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Jefferson River
Channel Migration Mapping

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Abstract

This report contains the results of a Channel Migration Zone (CMZ) mapping effort for the Jefferson River from Twin Bridges to the Missouri River Headwaters State Park in Three Forks, Montana. The Jefferson River begins at the confluence of the Big Hole and Beaverhead Rivers a few miles north of Twin Bridges Montana. Just upstream of Twin Bridges, the Ruby joins the Beaverhead as well, making the upper Jefferson River a system that is responding to the conditions in three different watersheds. The Beaverhead and Ruby Rivers both have reservoirs affecting flows, and they are both fairly low energy systems with disproportionately small sediment inputs to the upper Jefferson. Most of the flow and energy affecting the Jefferson River is driven by the dynamics of the Big Hole, which, although it has a smaller drainage area than the Red Rock/Beaverhead system, it carries about three times the mean annual discharge and significantly more coarse sediment. As a result, the Upper Jefferson shows an immediate response to the Big Hole influence, with a very dynamic confluence that has shifted over a half of a mile since 1955, exhibiting rapid channel migration and frequent avulsions.

As the Jefferson River flows north towards Jefferson Canyon at Cardwell, it crosses primarily agricultural lands within a broad floodplain that has an extensive relic channel system. In some cases, the floodplain channels remain active and support irrigation, in others they are require maintenance to keep them from closing off. Some older swales on the floodplain are used as ditches and canals; many of these were the main channel in the 1870s when the General Land Office (GLO) surveys were completed.

Below the Renova Diversion in the Whitehall Valley, the late 1800s GLO maps show the main river channel was located in what is now Jefferson Slough and Slaughterhouse Slough, forming two distinct forks. The river now occupies a new channel south of the GLO-mapped river course where virtually no channel was mapped. This marks a major avulsion that left the historic channels as sloughs that are, without intervention, progressively infilling.

At LaHood the river enters Jefferson Canyon, which is a deep confined bedrock canyon that records over a billion years of geologic time. Channel migration is limited in the canyon due to both the erosion resistant geology and encroaching transportation infrastructure.

Below Jefferson Canyon the river re-enters a very broad floodplain, flowing west of Three Forks and down to Headwaters State Park, where the Jefferson River floodplain coalesces with that of the Madison River, forming the beginning of the Missouri River north of I-90. In these reaches, active channel migration and avulsion have caused challenges with transportation infrastructure and residential developments where they encroach into the natural Channel Migration Zone.

Channel Migration Zone mapping on the Jefferson River has captured the geomorphic variability of the Jefferson River on a reach scale, with the CMZ ranging in width from essentially the active channel in Jefferson Canyon to over a mile wide in more dynamic reaches.

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Glossary and Abbreviations

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 Jefferson River Channel Migration Zone (CMZ) mapping project developed approximately 76 miles of CMZ mapping for the full length of the Jefferson River from its headwaters at the confluence of the Big Hole and Beaverhead Rivers in Twin Bridges, MT, downstream to its confluence with the Madison and Gallatin Rivers in Three Forks, MT. It is part of a larger effort to map approximately 440 miles of river in the Upper Missouri River headwaters. Other rivers in the study include the Beaverhead, Madison, Gallatin and East Gallatin Rivers, revising the 2005 Big Hole River mapping (Wisdom to Twin Bridges), 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 Jefferson River Channel Migration Zone (CMZ) mapping is part of a larger effort to map approximately 350 miles of river in the Missouri River headwaters. Other rivers in the study include the Beaverhead, Madison, Gallatin, and East Gallatin Rivers, 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. 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 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 (Kestrel). Over the past decade, we have been collaborating to develop CMZ maps for numerous rivers in Montana, to provide rational and scientifically sound tools for river management. It is our 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 believe the mapping supports the premise that managing rivers as dynamic, deformable systems contributes to ecological resilience while supporting sustainable, cost-effective development.

1.2 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).

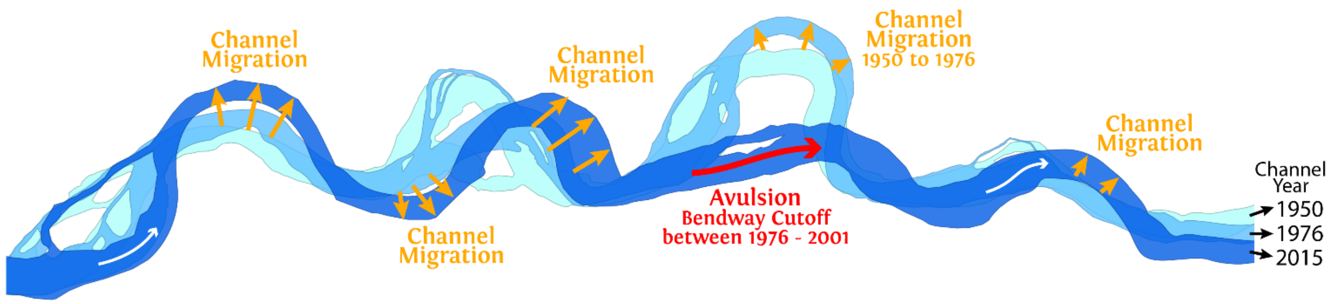

Figure 1. Typical patterns of channel migration and avulsion evaluated in CMZ development.

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 Historic Migration Zone, or 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. Average annual migration rates are calculated on a reach scale and 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, or EHA.

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, an unconfined meandering channel with high sediment loads would have higher migration rates than a geologically confined channel flowing through a bedrock 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 five- to 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 individual map units comprising the CMZ are as follows:

$$CMZ = HMZ + EHA + AHZ$$

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.

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).

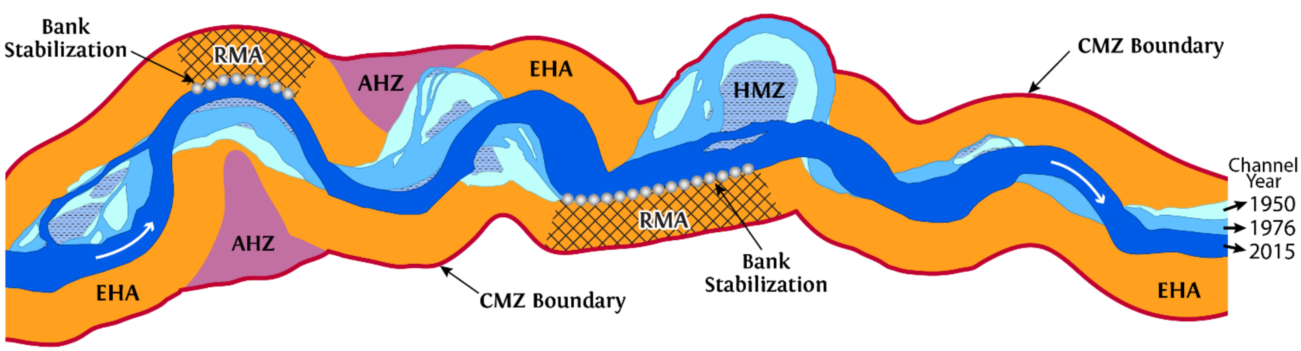

Figure 2. Channel Migration Zone mapping units.

1.3 CMZ Mapping on the Jefferson River

The Channel Migration Zone (CMZ) developed for Jefferson River extends 76 river miles from Twin Bridges, MT to its confluence with the Madison River at Three Forks, MT, marking the beginning of the Missouri River.

Although the basic concept for Channel Migration Zone mapping efforts is largely the same throughout the country, different approaches to defining CMZ boundaries are used depending on specific needs and situations. 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 Department of Ecology (www.ecy.wa.gov). This approach does not, however include a geotechnical setback on hillslopes; these areas would require a more site specific analysis than that presented here.

1.4 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.*

From Twin bridges to Cardwell, the upper Jefferson River shows historic patterns of lateral migration and avulsion, locally within a very broad floodplain surface that has dense networks of historic channels. Near Lewis and Clark Caverns, the river flows through a narrow bedrock canyon where migration is geologically impeded, before flowing into a dynamic corridor below Sappington Bridge and to Headwaters State Park. With potential contributing factors, such as woody debris jamming, sediment slugs, tectonic deformation, landslides, or ice jams, dramatic change could potentially occur virtually anywhere in the stream corridor. 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.

1.5 Relative Levels of Risk

The natural processes of streambank migration and channel avulsion both create risk to properties within stream corridors. Although the site-specific probability of any area experiencing either migration or an avulsion during the next century has not been quantified, the characteristics of each type of channel movement 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, and the risk of erosion into this map unit is relatively high. In contrast, avulsions tend to be a flood-driven process; the Avulsion Hazard Area delineates areas where conditions may support an avulsion, although the likelihood of such an event is highly variable between sites and typically depends on floods. Large, long duration floods have the potential to drive extensive avulsions, even after decades of no such events. During the spring of 2011, for example, the Musselshell River flood drove 59 avulsions in three weeks, carving 9 miles of new channel while abandoning about 37 miles of old river channel (Boyd et al, 2012).

1.6 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.

1.6.1 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 (left schematic on 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 escape flooding, but not resistant enough to avoid erosion (right schematic on Figure 3). 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.

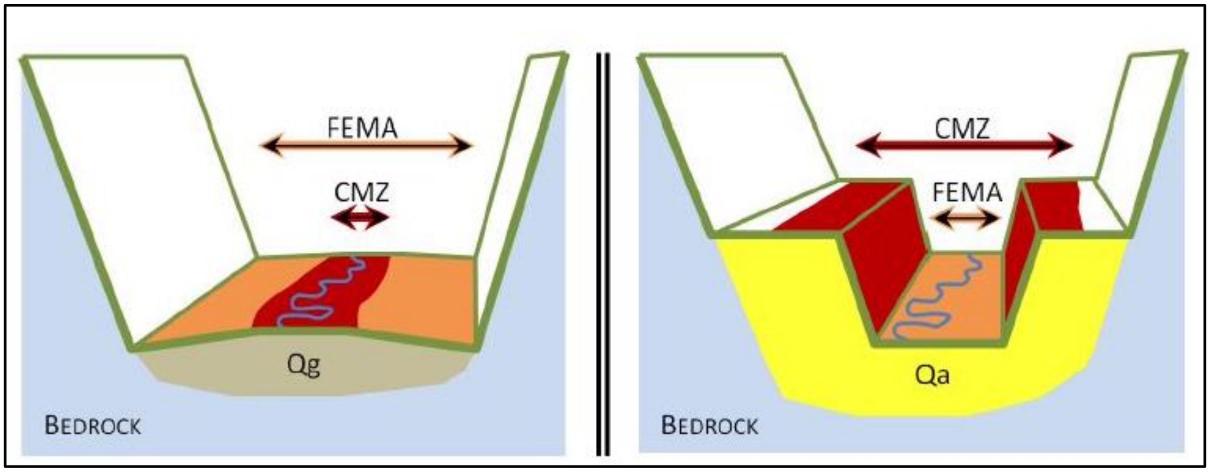

Figure 3. Schematic comparisons between CMZ and flood mapping boundaries (Washington Department of Ecology).

Figure 4 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 5), 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 4. Yellowstone River home on high glacial terrace that was burned down in 1997 to prevent its undermining by the river.

Figure 5. Photos from a 2005 in Saint George Utah, where homes several feet above the mapped floodplain were destroyed by channel migration (www.Utahfloodrelief.com).

1.6.2 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 Jefferson River as having 26 reported ice jams (Figure 6).

In February of 2011, ice jamming a few miles south of Silver Star resulted in the flooding of a rural subdivision. The flooding cut of several homes from vehicular access. The NWS reported that a 10-mile-long jam formed in this area that year (www.bozemandailychronicle.com, Jan 15, 2013). A flood watch was also issued in 2011 for ice-jam related flooding near Three Forks.

Ice jams can also cause avulsions by entirely blocking channels and forcing flows onto the floodplain.

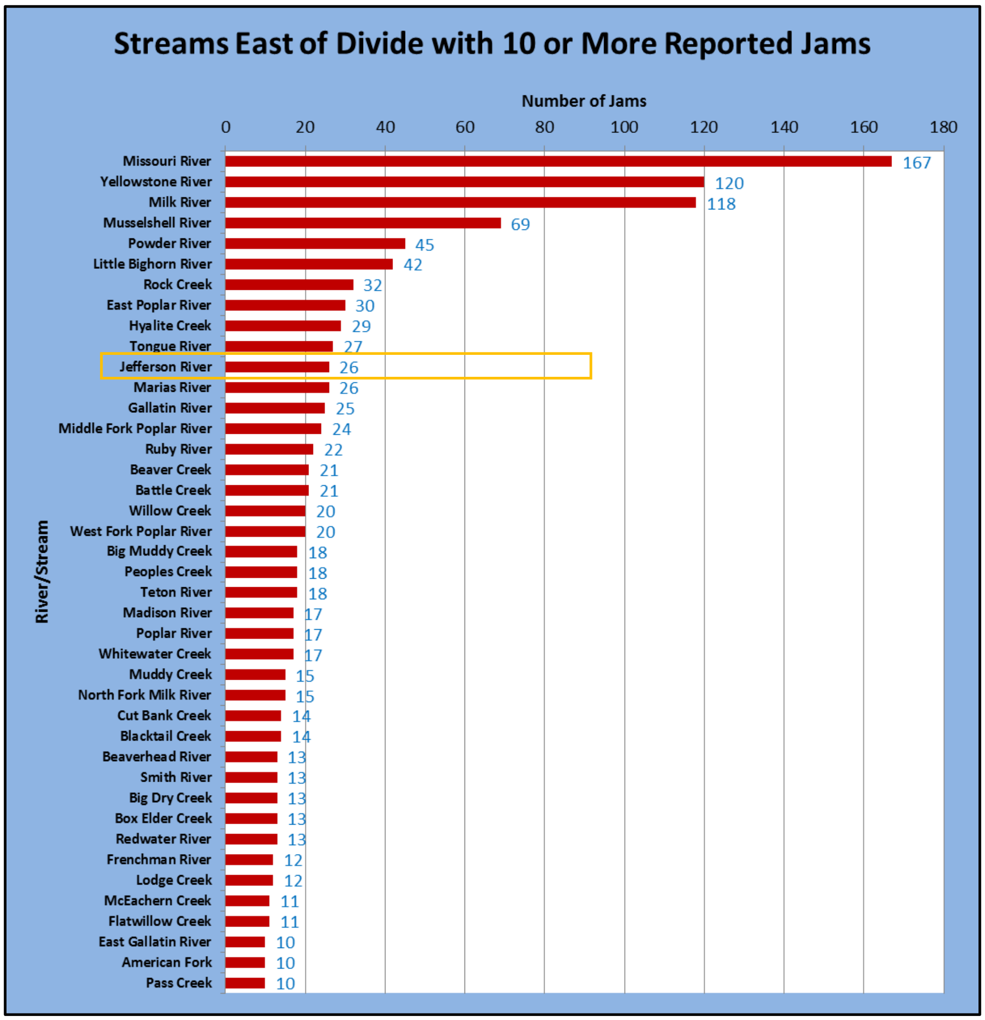

Figure 6. Montana rivers east of the continental divide with 10 or more reported ice jams.

