.64	4	77	47	105
MSID-BR-18.21	3	56	42	67
MSID-BR-18.29	5	126	74	174
MSID-BR-18.59	5	134	86	190
MSID-BR-18.72	4	112	88	154
MSID-BR-18.79	3	39	29	46
MSID-BR-18.91	4	61	38	75
MSID-BR-18.98	2	52	48	56
MSID-BR-19.03	3	57	53	60
MSID-BR-19.12	4	90	66	107
MSID-BR-19.2	3	56	37	67
MSID-BR-19.3	3	67	54	75
MSID-BR-19.4	5	111	64	149
MSID-BR-19.49	3	82	70	98
MSID-BR-19.59	6	54	49	57
MSID-BR-19.79	3	95	79	122
MSID-BR-19.88	6	104	57	143
MSID-BR-20.03	2	109	105	113
MSID-BR-20.11	5	117	84	153
MSID-BR-20.18	1	54	54	54
MSID-BR-20.22	4	88	64	111
MSID-BR-20.31	6	107	58	149
MSID-BR-20.47	7	110	53	163
MSID-BR-20.77	1	46	46	46
MSID-BR-20.85	5	65	46	93
MSID-BR-20.97	3	54	54	55
MSID-BR-21.03	3	35	31	39
MSID-BR-21.08	2	46	41	50
MSID-BR-21.34	3	34	26	44
MSID-BR-21.52	1	31	31	31
MSID-BR-21.59	5	40	26	48
MSID-BR-21.66	4	31	19	43
MSID-BR-21.93	5	31	26	39
MSID-BR-22.05	2	27	24	30

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-22.2	2	26	26	26
MSID-BR-22.3	8	54	34	67
MSID-BR-22.53	2	32	30	34
MSID-BR-23.25	2	39	36	42
MSID-BR-23.32	3	49	44	53
MSID-BR-23.53	8	43	23	75
MSID-BR-23.71	2	55	50	60
MSID-BR-23.77	3	73	55	92
MSID-BR-23.84	4	110	71	129
MSID-BR-24	4	84	51	134
MSID-BR-24.09	6	129	64	180
MSID-BR-24.35	3	90	74	100
MSID-BR-24.44	5	96	78	115
MSID-BR-24.52	3	51	31	64
MSID-BR-24.89	4	97	41	173
MSID-BR-24.97	3	64	54	74
MSID-BR-25.07	5	180	137	209
MSID-BR-25.38	2	61	52	69
MSID-BR-25.5	8	119	73	149
MSID-BR-25.65	4	88	59	100
MSID-BR-25.76	2	45	44	46
MSID-BR-25.81	1	25	25	25
MSID-BR-25.91	6	131	67	184
MSID-BR-26.04	5	61	44	72
MSID-BR-26.12	2	29	27	31
MSID-BR-26.16	2	36	30	41
MSID-BR-26.22	3	47	41	53
MSID-BR-26.31	3	41	40	43
MSID-BR-26.53	3	77	58	94
MSID-BR-26.75	4	82	59	96
MSID-BR-26.83	1	44	44	44
MSID-BR-26.91	2	43	38	48
MSID-BR-26.97	4	68	48	85
MSID-BR-27.11	5	110	64	138
MSID-BR-27.17	2	56	54	58
MSID-BR-27.39	3	42	36	52
MSID-BR-27.55	3	91	71	103
MSID-BR-27.6	3	76	65	92
MSID-BR-27.71	3	45	32	62
MSID-BR-27.85	3	80	60	99
MSID-BR-27.94	2	92	90	94
MSID-BR-28.02	2	49	43	55
MSID-BR-28.05	2	54	49	59
MSID-BR-28.12	5	83	75	92
MSID-BR-28.26	2	39	39	39
Reach 8				
MSID-BR-28.7	4	132	56	174
MSID-BR-28.86	8	96	60	132
MSID-BR-29.01	8	70	33	120
MSID-BR-29.14	2	43	39	46
MSID-BR-29.25	10	70	35	103
MSID-BR-29.46	6	79	33	129
MSID-BR-29.72	3	53	31	73
MSID-BR-29.78	3	40	38	44
MSID-BR-29.91	6	111	75	149