Figure 7. Ice jam related flooding on Jefferson River between Twin Bridges and Silver Star (www.jeffersonriver.org).

1.6.3 Landslides

There are no mapped landslides on the valley walls of the Jefferson River in the project area. During the 1925 earthquake, however, rockslides (Figure 8) were reported on the bluffs on the Jefferson River above Willow Creek (Pardee, 1926). The 6.6 magnitude quake was epicentered in Clarkston Valley, causing extensive damage at Manhattan, Three Forks, Logan, and Lombard (USGS). The dust that the rockslides generated appeared from a distance like smoke and led to a report that the town was on fire (Pardee, 1926). The earthquake also reportedly generated several new springs in the river valley, and several existing springs went dry.

Landslides and rockslides have the potential to create river hazards by blocking the channel and potentially diverting or impounding flow. The 1925 Clarkston quake caused a slide on Sixmile Creek that blocked the channel forming a lake. Figure 9 shows an example of a relatively small 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 (Figure 10). The river breached the landslide and flows returned to normal, however the river was shifted hundreds of feet. 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 and relocated the river causing extensive flooding upstream (Figure 11).

B. ROCKS ON RAILROAD TRACK NEAR LOMBARD, MONT.

Photograph by J. P. Swarts

Figure 8. Rock slide near Lombard caused by the 1925 earthquake (Pardee, 1926.)

Figure 9. Hillslope failure on Nooksack River near Bellingham Washington on February 21, 2014 (K. Boyd).

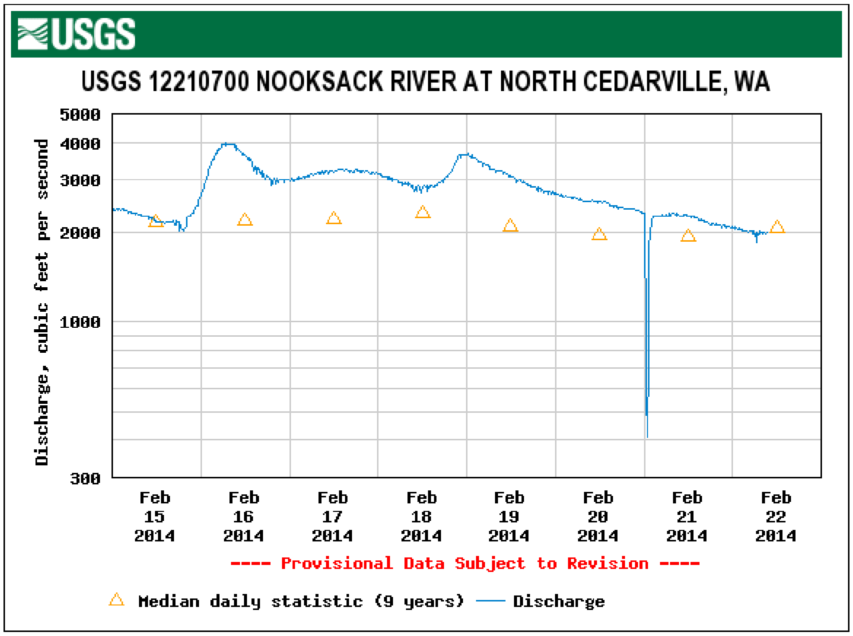

Figure 10. USGS gage data showing rapid drop in river flow following upstream hillslope failure.

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

1.7 Potential Applications of the CMZ Maps

The CMZ mapping developed for the Jefferson 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; and,
- Assist long-term residents in conveying their experiences of river process and associated risk to newcomers.

1.8 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.*

1.9 Image Licensing and Use Restrictions

Many of the oblique color photographs taken by plane presented in this document and included on the associated project DVD were taken by Kestrel Aerial Services (Kestrel) and are subject to use restrictions. Kestrel grants that these photos can be used as follows:

> ***For use as river and floodplain documentary imagery in efforts related to this study by project partners.***

For uses outside these stated rights, contact Kestrel Aerial Services, Inc. (406) 580-1946.

1.10 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. Additionally, we appreciate the assistance of Ted Dodge in coordinating public meetings for the Jefferson River. We also acknowledge the professionalism and talent of Chris Boyer of Kestrel Aerial Services (Kestrel), in obtaining oblique aerial photography that provides a perspective of the river that can't be made with conventional air photos. We look forward to receiving comments on this draft report, and those contributors will be acknowledged accordingly.

2 Physical Setting

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

2.1 Geography

The Jefferson River in southwest Montana is one of three tributary rivers that form the Missouri River, along with the Gallatin and Madison Rivers (Figure 12). At its start near Twin Bridges, it is fed by upstream contributing watersheds of the Red Rock, Beaverhead, Ruby, and Big Hole Rivers, which encompass 7,571 square miles, or 54% of the total Upper Missouri Watershed area. The 76-mile long Jefferson River segment contributes an additional 1,299 square miles, or 9% of the total area of the Missouri Headwaters watershed. The river was named for the then U.S. President Thomas Jefferson by Meriwether Lewis in July 1805. The geography of the Jefferson River segment is highly varied, with high elevation areas along the Continental Divide and Tobacco Root Mountains (Hollow Top Mountain, 10,604') down to approximately 4,400 feet at Three Forks. Similarly, the precipitation is highly varied with over 18 inches of annual precipitation in the high elevations mainly as snow, to just 10 inches in the valleys (Jefferson River Watershed Council, 2010).

The upper approximate 20 miles of the Jefferson River flows through Madison County. Starting near the Waterloo Road bridge and continuing for approximately 21 miles, the river forms the approximate boundary between Jefferson and Madison Counties. For the next ten miles, the river forms the approximate boundary between Jefferson and Gallatin Counties. And for the final 15 miles, it forms the boundary between Gallatin and Broadwater Counties. Twin Bridges, Whitehall, and Three Forks are the largest communities, located on the upper, middle, and lower river, respectively.

The Jefferson River can be divided into three segments: the Jefferson Valley, Jefferson Canyon, and lower river. The Jefferson Valley section runs from the headwaters at Twin Bridges, northward to Whitehall, and ending at the Boulder River confluence near Cardwell. The Boulder River and the South Boulder Rivers are the major contributing watersheds in this section of river; the Boulder River being the largest with a 758 square mile drainage area. Additionally, numerous small streams flow out of the surrounding mountains. The Jefferson Canyon section begins at the Boulder River confluence, and ending downstream of Sappington Bridge where the river spreads out into the broad valley near Three Forks. There are no significant tributaries entering the canyon section of the Jefferson River. The lower section of the river is characterized by the complex historic interactions between the Jefferson and Madison Rivers as it approaches Three Forks. Willow Creek is the only significant tributary to the Jefferson in the lower section of the river, entering the river from the east near the town of Willow Creek.

The Lewis and Clark Expedition came up the Jefferson River valley in the summer of 1805. They camped in Jefferson Canyon on August 1, 1805, and while there shot elk, antelope, and a bighorn sheep. Twin Bridges served as a commercial hub for southwest Montana in the late 1800s, and the Silver Star Post office is one of the oldest in the state, established in 1869.

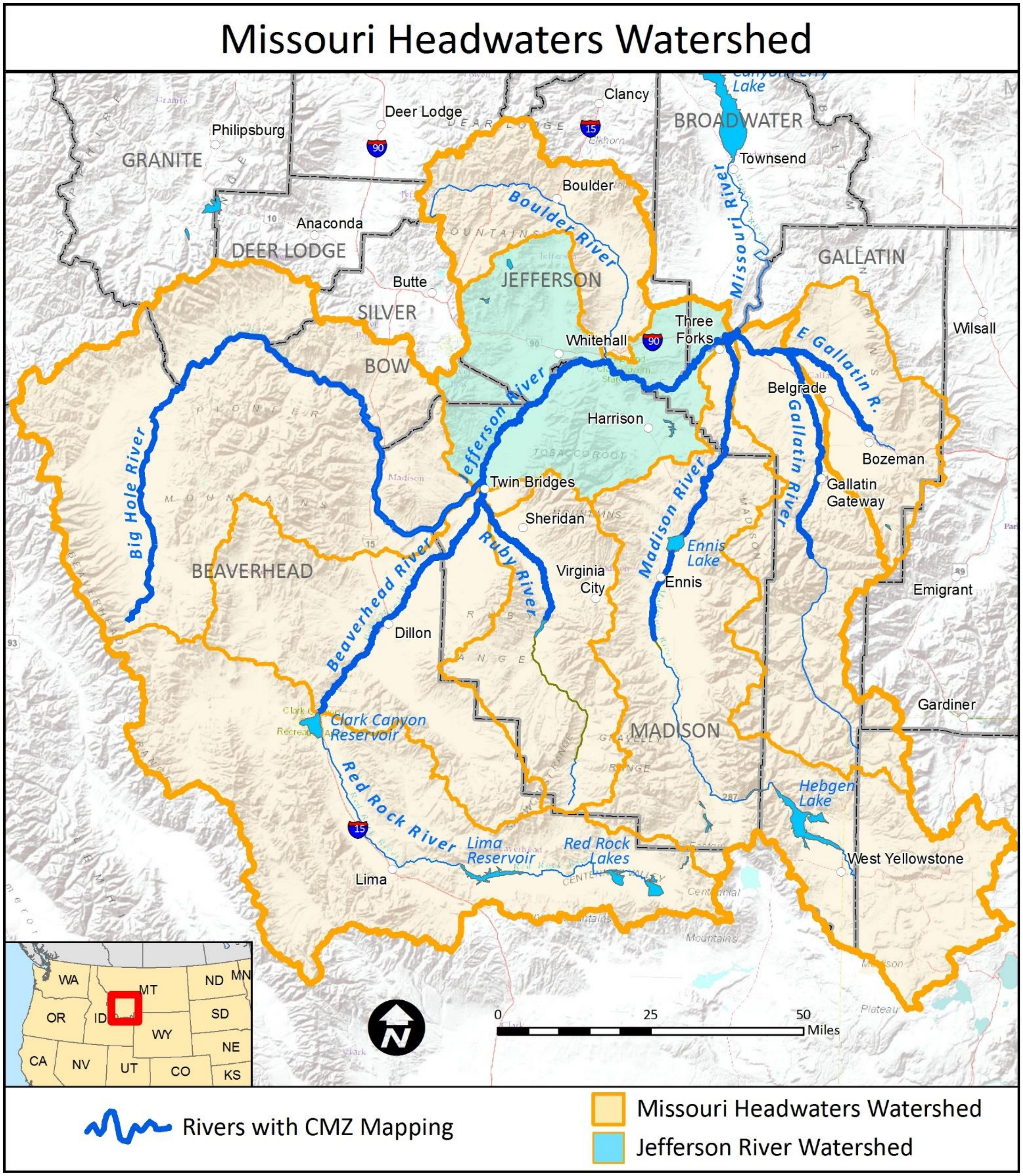

Figure 12. Jefferson River Watershed.

2.2 Geology and Glacial History

The following summary of the geological setting of the project reach is intended to provide some context as to how the physical setting influences river process. The Jefferson Valley (Twin Bridges to Boulder River Confluence) is bound by the Tobacco Root Mountains to the east and the Highlands to the west. The glaciated crest of the Tobacco Roots is made up of rocks of the Tobacco Root Batholith. The Highland Mountains west of the Jefferson consist of Precambrian basement rocks in the south and the Boulder Batholith to the north. The Boulder Batholith is a is a massive granitic intrusion that dominates Homestake Pass and contributes large volumes of granitic sand to streams. The river valley itself is filled with three to four thousand feet of young unconsolidated sediments of the Renova Formation (Alt and Hyndman, 1986). Young alluvial deposits derived from the high mountains form extensive terraces and alluvial fans on the valley margin that commonly form the edge of the Channel Migration Zone (CMZ). In general, however, the valley floor is wide and largely unconfined.

In contrast, the Jefferson Canyon is about twelve miles long and exposes over a billion years of geologic history. All of the geologic units exposed in the canyon are resistant to erosion and do not appear especially prone to mass failure. As a result, the CMZ in the canyon is notably narrow.

Downstream of Sappington Bridge the river follows the west valley wall near Three Forks for about five miles. There is no evidence of active migration into these older sedimentary units, however the river is actively reworking more recent floodplain deposits through both migration and avulsion processes.

2.3 Hydrology and Flow Management

The hydrology of the Jefferson River reflects combined inputs from contributing watersheds of the Big Hole, Beaverhead, and Ruby Rivers. While there are no constructed or natural impoundments on the Jefferson River, flows on the Beaverhead and Ruby Rivers are affected by reservoir operations.

Water in the Jefferson and upstream watershed areas is used extensively for irrigation and other uses, and the Jefferson River is classified as chronically dewatered from its headwaters to its mouth (MT DEQ, 2014). Flows less than 50 cfs are common during drought cycles, and in 1988 only 4.7 cfs were measured near Silver Star (www.jeffersonriver.org).

2.3.1 Major Diversion Structures

There are five major diversions on the Jefferson River, feeding extensive canal systems. Additionally, the Montana Department of Natural Resources and Conservation Water Rights data show 121 headgate points of diversion listed for the Jefferson River. Oblique aerial photographs of major diversion are compiled in Appendix C. Contributing watersheds also have intensive agricultural water use and associated infrastructure.

2.3.2 Jefferson River Flood History

The flow records on the Jefferson River are relatively short, with 36 years of record from the gage at Three Forks (USGS #06036650). That record indicates that over those 36 years, the Jefferson River has had four floods exceeding a 10-year event and none exceeding a 25-year event (Figure 13). The largest flood recorded on the Jefferson at Three Forks peaked at 17,400 cfs on June 12, 2011. Figure 14 shows that floods on the Big Hole River have a much larger influence on Jefferson River flooding than the Beaverhead River does, even though the Beaverhead has a larger drainage area. 1984 for example, the Beaverhead River experienced a major flood that exceeded a 100-year event, which was less than a 10-year event on the Jefferson at Three Forks.

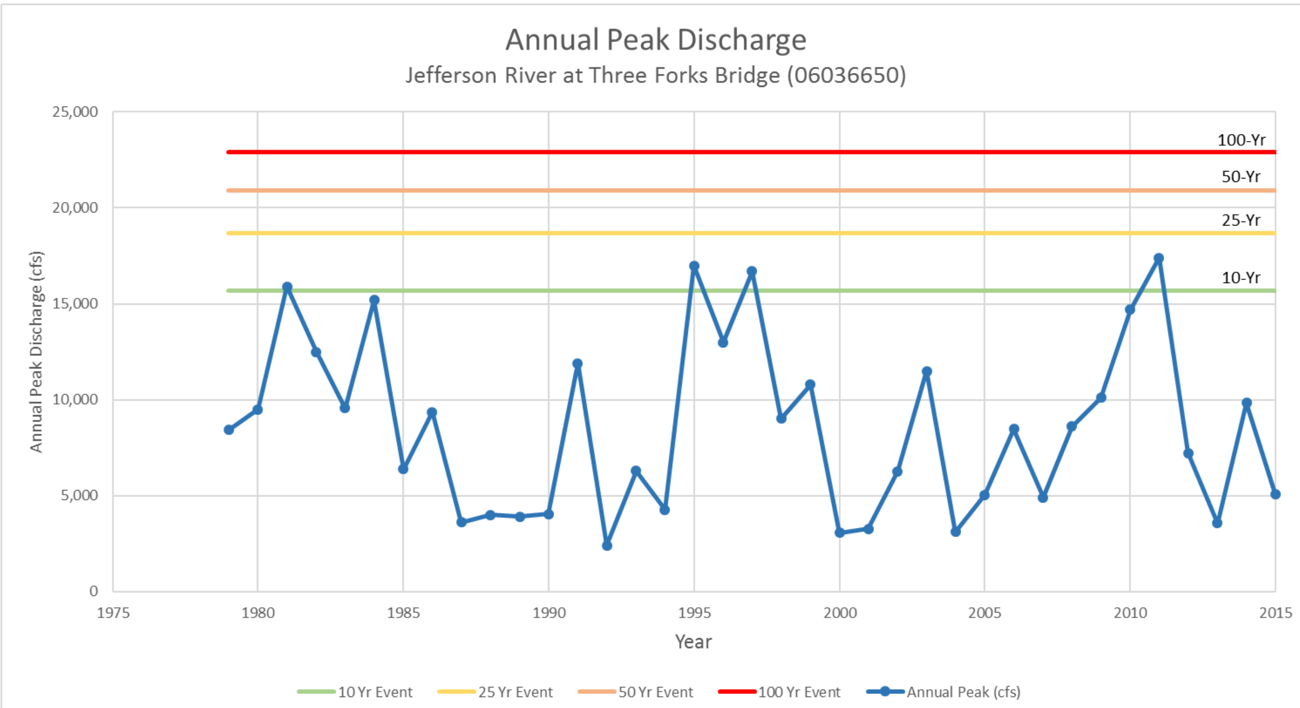

Figure 13. Annual peak flow record for Jefferson River below at Three Forks.

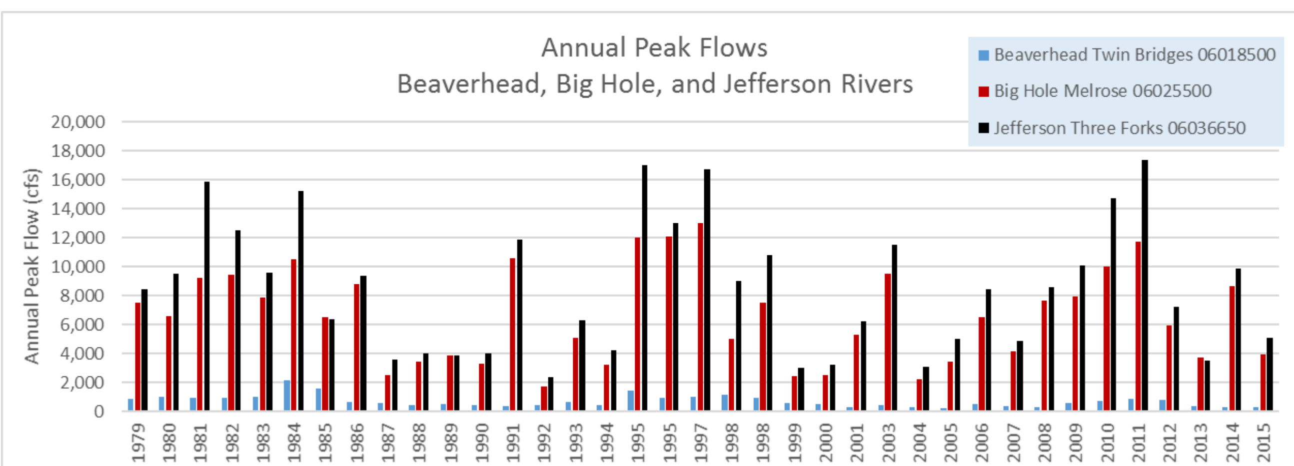

Figure 14. Annual peak flows for 1979-2015 on Beaverhead, Big Hole, and Jefferson Rivers.

2.4 Dikes and Levees

Dikes and levees on the Jefferson River commonly parallel streambanks and serve as access routes to agricultural fields and bank protection sites. In general, however, the extent of floodplain dikes and levees on the Jefferson River is relatively small. We mapped just over three miles of dikes within the Historic Migration Zone, which reflects about 2.1% of the total bank length. Some of the dikes follow the active bankline and others are older and set back from the active corridor. Examples of dikes on the channel margin are shown in (Figure 15) and (Figure 16). The impact of dikes on the CMZ is described in more detail in Section 4.5.

Figure 15. A 0.8-mile levee on the Lower Jefferson River. (Kestrel)

Figure 16. View (looking downstream) of the Meridian Bridge approach near Willow Creek showing a left bank levee. (Kestrel)

2.5 Bank Armor

Bank armor was mapped where visible on air photos, 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. Additionally, the bank armor inventory has not assessment of condition or functionality. Along the length of the Jefferson River, we mapped 13.3 miles of bank armor which covers about 9% of the total bankline. The bank armor consists of rock riprap, barbs, and other revetments such as wood structures, and potentially concrete rubble.

The extent and impact of bank armoring on the CMZ is described in more detail in Section 4.5.

2.6 Transportation Infrastructure

Mapped transportation infrastructure in the Jefferson River corridor includes highways, rail lines, and minor roads that parallel or cross the river. Transportation infrastructure running down-valley typically constricts the river corridor and channel migration footprint, whereas bridges commonly cause the Channel Migration Zone (CMZ) to "hourglass" through a pinch point created by the bridge approaches and footings.

Road encroachment into the Jefferson River corridor is fairly minimal, with most of the roads in the CMZ consisting of unimproved dirt roads that provide private property access. There is a relatively high concentration of field access roads in the CMZ below the Renova Diversion, near Cardwell, and near Three Forks.

In Jefferson Canyon the rail line locally encroaches into the stream corroder, although most of the rail line was built in non-erosion prone areas that are out of the CMZ.

Seventeen bridges span the entire primary channel or major side channels within the project area. The bridges are dispersed along the river's length, with a local concentration near Three Forks where Interstate-90 (2 spans), local roads (2 spans), and the railroad (1 span) cross the river. These bridges and their associated approaches locally constrict the CMZ, and they are commonly armored and/or leveed to manage alignment of the river through the structure (Figure 17).

Figure 17. Extensive armor associated with the Kountz Road bridge approach. (Kestrel)

3 Methods

The development of the Jefferson River Channel Migration Zone (CMZ) mapping is based on established methods used by the Washington State Department of Ecology (Rapp and Abbe, 2003), and closely follows methodologies used on other rivers in Montana.

3.1 Aerial Photography

CMZ development from historic imagery is dependent on the availability of appropriate imagery that covers the required time frame (50+ years), the spatial coverage of that imagery, and the quality of the photos. It is important to use imagery with the best possible quality, scale, extent, and dates so that historic and modern features can be mapped in sufficient detail.

Several imagery sources are available for the Jefferson River study area. The most recent sources, starting around 1995 with the black-and-white Digital Orthophoto Quad imagery (DOQ) and continuing through the current NAIP (National Agriculture Imagery Program) imagery, are freely available in GIS-compatible format. The quality of these images, both spatially and resolution, ranges from good to excellent and they cover the entire project area.

Imagery older than 1995 must be acquired from various archival services as digital scans, and then mosaiced into a single spatially-referenced image for use in the GIS. For this project, the historic imagery scans were ordered from the United States Department of Agriculture (USDA) Air Photo Field Office (APFO) in Salt Lake City, Utah. Approximately 134 individual images were ordered from the APFO to cover two time periods for the Jefferson River. The area around Three Forks is shared by both the Madison and Gallatin Rivers, so there is some common imagery between the three rivers.

The scans were delivered as high-resolution (12.5 micron) TIFF images, each approximately 330 MB in size. They were then orthorecitified by Aerial Services, Inc. (ASI) in Cedar Falls, Iowa, using 2013 NAIP imagery as the spatial reference, providing identifiable ground control points. The resulting mosaics were assessed for spatial accuracy using National Spatial Data Accuracy standards, and reviewed for image quality. In some areas, the project team requested adjustments to the spatial referencing to provide a higher degree of accuracy.

Table 1 lists imagery used for this project from the USDA and archives of current GIS data sets. Examples of the imagery used in the analysis are shown in Figure 18 through Figure 21.

Table 1. Aerial photography used for the Jefferson River Channel Migration mapping study.

Date	Source	Scale	Notes
1955	USDA APFO	1:20,000	High-resolution Scans (black-and-white)
1979	USDA APFO	1:40,000	High-resolution Scans (black-and-white)
2013 NAIP	NRIS	~ 1 meter resolution	Digital Download, Compressed County Mosaics (color)
2015 NAIP	NRIS	~ 1 meter resolution	Digital Download, Compressed County Mosaics (color)

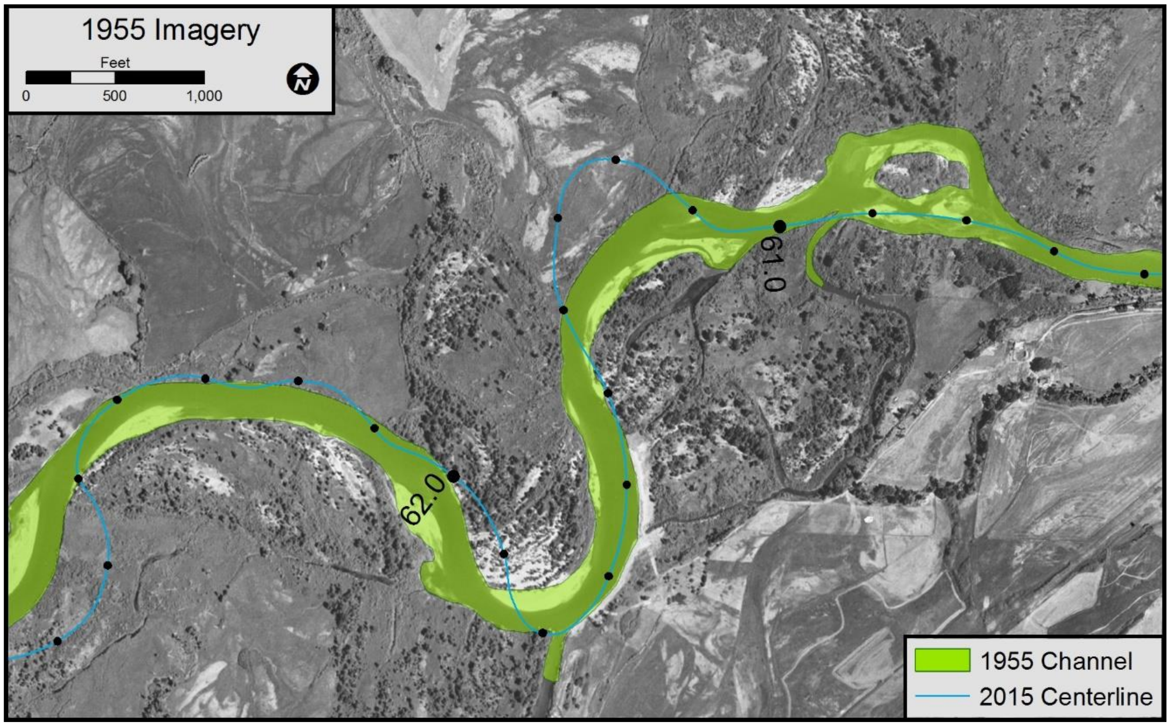

Figure 18. Example 1955 imagery, Jefferson River CMZ development.

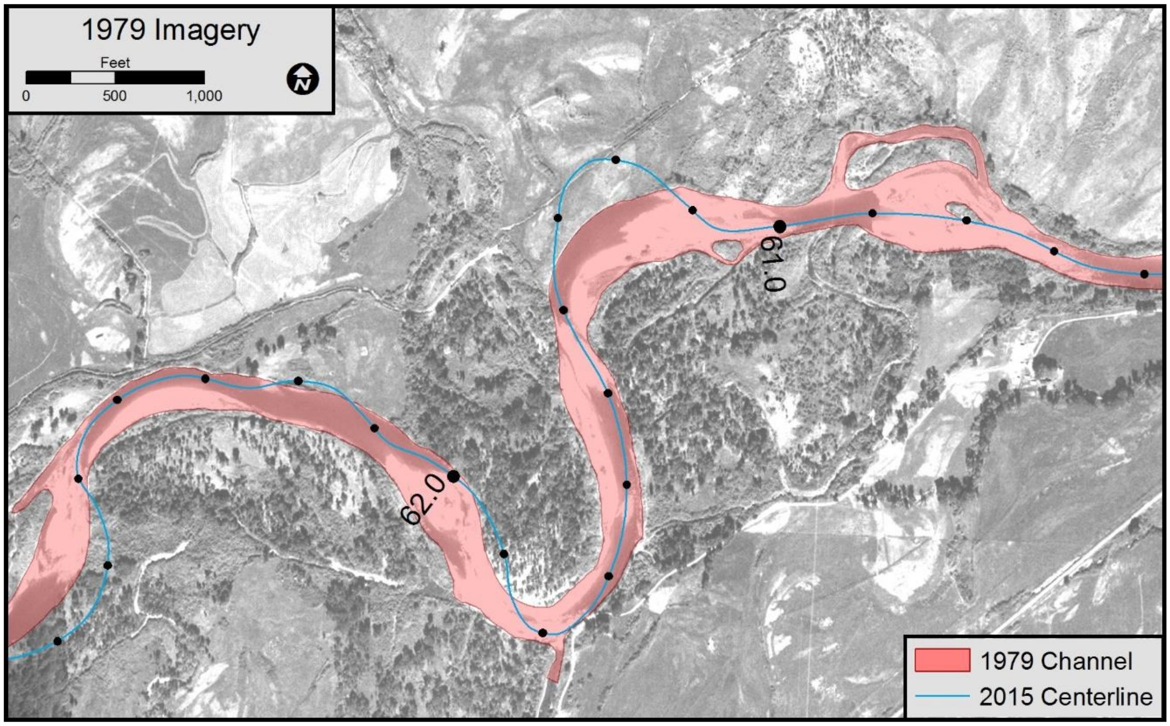

Figure 19. Example 1979 imagery, Jefferson River CMZ development.