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-30	4	54	45	63
MSID-BR-30.07	2	32	27	36
MSID-BR-30.18	3	63	47	80
MSID-BR-30.28	4	68	58	76
MSID-BR-30.42	8	80	64	124
MSID-BR-30.53	3	92	55	111
MSID-BR-30.6	4	69	41	89
MSID-BR-30.66	2	41	36	46
MSID-BR-30.76	2	39	38	40
MSID-BR-30.89	3	58	33	72
MSID-BR-30.96	4	85	65	114
MSID-BR-31.09	4	56	51	59
MSID-BR-31.19	4	67	57	76
MSID-BR-31.3	6	114	34	188
MSID-BR-31.46	4	95	65	140
MSID-BR-31.53	4	64	47	73
MSID-BR-31.67	5	43	38	50
MSID-BR-31.8	8	51	23	66
MSID-BR-31.92	5	57	43	68
MSID-BR-32.06	11	61	33	83
MSID-BR-32.18	4	60	49	75
MSID-BR-32.28	3	44	42	45
MSID-BR-32.33	3	43	38	51
MSID-BR-32.43	4	48	34	63
MSID-BR-32.5	2	61	59	62
MSID-BR-32.69	3	46	45	48
MSID-BR-33.05	2	62	61	63
MSID-BR-33.19	2	41	38	44
MSID-BR-33.25	1	55	55	55
MSID-BR-33.48	6	62	44	74
MSID-BR-33.57	2	49	48	50
MSID-BR-33.61	3	53	45	58
MSID-BR-33.69	4	42	40	47
MSID-BR-33.79	3	36	31	44
MSID-BR-34.02	4	44	37	50
MSID-BR-34.2	10	95	56	122
MSID-BR-34.81	5	111	61	142
MSID-BR-34.92	4	130	89	164
MSID-BR-35.06	3	118	76	155
MSID-BR-35.5	3	150	91	182
MSID-BR-35.73	3	60	52	68
Reach 9				
MSID-BR-36.23	3	65	45	78
MSID-BR-36.45	4	139	95	171
MSID-BR-36.59	4	180	118	233
MSID-BR-36.71	5	47	34	59
MSID-BR-36.86	4	57	39	77
MSID-BR-36.94	5	44	40	46
MSID-BR-37.05	3	40	26	55
MSID-BR-37.09	2	47	45	48
MSID-BR-37.13	3	54	39	61
MSID-BR-37.27	4	58	35	69
MSID-BR-37.43	6	133	86	164
MSID-BR-37.57	4	110	67	149
MSID-BR-37.66	4	40	32	54

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-38.3	3	38	25	45
MSID-BR-38.42	5	72	38	97
MSID-BR-38.69	3	96	73	112
MSID-BR-38.78	6	61	56	66
MSID-BR-38.86	3	69	61	77
MSID-BR-39.22	5	43	21	68
MSID-BR-39.54	2	84	64	104
MSID-BR-39.6	2	49	46	51
MSID-BR-39.67	4	92	73	108
MSID-BR-39.82	3	60	53	70
MSID-BR-39.91	6	60	42	76
MSID-BR-40.13	4	72	57	86
MSID-BR-40.95	3	50	46	56
MSID-BR-41.12	4	79	62	92
MSID-BR-41.43	2	57	44	69
MSID-BR-41.48	3	75	61	91
MSID-BR-41.53	2	63	59	67
MSID-BR-41.59	3	102	78	128
MSID-BR-41.72	4	165	101	222
MSID-BR-41.86	4	84	62	123
MSID-BR-42.05	3	63	32	84
MSID-BR-42.14	4	113	78	141
MSID-BR-42.35	3	78	55	96
MSID-BR-42.43	5	104	63	121
MSID-BR-42.54	3	97	68	115
Reach 10				
MSID-BR-42.87	5	83	58	108
MSID-BR-42.97	4	64	54	78
MSID-BR-43.04	4	79	57	98
MSID-BR-43.11	3	60	54	66
MSID-BR-43.15	2	44	36	52
MSID-BR-43.27	3	71	55	86
MSID-BR-43.4	4	60	48	69
MSID-BR-44.06	3	31	30	31
MSID-BR-44.13	2	60	48	72
MSID-BR-44.17	3	49	36	57
MSID-BR-44.26	4	88	76	100
MSID-BR-44.34	3	85	58	100
MSID-BR-44.46	2	27	26	27
MSID-BR-44.53	4	53	30	75
MSID-BR-44.64	4	58	48	68
MSID-BR-44.71	3	72	54	99
MSID-BR-44.78	3	81	65	96
MSID-BR-44.84	2	57	53	61
MSID-BR-44.95	5	113	70	193
MSID-BR-45.24	5	54	26	76
MSID-BR-45.31	3	37	33	43
MSID-BR-45.48	3	63	31	88
MSID-BR-45.54	5	47	34	61
MSID-BR-45.62	2	43	34	52
MSID-BR-45.68	3	65	57	75
MSID-BR-45.73	1	47	47	47
MSID-BR-45.79	3	58	39	70
MSID-BR-46.05	3	65	50	78
MSID-BR-46.09	2	51	48	53

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-46.13	1	47	47	47
MSID-BR-46.18	2	38	30	46
MSID-BR-46.25	5	40	26	49
MSID-BR-46.31	2	31	27	34
MSID-BR-46.36	5	52	37	65
MSID-BR-46.44	4	38	33	44
MSID-BR-46.56	4	64	46	76
MSID-BR-46.66	2	32	29	35
MSID-BR-47.09	3	41	33	53
MSID-BR-47.15	6	51	40	66
MSID-BR-47.24	5	42	28	53
MSID-BR-47.3	3	31	28	34
MSID-BR-47.59	3	91	75	100
MSID-BR-47.66	5	69	38	97
MSID-BR-47.81	2	42	41	42
MSID-BR-48	6	75	50	90
MSID-BR-48.08	3	74	63	95
MSID-BR-48.46	2	62	61	63
MSID-BR-48.51	2	54	53	54
MSID-BR-48.57	4	58	41	89
MSID-BR-48.7	6	120	87	172
MSID-BR-48.77	2	64	62	66
MSID-BR-48.89	4	44	39	48
MSID-BR-49.58	3	53	46	57
MSID-BR-49.71	6	117	56	159
MSID-BR-49.81	2	38	36	40
MSID-BR-49.87	4	53	40	62
MSID-BR-50.18	2	37	31	42
MSID-BR-50.23	2	57	52	62
MSID-BR-50.31	6	55	43	79
MSID-BR-50.75	4	148	99	172
MSID-BR-50.84	3	84	74	91
MSID-BR-50.97	3	80	62	98
MSID-BR-51.07	3	73	55	87
MSID-BR-51.18	6	89	69	105
MSID-BR-51.26	3	88	79	95
MSID-BR-51.33	2	54	52	56
MSID-BR-51.9	6	70	34	102
MSID-BR-51.97	4	68	52	85
MSID-BR-52.03	2	49	46	51
MSID-BR-52.1	7	70	39	96
MSID-BR-52.18	4	43	38	53
MSID-BR-52.26	6	49	40	57
MSID-BR-52.32	2	51	38	63
Reach 11				
MSID-BR-52.54	3	32	26	36
MSID-BR-52.78	3	48	32	60
MSID-BR-52.84	4	67	35	85
MSID-BR-52.97	2	59	55	62
MSID-BR-53.05	2	48	44	51
MSID-BR-53.98	3	86	63	112
MSID-BR-54.34	7	133	52	199
MSID-BR-54.82	2	29	26	32
MSID-BR-55.08	5	59	40	90
MSID-BR-55.17	4	53	45	61