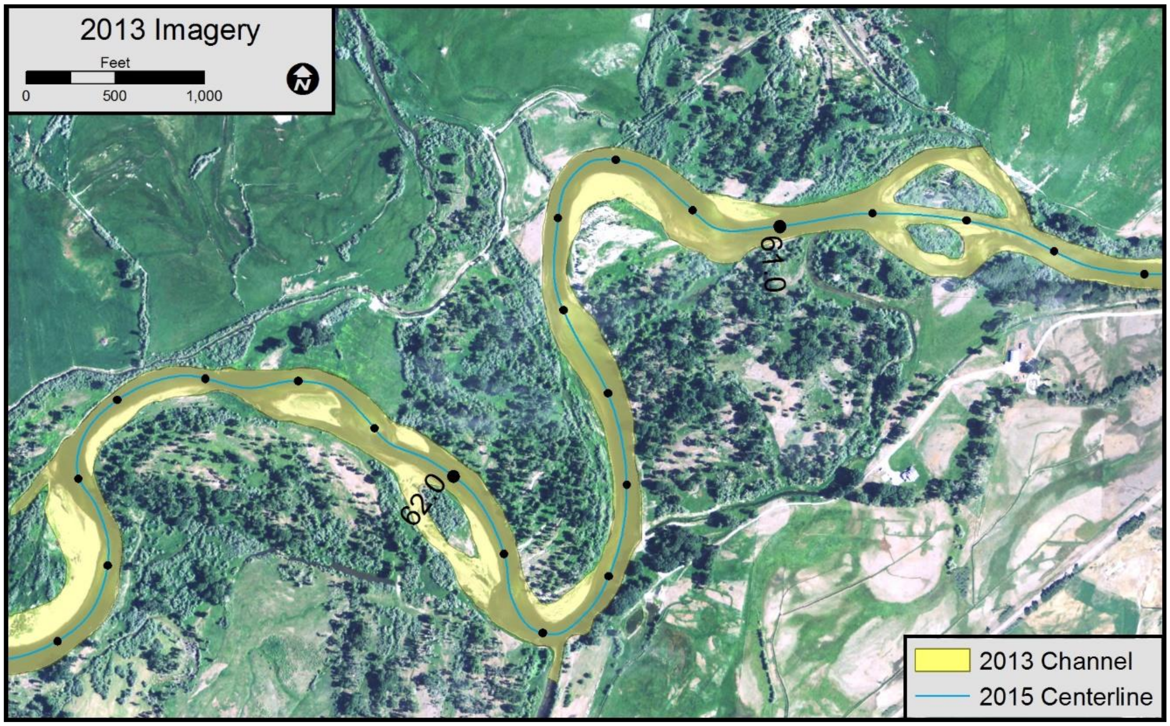

Figure 20. Example 2013 NAIP imagery, Jefferson River CMZ development.

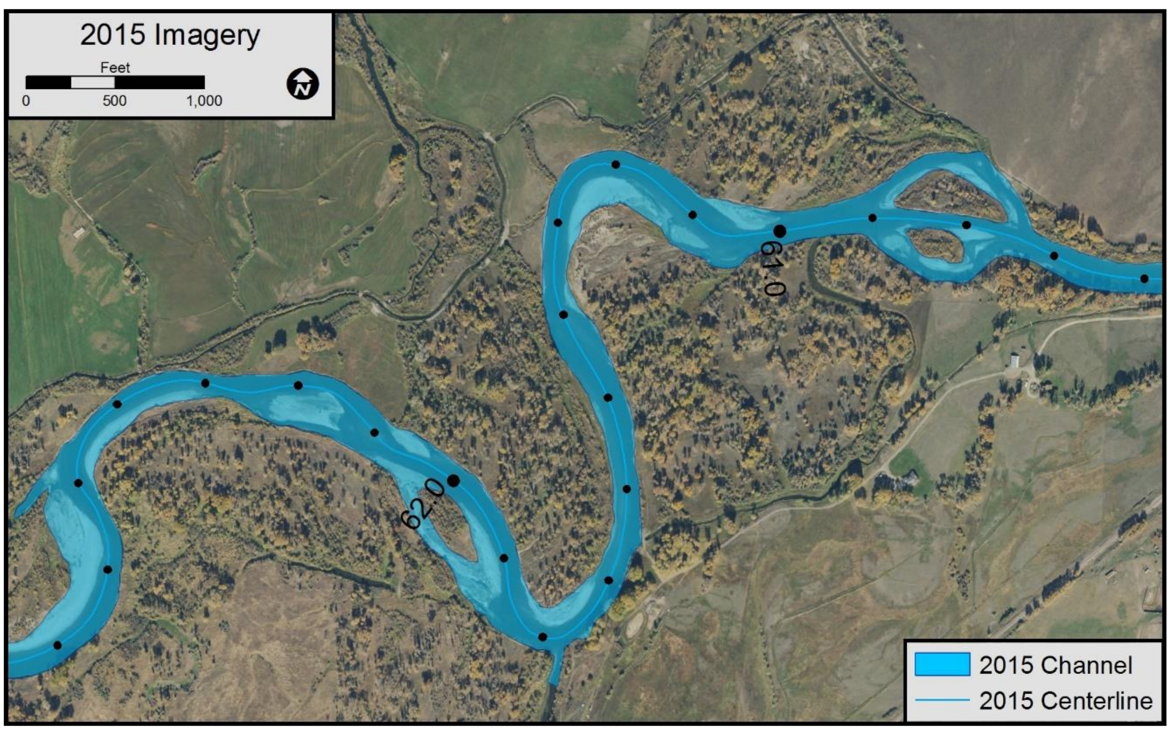

Figure 21. Example 2015 NAIP imagery, Jefferson River CMZ development.

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 2010 Ruby River CMZ Study (AGI/DTM, 2010) utilized this coordinate system as it was the recommended best practice at the time. To be consistent with that study, the Jefferson mapping utilizes this reference system. The orthorectified air photos provide the basis for CMZ mapping; other existing datasets included roads, stream courses as depicted in the National Hydrography Dataset, scanned General Land Office Survey Maps 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 flow starts to spread onto the floodplain. Although that boundary can be identified using field indicators or modeling results (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.

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 approximately every 200 feet (Figure 22). A total of 634 migration vectors were generated for the Jefferson 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 4.3.

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 12 migration vectors, depending on the length of the site. A total of 142 migration sites were identified throughout the study area. An accounting of the reach and site based statistics can be found in Appendix A.

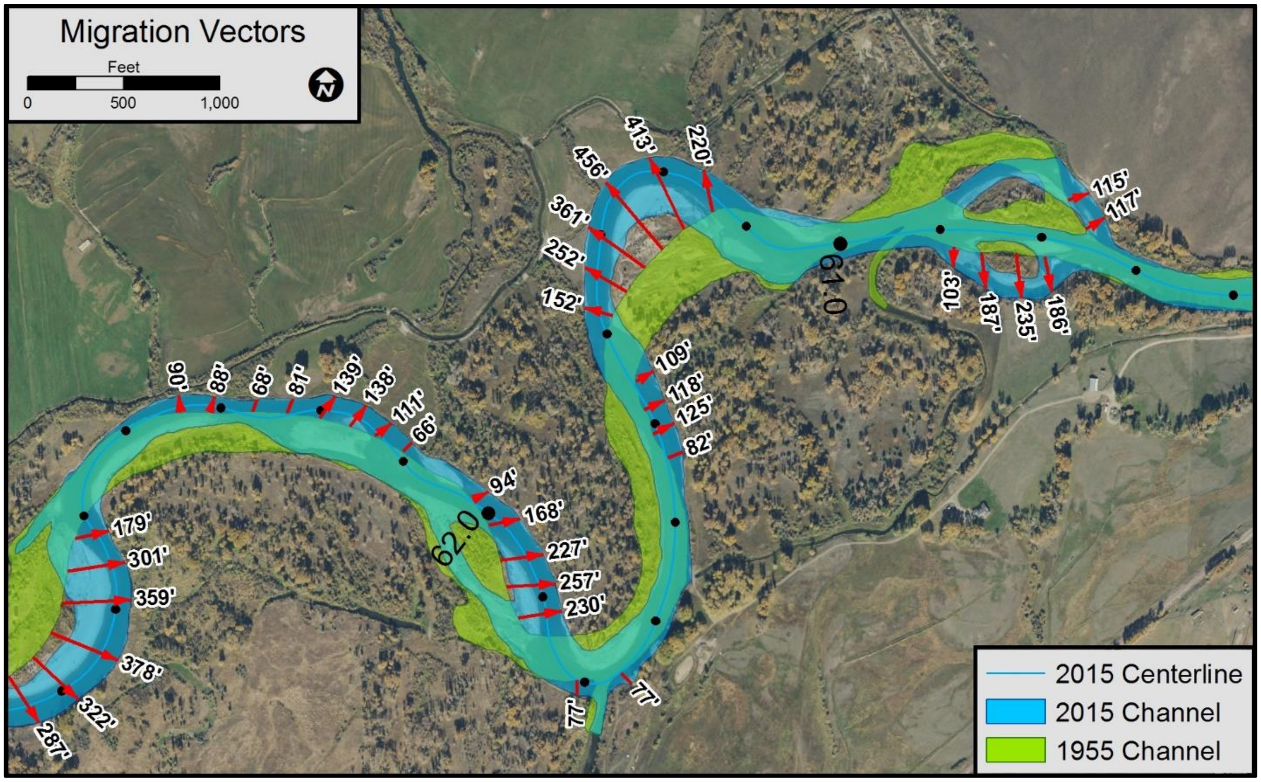

Figure 22. Example of migration measurements between 1955 and 2015 (migration distance in feet).

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.

Inundation modeling is a static model of relative elevations based upon Digital Elevation Model (DEM) data. The 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 elevation 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.

Additionally, the accuracy of an inundation model is directly related to the quality of the elevation data. While high-resolution LiDAR data provides the best results, modeling using 10-meter USGS National Elevation Dataset (NED) still provides sufficient resolution to identify broad trends in the floodplain. For the Jefferson River study area, inundation modeling was generated using the NED dataset (Figure 23).

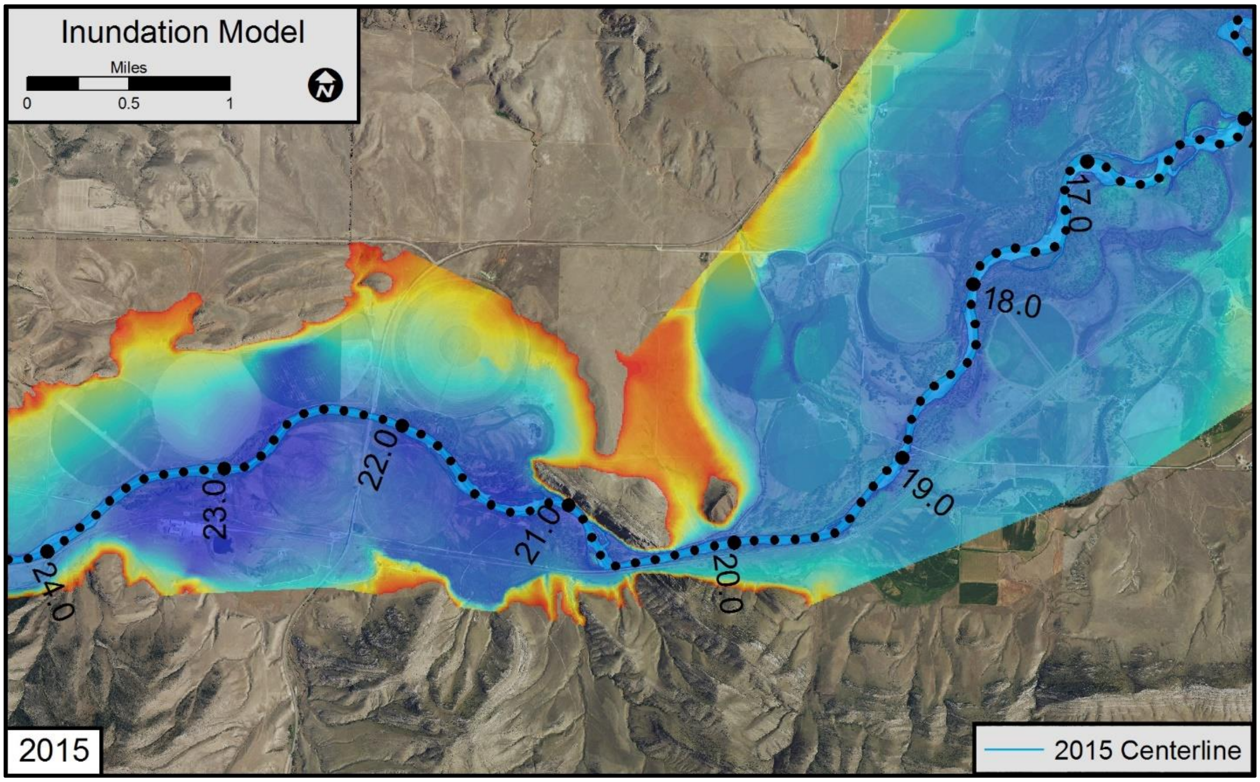

Figure 23. Example Inundation Modeling results. Colors represent elevations relative to the water surface elevation of the main channel. Dark blue areas are equal to or lower than the channel. Yellows and reds are significantly higher than the adjacent main channel.