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-55.23	3	54	46	62
MSID-BR-55.28	4	44	28	64
MSID-BR-55.55	7	42	35	52
MSID-BR-56.21	3	21	18	23
MSID-BR-56.36	2	40	34	46
MSID-BR-56.5	6	51	34	62
MSID-BR-56.69	5	49	26	66
MSID-BR-56.74	2	46	37	54
Reach 12				
MSID-BR-56.86	4	141	86	164
MSID-BR-56.93	2	63	43	83
MSID-BR-57.71	2	44	42	46
MSID-BR-57.75	2	39	38	40
MSID-BR-57.91	2	27	27	27
MSID-BR-57.98	4	51	40	57
MSID-BR-58.05	2	49	48	50
MSID-BR-58.08	2	31	24	37
MSID-BR-58.15	3	44	34	50
MSID-BR-58.25	4	28	25	34
MSID-BR-58.33	5	31	23	38
MSID-BR-58.44	4	44	33	53
MSID-BR-58.53	7	55	38	67
MSID-BR-58.61	3	37	30	41
MSID-BR-58.68	5	66	43	78
MSID-BR-58.87	6	42	30	56
MSID-BR-58.93	4	56	36	69
MSID-BR-58.97	1	35	35	35
MSID-BR-58.99	2	30	26	33
MSID-BR-59.13	1	25	25	25
MSID-BR-59.2	2	25	19	31
MSID-BR-59.52	4	41	36	47
MSID-BR-59.6	2	25	23	26
MSID-BR-59.69	2	29	29	29
MSID-BR-59.78	8	40	25	60
MSID-BR-59.89	3	62	46	74
MSID-BR-60.3	3	31	29	33
MSID-BR-60.35	2	34	33	34
MSID-BR-60.54	3	60	43	71
MSID-BR-60.75	2	48	43	53
MSID-BR-60.83	5	27	20	35
MSID-BR-60.9	3	55	42	68
MSID-BR-61.15	5	37	21	53
MSID-BR-61.35	2	37	36	37
MSID-BR-61.39	3	46	44	49
MSID-BR-61.43	1	47	47	47
MSID-BR-61.45	3	29	24	36
MSID-BR-61.46	3	34	25	41
MSID-BR-61.71	1	35	35	35
MSID-BR-61.75	1	32	32	32
MSID-BR-61.81	2	28	27	29
MSID-BR-61.84	2	34	30	38
MSID-BR-61.91	3	30	22	38
MSID-BR-61.97	11	36	20	79
MSID-BR-61.98	9	45	23	72
MSID-BR-62.02	3	64	52	77

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-62.09	5	110	82	124
MSID-BR-62.31	8	41	26	61
MSID-BR-62.4	5	66	35	91
MSID-BR-62.48	3	55	41	63
MSID-BR-62.54	2	29	28	29
MSID-BR-62.62	3	47	33	57
MSID-BR-62.78	3	41	28	53
MSID-BR-62.88	2	40	39	41
MSID-BR-62.93	4	55	34	66
MSID-BR-63.14	5	35	26	40
MSID-BR-63.24	7	39	29	52
MSID-BR-63.31	2	30	23	36
MSID-BR-63.52	5	38	25	60
Reach 13				
MSID-BR-63.62	3	44	30	55
MSID-BR-63.67	2	50	44	55
MSID-BR-63.72	3	40	29	48
MSID-BR-63.76	3	34	32	36
MSID-BR-63.92	6	42	34	56
MSID-BR-64.05	2	31	28	33
MSID-BR-64.14	2	32	31	33
MSID-BR-64.48	4	59	41	71
MSID-BR-64.84	4	30	23	35
MSID-BR-65.04	7	38	25	51
MSID-BR-65.12	2	19	19	19
MSID-BR-65.17	3	39	31	46
MSID-BR-65.6	5	42	34	50
MSID-BR-65.76	2	27	26	28
MSID-BR-65.86	3	24	21	28
MSID-BR-65.91	3	33	27	40
MSID-BR-67.52	3	32	24	42
MSID-BR-67.58	3	41	34	51
Reach 14				
MSID-BR-68.06	2	35	31	39
MSID-BR-68.25	3	35	32	37
MSID-BR-69.57	3	43	39	50
MSID-BR-69.71	3	66	45	83
MSID-BR-69.78	3	77	65	90
MSID-BR-69.96	3	53	45	60
MSID-BR-70.01	3	68	61	73
MSID-BR-70.69	3	34	31	36
Reach 15				
MSID-BR-72.84	5	99	61	137
MSID-BR-72.91	2	69	65	73
MSID-BR-73.08	3	63	54	68
MSID-BR-73.18	6	100	63	122
MSID-BR-73.47	4	36	29	44
MSID-BR-73.53	6	117	54	162
MSID-BR-73.93	3	52	42	57
MSID-BR-74.06	6	92	47	134