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. As such, 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 Jefferson 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 24). Additional information used in mapping avulsion paths included oblique photos from Kestrel Aerial Services and air photos.

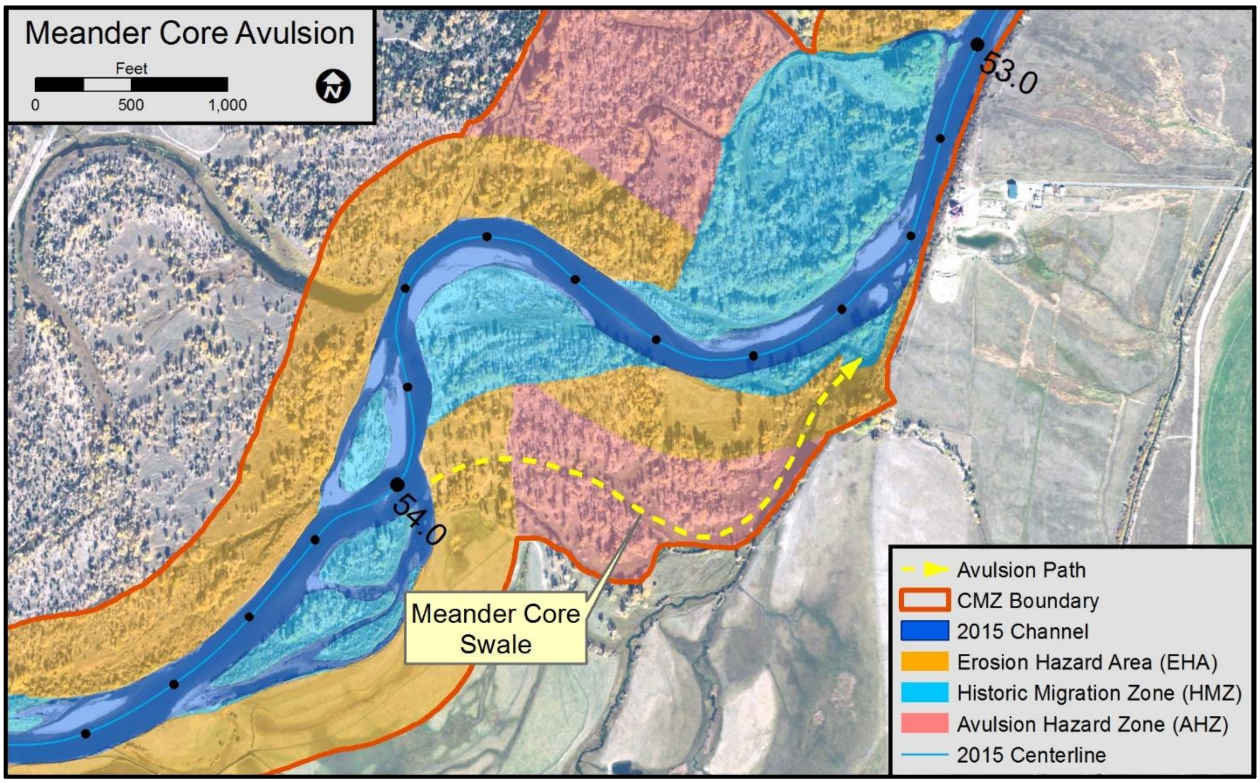

Figure 24. Example meander core swale indicating an avulsion pathway.

4 Results

The Channel Migration Zone (CMZ) developed for the Jefferson 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

The approach to CMZ mapping used here includes a reach-scale evaluation of channel migration rates. For the 76 miles of project length, the river was broken into twelve reaches based on geomorphic character such as river pattern, rates of change, geologic controls, etc. (Figure 29). The reaches range in length from 2.7 to 12.5 miles (Table 2).

Table 2. Jefferson River reaches.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)
JR01	I-90 to Mouth	5.0	0.0	5.0
JR02	Three Forks Road to I-90	8.3	5.0	3.3
JR03	Below Milligan Canyon to Three Forks Road	11.0	8.3	2.7
JR04	Williams Bridge Road to just below Milligan Canyon	18.9	11.0	7.9
JR05	Sappington Bridge to Williams Bridge Road	22.2	18.9	3.3
JR06	LaHood to Sappington Bridge (Jefferson River Canyon)	34.6	22.2	12.4
JR07	Kountz Road to LaHood	43.3	34.6	8.7
JR08	Renova Diversion to Kountz Road	48.2	43.3	4.9
JR09	Upstream of Renova Diversion	53.2	48.2	5.0
JR10	Below Silver Star and Primrose Lane	65.7	53.2	12.5
JR11	Below Cottonwood Creek to Primrose Lane	72.9	65.7	7.2
JR12	Big Hole/Beaverhead Confluence to below Cottonwood Crk	76.0	72.9	3.1

4.2 The Historic Migration Zone (HMZ)

The Historic Migration Zone (HMZ) is created by combining the bankfull channel polygons into a single HMZ polygon. The bankfull channels commonly split and rejoin, creating a mosaic of channel courses with intervening islands, some of which are seasonal. The HMZ footprint includes all channels as well as any area between split flow channels. By including islands, the HMZ captures the entire footprint of the active river corridor from 1955-2015. 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 Jefferson River, however, these areas have been retained in the CMZ since they are made up of young alluvial deposits that are prone to reworking or avulsion, and are thus part of the active meander corridor.

Any side channels that have not shown unrestricted connectivity to the main channel since 1955 were not mapped as active channels and are not included in the HMZ. As a result, miles of channel mapped as active in the General Land Office Survey of the late 1800s are excluded (e.g., Slaughterhouse and Jefferson Sloughs), even though many of these relic channels probably carry water during floods.

For this study, the Historic Migration Zone is comprised of the total area occupied by Jefferson River channel locations in 1955, 1979, 2013 and 2015 (Figure 25). The resulting area reflects 60 years of channel occupation for the length of the Jefferson River.

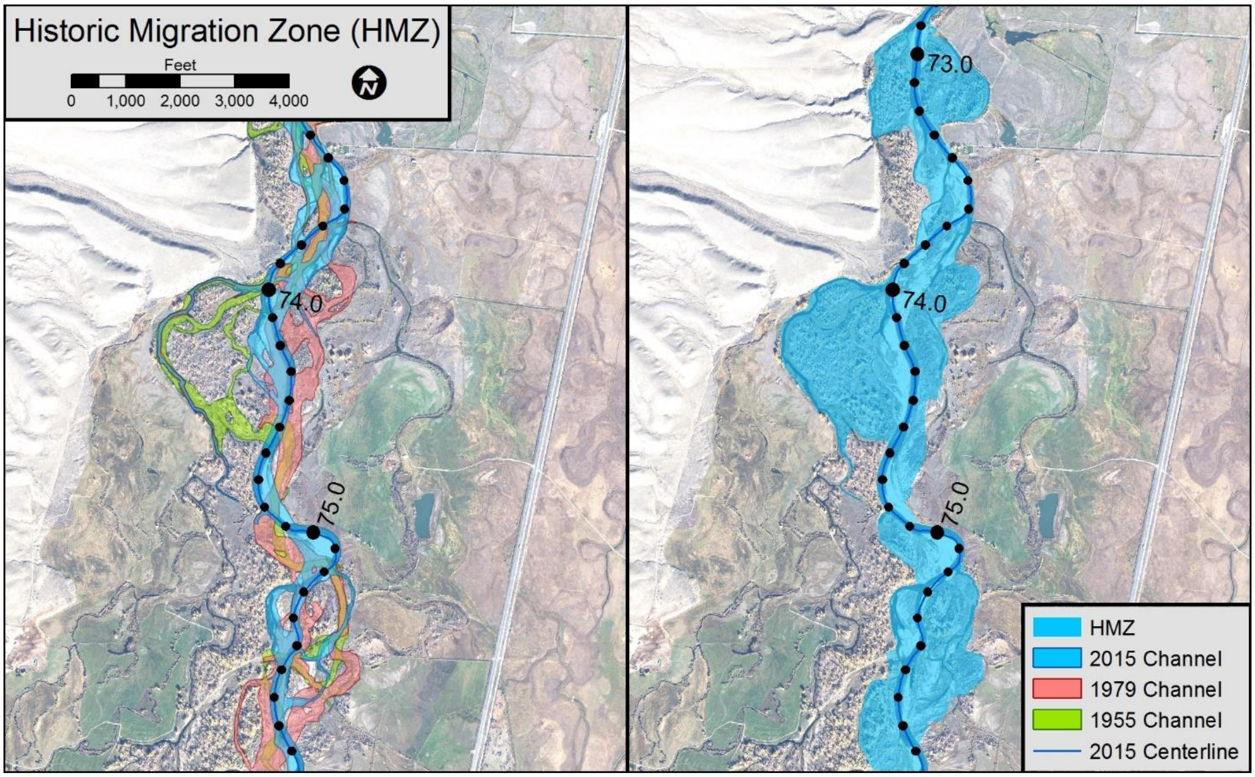

Figure 25. The Historic Migration Zone (HMZ) is the combined footprint of all mapped channel banklines.

4.3 The Erosion Hazard Area (EHA)

The Erosion Hazard Area (EHA) is based on measured migration rates, which are derived from measured migration distances. Migration distances were measured where it was clear that the channel movement was progressive lateral movement and not an avulsion. A total of 634 measurements were collected on the Jefferson River. The minimum distance measured is 25 feet, which proved to be an easily measurable distance that is not compromised by the resolution or spatial accuracy of the data. Migration rates were attributed in terms of the time frame they represented, so that average annual rates could be calculated as accurately as possible. The timeframes recorded include 1955-1979, 1979-2015, and 1955-2015. A summary of the measured migration distances (Figure 26) and calculated migration rates (feet per year) (Figure 27) for each reach and for each timeframe show that channel movement varies both spatially between reaches, and in some cases short-term rates are higher than long-term rates. In Reach JR07 for example, which is below Kountz Road, notably rapid migration occurred between 1979 and 2015 (Figure 27). However, these shorter-term rates represent a relatively small proportion of the total number of measurements, so short-term migration does not disproportionately influence mean migration rates. In Reach JR07 for example, the rapid 1979-2015 rates reflects only two of 74 total measurements (Figure 28). The resulting mean migration rates and EHA buffer widths are shown in Table 3 and Figure 30. The buffer width is calculated as that distance the river would move over a century's time at the mean annual rate.

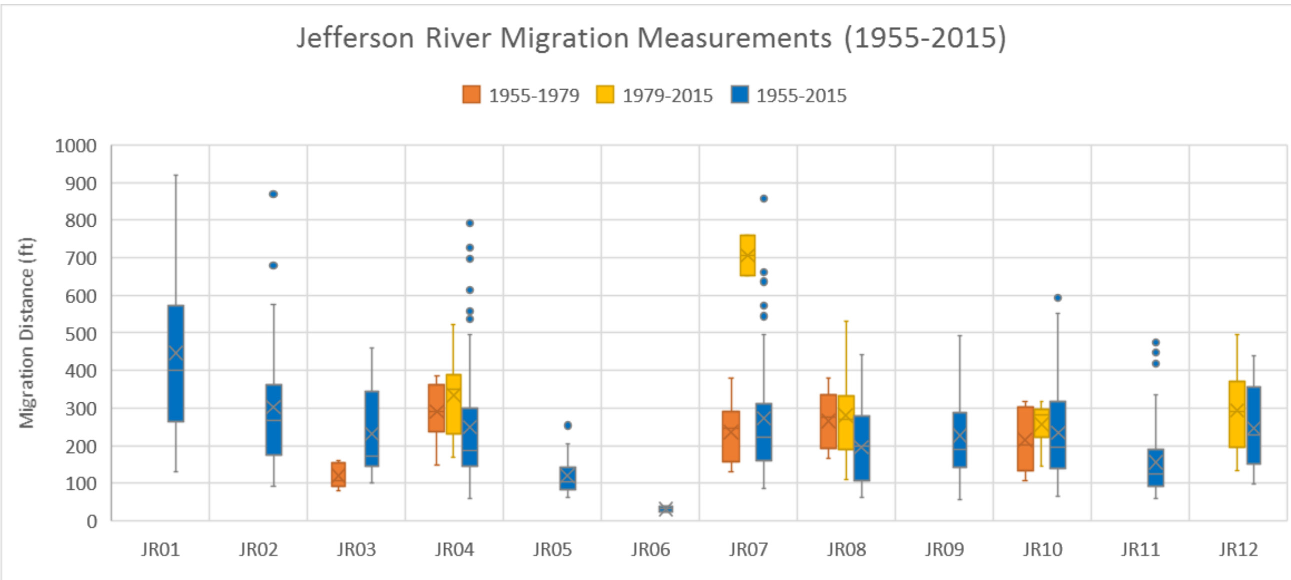

Figure 26. Box and whisker plot showing migration distance measurements for three timeframes.

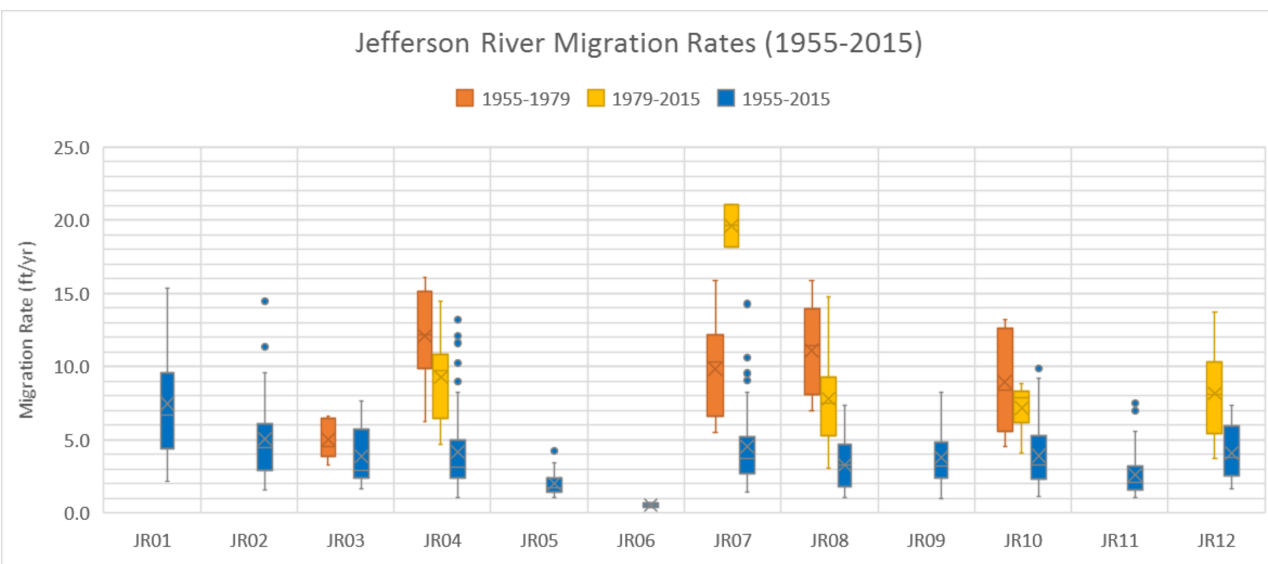

Figure 27. Box and whisker plot showing migration rate measurements for different timeframes.