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-BR-74.24	3	43	29	55
MSID-BR-74.29	3	53	43	62
MSID-BR-74.34	6	58	36	79
MSID-BR-74.43	5	58	36	85
MSID-BR-74.49	2	58	54	61
MSID-BR-74.56	7	98	52	138
MSID-BR-74.64	4	82	56	92
MSID-BR-74.67	3	71	57	91
MSID-BR-74.78	9	99	42	148
MSID-BR-74.96	9	44	21	61
MSID-BR-75.2	2	40	37	43
MSID-BR-75.24	4	44	35	61
MSID-BR-76.1	6	55	36	80
MSID-BR-76.16	4	50	32	70
MSID-BR-76.2	2	56	51	61
MSID-BR-76.25	4	81	64	97
MSID-BR-76.3	3	55	31	68
MSID-BR-76.38	7	35	21	48
MSID-BR-76.45	3	45	42	48
MSID-BR-76.5	3	43	35	48
MSID-BR-76.54	3	43	35	49
MSID-BR-76.56	2	41	41	41
MSID-BR-76.67	1	46	46	46
MSID-BR-76.73	5	80	54	107
MSID-BR-77.03	6	64	39	86
MSID-BR-77.67	4	72	56	82
MSID-BR-77.72	4	61	45	83
MSID-BR-77.94	5	115	59	143
MSID-BR-78.05	7	86	50	133
MSID-BR-78.2	4	81	48	116
MSID-BR-78.35	5	82	43	119
MSID-BR-78.74	5	72	40	105
MSID-BR-78.88	3	53	37	63
MSID-BR-78.95	6	90	34	123
MSID-BR-79.29	4	34	32	36
MSID-BR-79.39	4	86	28	112
MSID-BR-79.41	5	98	71	126
MSID-BR-79.53	6	71	35	118
MSID-BR-79.95	8	80	39	122
MSID-BR-80.05	2	82	74	89
MSID-BR-80.16	4	137	94	162
MSID-BR-80.43	5	39	27	55
MSID-BR-80.51	4	59	45	67
MSID-BR-80.7	3	63	51	74
MSID-BR-80.82	3	67	66	69
MSID-BR-82.57	2	20	17	23
MSID-BR-82.59	2	36	33	38
MSID-BR-82.81	4	37	35	40

Appendix B: Oblique Photos of Major Bridge Crossings

Figure 73. I-15 crosses the Beaverhead River below Clark Canyon Reservoir (RM 82.7 and RM 81.6), July 21, 2016. (Kestrel)

Figure 74. Hennaberry Road bridge (south) at river mile 80.4, July 21, 2016. (Kestrel)

Figure 75. Hennaberry Road bridge (north) at river mile 77.3, July 21, 2016. (Kestrel)

Figure 76. Interstate 15 (3rd crossing) and High Road at river mile 75.4, July 21, 2016. (Kestrel)

Figure 77. Interstate 15 (4th crossing) and Grasshopper Road onramp at river mile 71.5, July 21, 2016. Grasshopper Creek enters at the upper left of the photo. (Kestrel)

Figure 78. Interstate 15 (5th crossing) at river mile 70.9, July 21, 2016. (Kestrel)

Figure 79. Frontage road bridge at river mile 70.3, July 21, 2016. (Kestrel)

Figure 80. Union Pacific railroad crosses the Beaverhead River as it exits Clark Canyon along with Ryan Canyon Road (river mile 69.2), July 21, 2016. (Kestrel)

Figure 81. Barretts Park bridge at river mile 68.0, July 21, 2016. (Kestrel)

Figure 82. Barrett's Diversion at river mile 67.8, Montana, July 21, 2016. (Kestrel)

Figure 83. Union Pacific railroad crosses the Beaverhead River (2 crossings)(river mile 62.0) and Poindexter Slough (top of photo), July 21, 2016. (Kestrel)

Figure 84. A private road (center, river mile 61.5) and Hwy 91 (upper right, river mile 61.1) cross the Beaverhead River, July 21, 2016. (Kestrel)

Figure 85. Interstate 15 (6th crossing) at river mile 60.6, July 21, 2016. (Kestrel)

Figure 86. Private road bride at river mile 57.1, July 21, 2016. (Kestrel)

Figure 87. Two private crossings at river mile 56.4, July 21, 2016. (Kestrel)