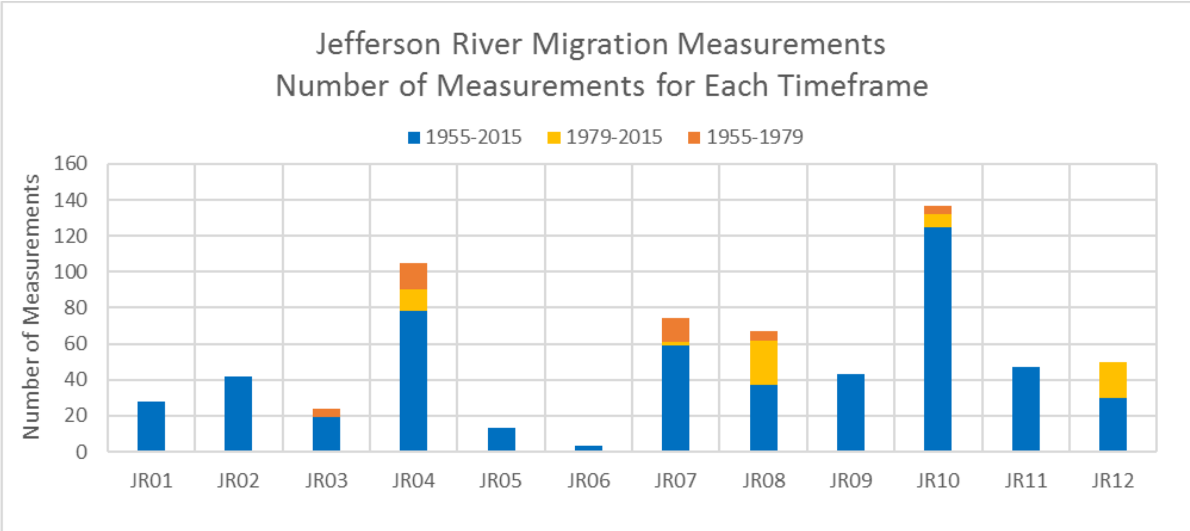

Figure 28. Number of measurements collected for each timeframe by reach.

Table 3. Average migration rate and 100-year EHA buffer by reach.

Reach	Number of Measurements	Maximum Migration Distance (ft)	Average Annual Migration Rate (ft/yr)	100- Year Buffer Width (ft)
JR01	28	919	7.4	744
JR02	42	886	5.0	503
JR03	24	459	4.1	411
JR04	105	792	5.9	588
JR05	13	254	2.0	200
JR06	3	39	0.5	53
JR07	74	858	5.9	588
JR08	67	532	5.5	554
JR09	43	492	3.8	379
JR10	137	601	4.3	426
JR11	47	475	2.6	260
JR12	50	495	5.7	572

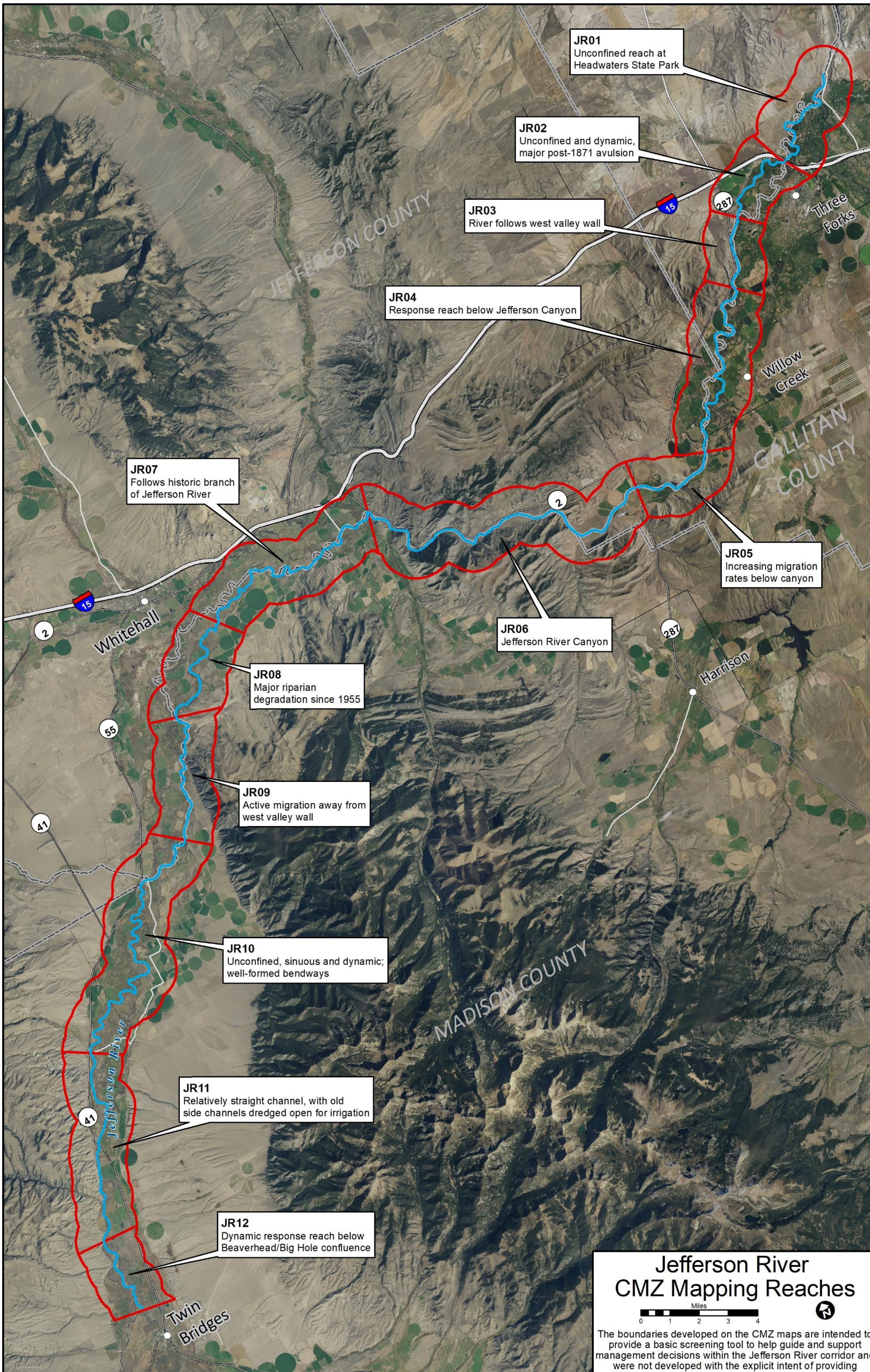

Figure 29. Jefferson River Channel Migration Zone reaches.

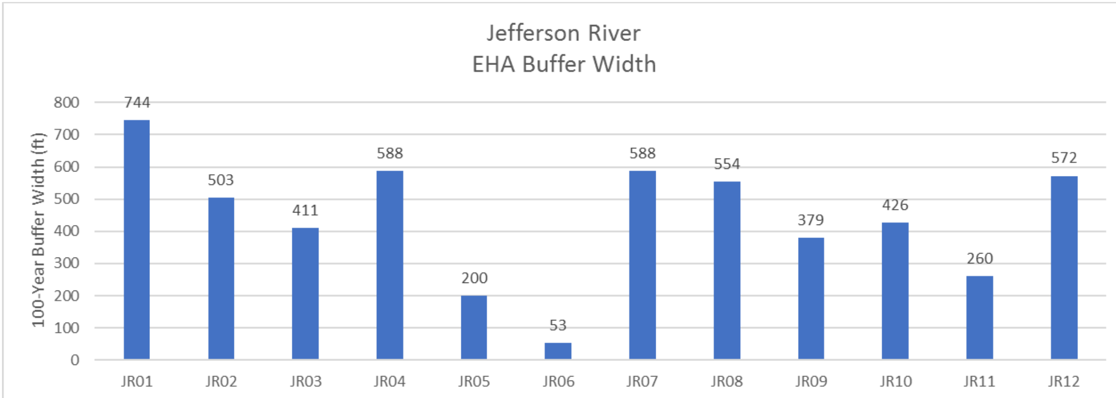

Figure 30. Mean migration rate-based EHA buffer width, Jefferson River.

As the *mean* migration rate is the statistic used to define the EHA buffer, the results are inherently conservative. Thus, some localized channel migration through and beyond the EHA buffer should be anticipated over the next century. Table 3 shows that in several reaches, the 100-year erosion buffer is less than the maximum measured migration distance. Typically, however, these areas of rapid bankline movement are within the Historic Migration Zone, and thereby captured in the CMZ.

The location and intensity of rapid streambank erosion shifts with time. Over a century, areas that currently show no erosion may become more active. Predicting these shifts is difficult due to the number of drivers that can cause these shifts (ice, woody debris, floods, cutoffs, etc.). 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 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 31. 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.

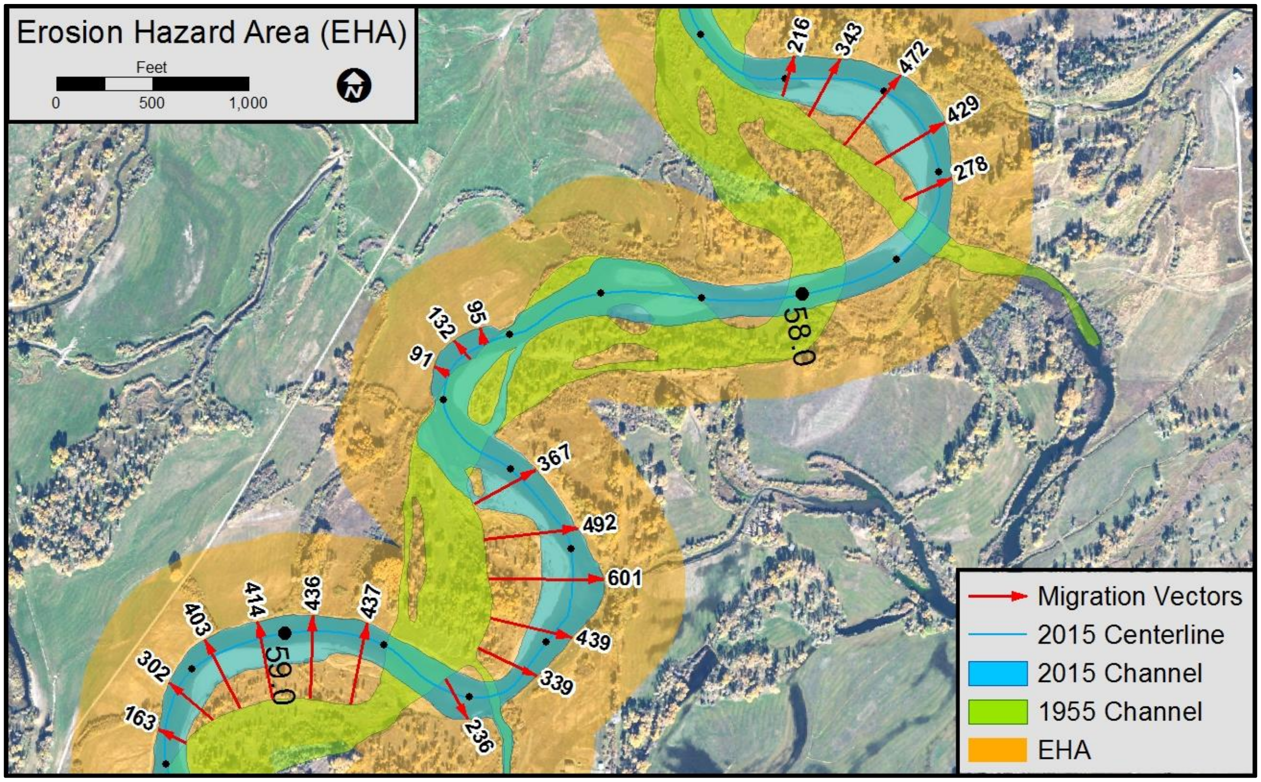

Figure 31. The Erosion Hazard Area (EHA) is a buffer placed on the 2015 banklines based on 100 years of channel migration for the reach.

4.4 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).

A total of 25 avulsions occurred on the Jefferson River between 1955 and 2015, with 14 occurring prior to 1979 and 11 occurring after (Figure 32). Figure 33 shows an example of a major 1955-1979 avulsion in Reach JR12 just downstream of Twin Bridges. The imagery shows a small 1955 floodplain swale that effectively captured the entire river by 1979.

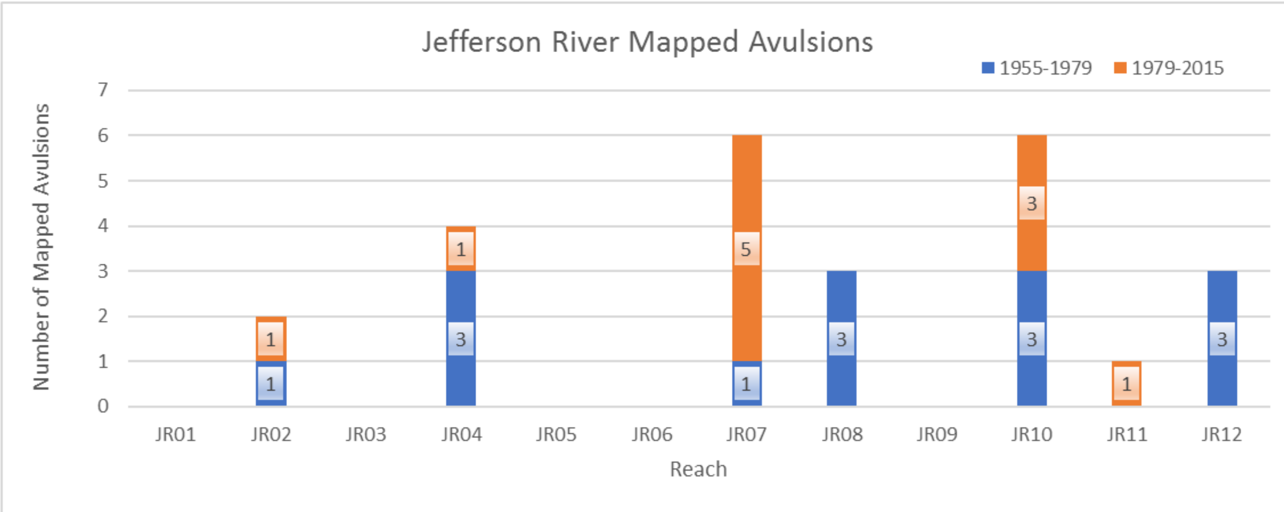

Figure 32. Number of mapped avulsions by Reach, Jefferson River.