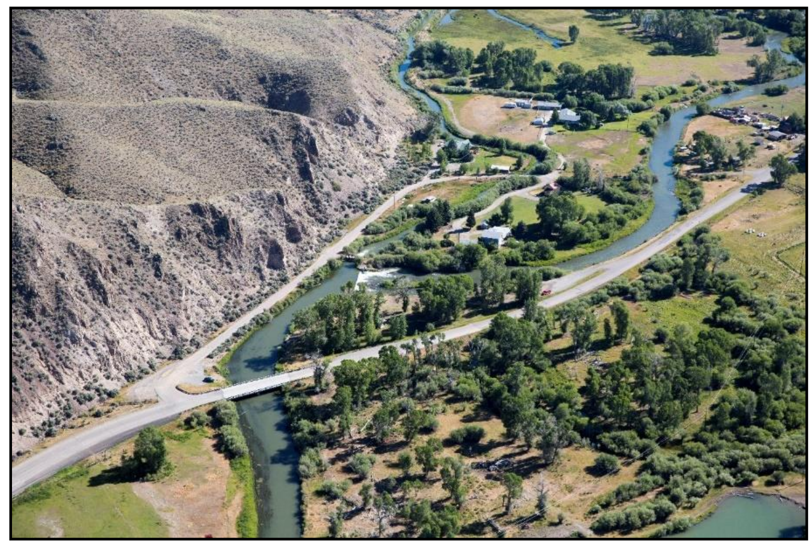

Figure 88. 10 Mile Road bridge at river mile 55.7, July 21, 2016. (Kestrel)

Figure 89. Interstate 15 (7th crossing) at river mile 54.1, July 21, 2016. (Kestrel)

Figure 90. Union Pacific railroad and Highway 91 cross the Beaverhead River at river mile 53.5, July 21, 2016. (Kestrel)

Figure 91. Highway 91 bridge at river mile 53.1, July 21, 2016. (Kestrel)

Figure 92. Private bridge at river mile 45.4, July 21, 2016. (Kestrel)

Figure 93. Anderson Lane bridge at river mile 42.8, July 21, 2016. (Kestrel)

Figure 94. Diamond O Ranch bridge at river mile 33.1, with Albers Slough at the top of the image, July 21, 2016. (Kestrel)

Figure 95. Highway 41 bridge at river mile 28.2, with Beaverhead rock on the left, July 21, 2016. (Kestrel)

Figure 96. Private bridge at river mile 15.8, July 21, 2016. (Kestrel)

Figure 97. Silver Bow Lane bridge at river mile 12.0, July 21, 2016. (Kestrel)

Figure 98. Private bridge at river mile 8.7, July 21, 2016. (Kestrel)

Figure 99. Highway 41 bridge in Dillon at river mile 2.2, July 21, 2016. (Kestrel)

Appendix C: Oblique Photos of Select Irrigation Structures

Figure 100. Diversion at Barretts, RM 68, July 21, 2016 (Kestrel).

Figure 101. Poindexter Diversion, RM 63.5, July 21, 2016 (Kestrel).

Figure 102. Smith Rebich Ditch Diversion at RM 55.6, July 21, 2016 (Kestrel).

Figure 103. Diversion at RM 53.1, Lacknar Lane, July 21, 2016 (Kestrel).

Figure 104. Diversion at RM 46.2 July 21, 2016 (Kestrel).

Figure 105. Diversion at RM 43.6, July 21, 2016 (Kestrel).

Figure 106. Diversion at RM 42.8, Anderson Lane, July 21, 2016 (Kestrel).

Figure 107. Diversion at RM 41.5, July 21, 2016 (Kestrel).

Figure 108. Diversion at RM 40.9, July 21, 2016 (Kestrel).

Figure 109. Diversion at RM 37.9, July 21, 2016 (Kestrel).

Figure 110. Co-op Ditch Diversion at RM 29.2 (Beaverhead Rock), July 21, 2016 (Kestrel).

Figure 111. Diversion at RM 26.4, July 21, 2016 (Kestrel).

Figure 112. Diversion at RM 24.2, July 21, 2016 (Kestrel).

Figure 113. Diversion at RM 23.0, July 21, 2016 (Kestrel).

Appendix D: Reach Maps