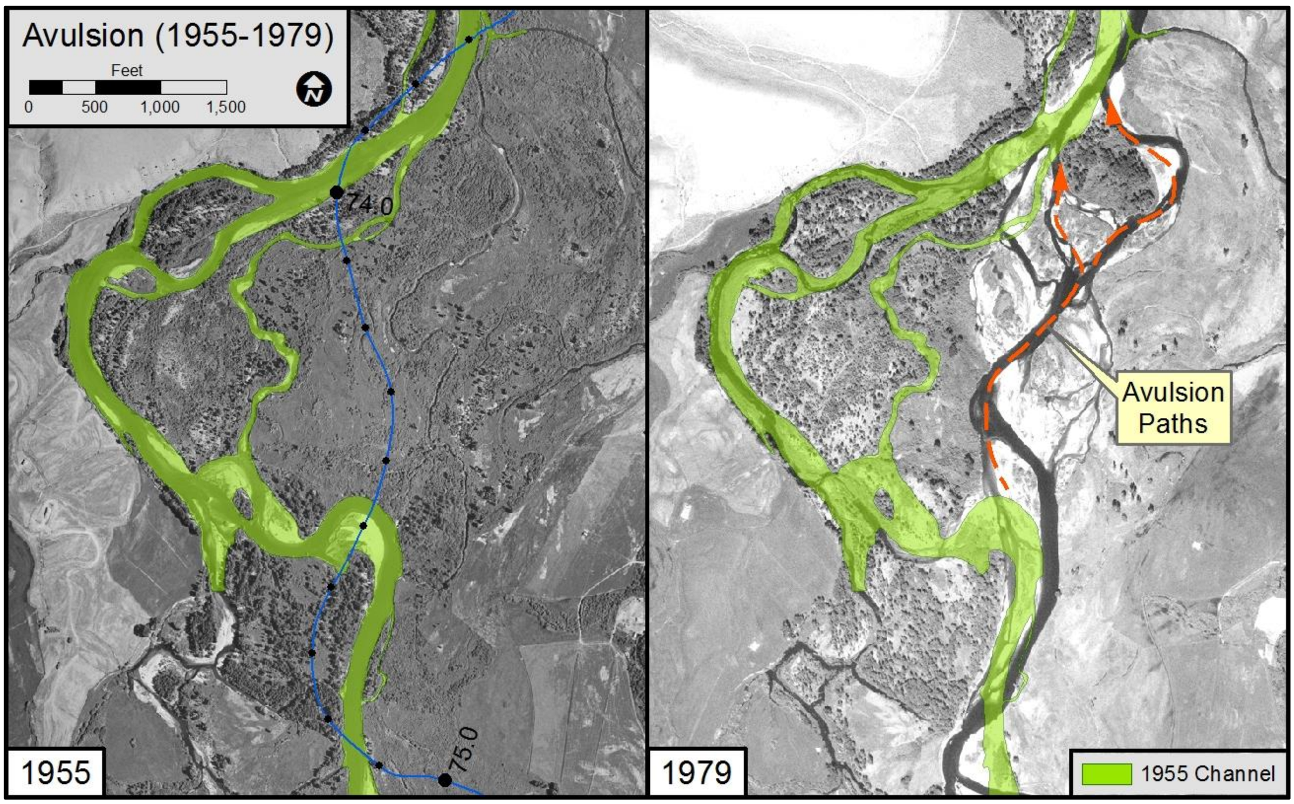

Figure 33. Imagery from 1955 (left) and 1979 (right) showing a major avulsion about 2.5 miles downstream of Twin Bridges.

Avulsion areas were mapped to capture areas of floodplain that, while beyond the HMZ or EHA, show the potential for channel formation Figure 35. Typically, these areas would result in channel shortening between bendways (meander cutoffs) or floodplain swale capture (floodplain avulsion).

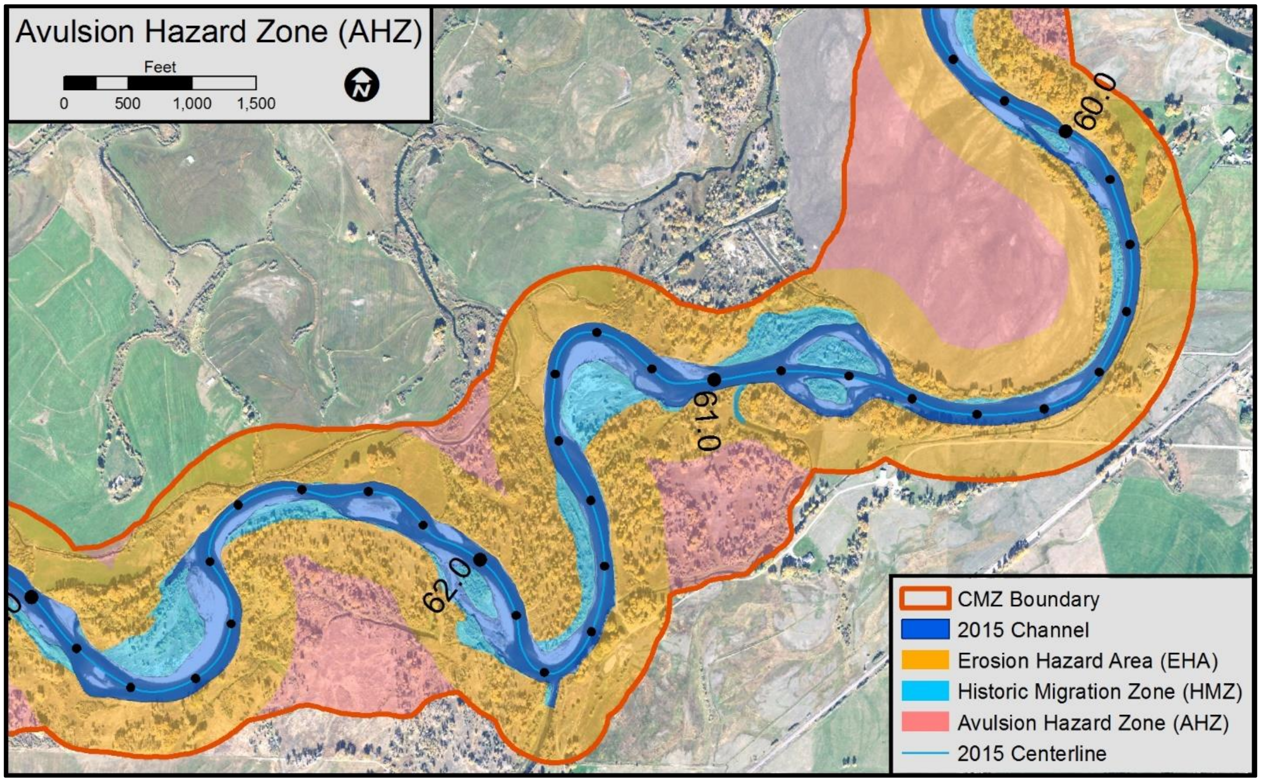

Figure 34. Jefferson River Avulsion Hazard Area mapping, RM61.

4.5 The Restricted Migration Area (RMA)

The extent of migration area that is restricted by physical features is largely dependent on the extent and locations of mapped bank armor, with some additional restrictions by transportation infrastructure.

A total of 13.3 miles of bank armor were mapped on the river. Figure 35 shows that the extent of armored banks ranges from 0% to 14% of the total bankline in any given reach (discounting islands). Only one reach, JR12 at the upstream end of the river, contained no visible armor. The densest armor is in Reach JR04, where about 12,200 feet or 14% of the total bankline is armored to largely protect agricultural fields. Floodplain dikes levees play a lesser role on the Jefferson River (Figure 36), with the total dike length of just over three miles representing about 2% of the bank length river-wide. Reach JR04 near Willow Creek, which has the most bank armoring, also has the most extensive diking, with just over a mile of floodplain mapped dikes.

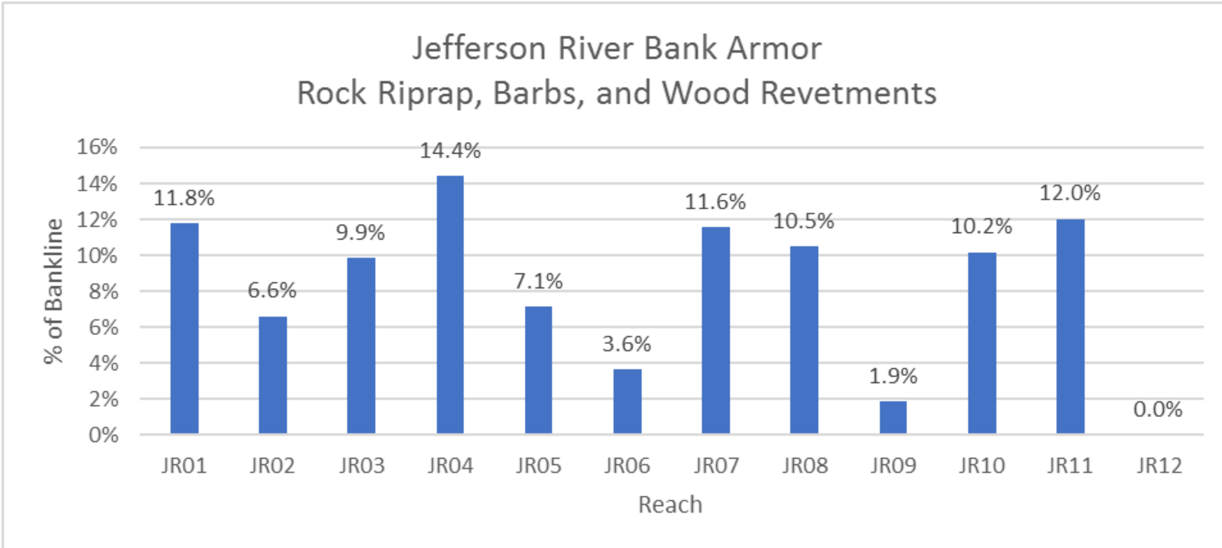

Figure 35. Percentage of bankline protected by armor by reach.

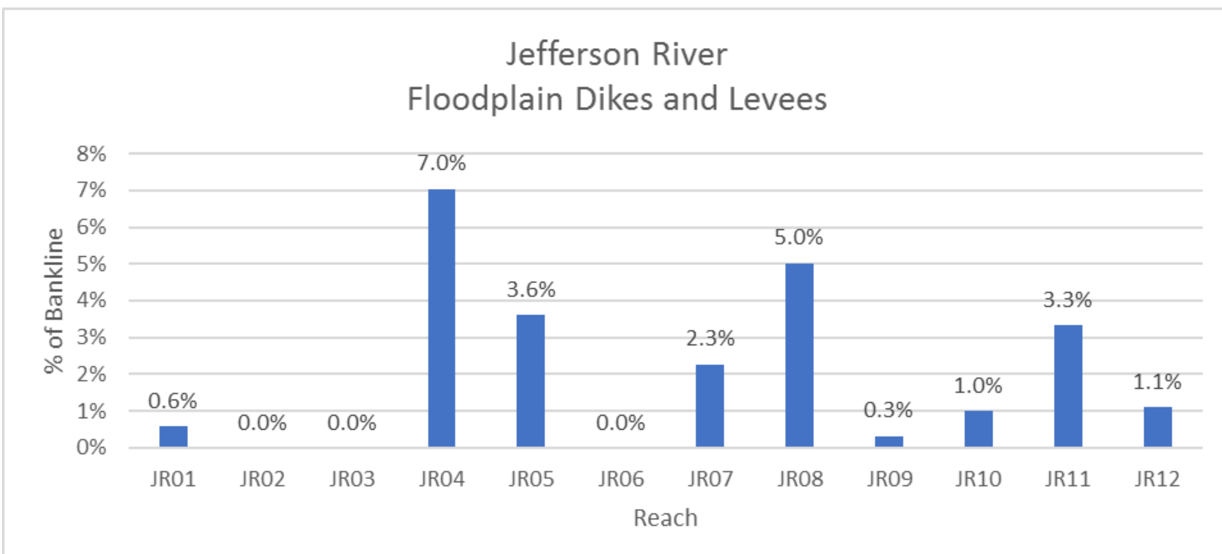

Figure 36. Percentage of bankline protected by berms or levees by reach.

Figure 37 shows an example of Restricted Migration Areas at the Cardwell Bridge. In total, 794 acres of the CMZ are mapped as Restricted, with 616 acres attributed to bank protection and 178 acres to transportation (Figure 38).

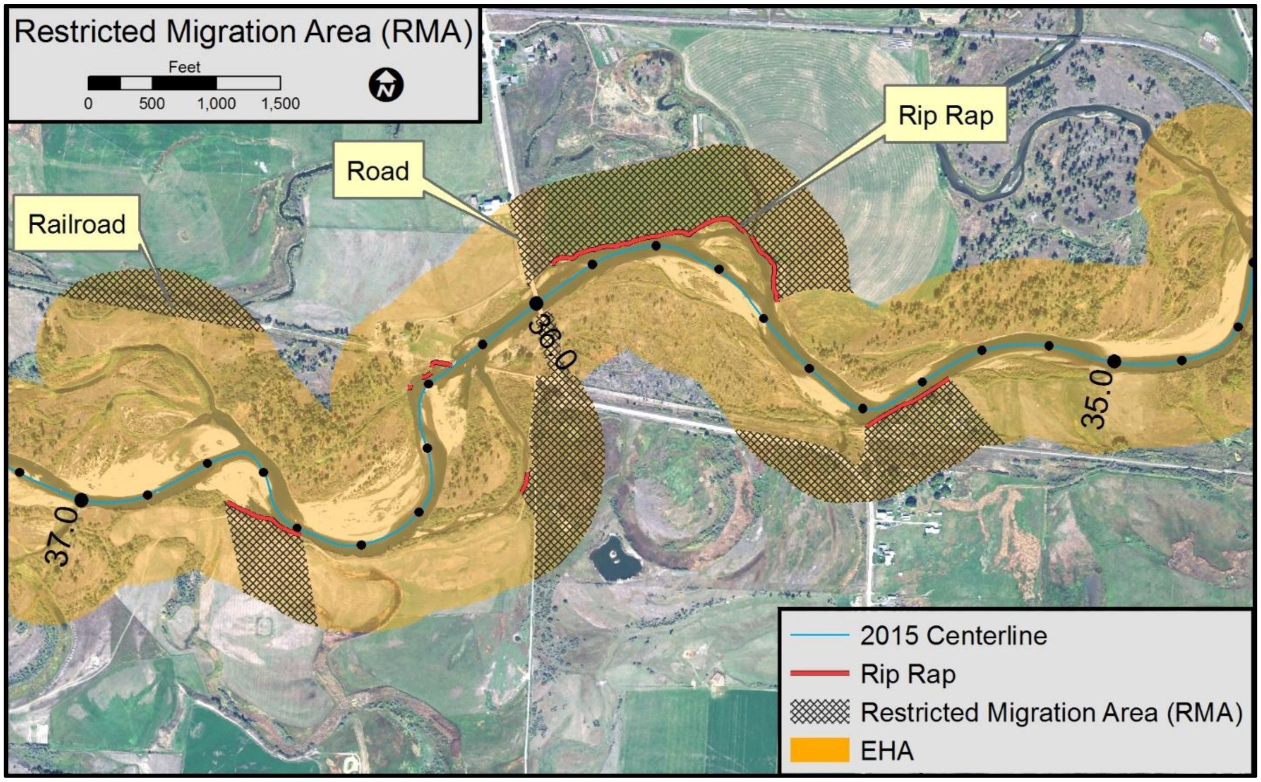

Figure 37. Restricted Migration Areas at Cardwell Bridge.

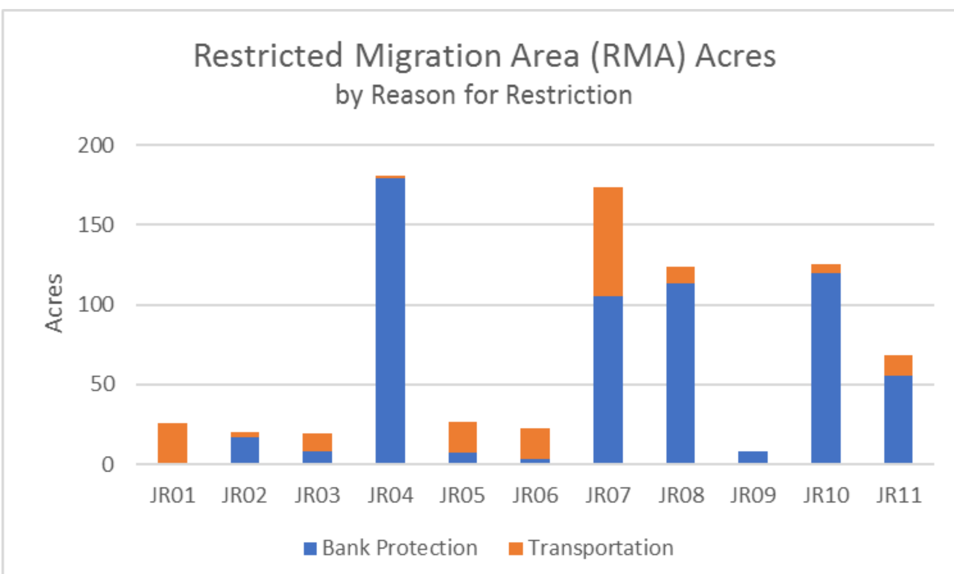

Figure 38. Acres of the CMZ mapped as restricted by reach.

4.6 Composite Map

An example portion of a composite CMZ map for a section of the Jefferson River project area is shown in Figure 39. Each individual mapping unit developed for the CMZ has its own symbology, so that any area within the overall boundary can be identified in terms of its basis for inclusion.

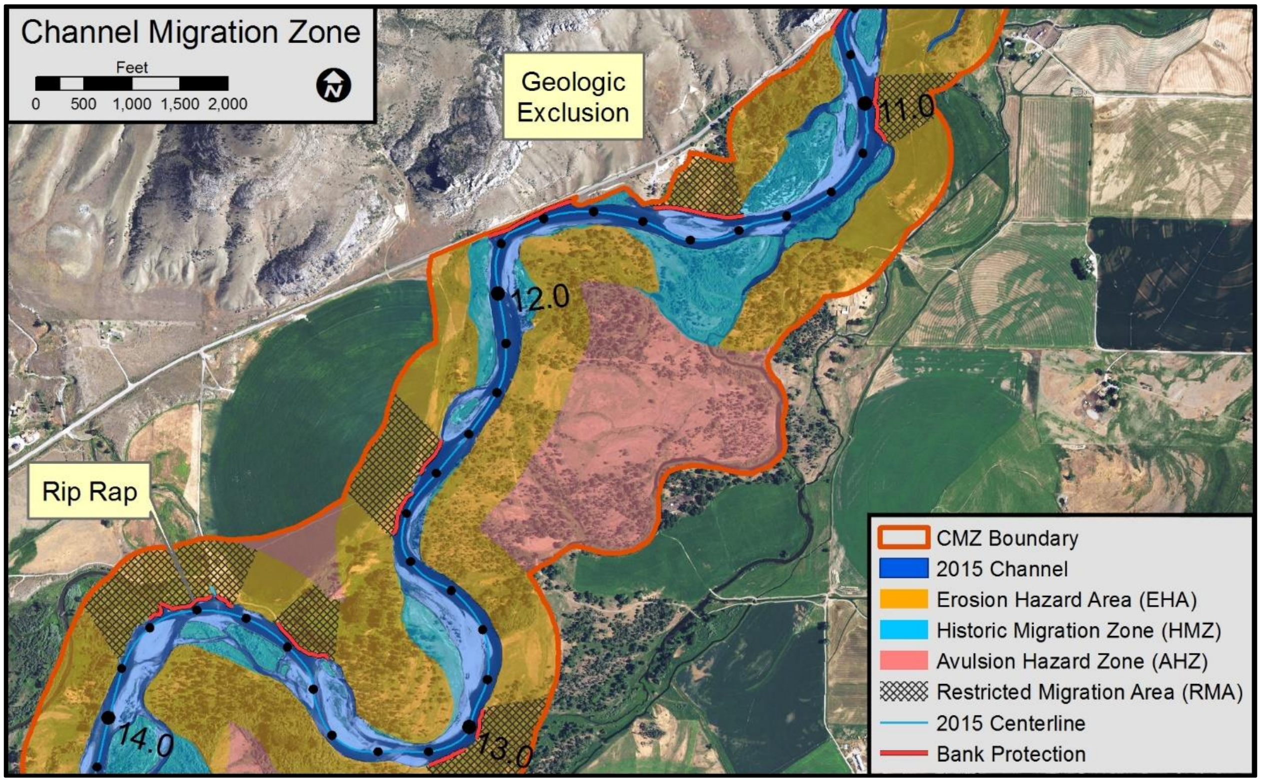

Figure 39. Composite Channel Migration Zone map.

4.7 Geologic Controls on Migration Rate

Many CMZ mapping efforts incorporate a Geotechnical Setback on valley walls, which is an area of expanded Erosion Hazard Area (EHA) against geologic units that may be prone to geotechnical failure such as landslides, slumps, or rockslides. Between Twin Bridges and Three Forks, there are no mapped active landslides against the river, which suggests indicate that the CMZ will not likely be altered by hillslope failure. Even so, Jefferson Canyon could still be prone to rockslides or debris delivery via avalanches that may impact the river's course. 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 Jefferson River Reach Descriptions

The following sections describe each reach of the Jefferson River. The reaches are numbered sequentially from downstream. To best describe the downstream trends in geomorphology and mapping results, they are described below in the opposite order, starting with Reach JR12 at the Jefferson/Big Hole River Confluence, and ending with Reach JR01 at Headwaters State Park. The maps can be found in Appendix D.

Note: All references to River Miles (RMs) reflect the distance upstream from Three Forks along the 2015 channel centerline. River Miles are labeled on the maps in Appendix D. Wherever streambanks or floodplain areas are described as “right” or “left”, that refers to the side of the river as viewed in the downstream direction. For example, “RM6.4R” refers to the right streambank located 6.4 miles upstream of the river’s mouth.

5.1 Reach JR12

Reach JR12		
Upstream/Downstream RM	76.0	72.9
Length (miles)	3.1	
General Location	Immediately downstream of Big Hole/Beaverhead Confluence to below Cottonwood Creek	
Mean Migration Rate (ft/yr)	5.7	
Max 60-year Migration Distance (ft)	495	
100-year Buffer (ft)	572	

Reach JR12 begins about a mile north of Twin Bridges at the confluence of the Big Hole and Beaverhead Rivers, which marks the start of the Jefferson River. The reach is just over three miles long and shows complexity associated with the confluence of two very different river systems. Although the Big Hole River watershed is about three quarters the size of the Beaverhead/Red Rock contributing drainage areas, the mean annual discharge of the Big Hole River at Melrose (about 1,100 cfs) is about three times that of the Beaverhead at Twin Bridges. The Big Hole River also has a coarse sediment load that results in active sediment storage and channel migration where it enters the Jefferson River Valley.

The mouth of the Big Hole River was about 0.5 miles north of its current location in 1955. The confluence area hosts a complex network of active channels, side channels, and ditches; along with high sediment loading the area is prone to relatively rapid rates of change. One of the largest avulsions mapped in project area occurred between 1955 and 1979 at River Mile 74.5 where a bendway cut off through a half-mile long swale, relocating the river 0.4 miles eastward on the Jefferson River floodplain and shortening the main channel by about 2,500 feet (Figure 40).

Although channel migration and avulsions in Reach JR12 have caused rapid bank erosion, these changes have generated excellent conditions for aquatic and riparian habitat. The wide swaths of open gravel bars in Reach JR12 have become colonized by young riparian vegetation and active side channels are common (Figure 41). No bank armor was mapped in the reach.

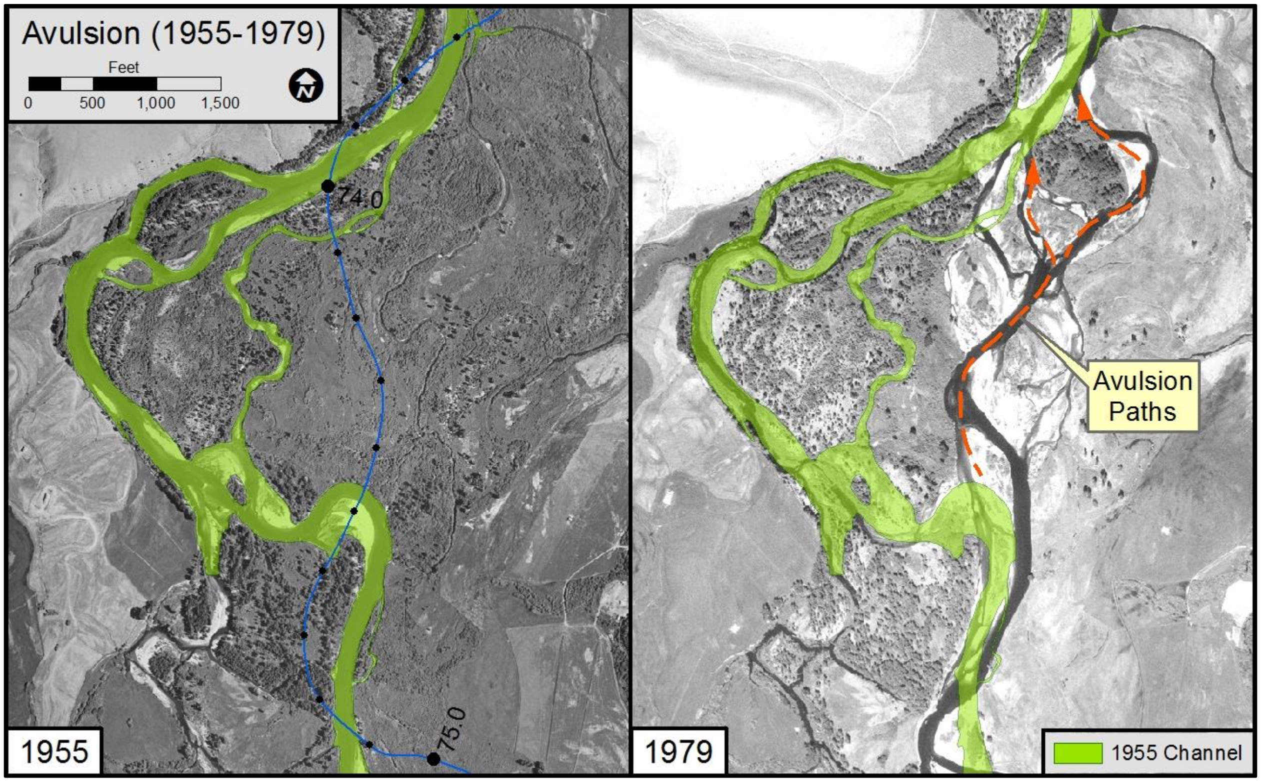

Figure 40. Air photos from 1955 (left) and 1979 (right) showing Reach JR12 avulsion.

Figure 41. View downstream of open gravel bars, riparian colonization and active side channels, RM 74, Reach JR12. (Kestrel)

There has been some development within the CMZ in Reach JR12 where residences are demonstrably at risk of river erosion. At RM 73.4, for example, a home is about 200 feet landward of the right bank of the river, located between the active river channel and an historic swale that has been partially excavated to create a pond. The maximum migration distance measured in Reach JR12 is 495 feet, and the EHA buffer width is 592 feet, placing the residence well within the CMZ. Air photos indicate that between 2011 and 2013, buried rock revetment was placed upstream of the structure where the bank has been rapidly migrating in that direction (Figure 42).

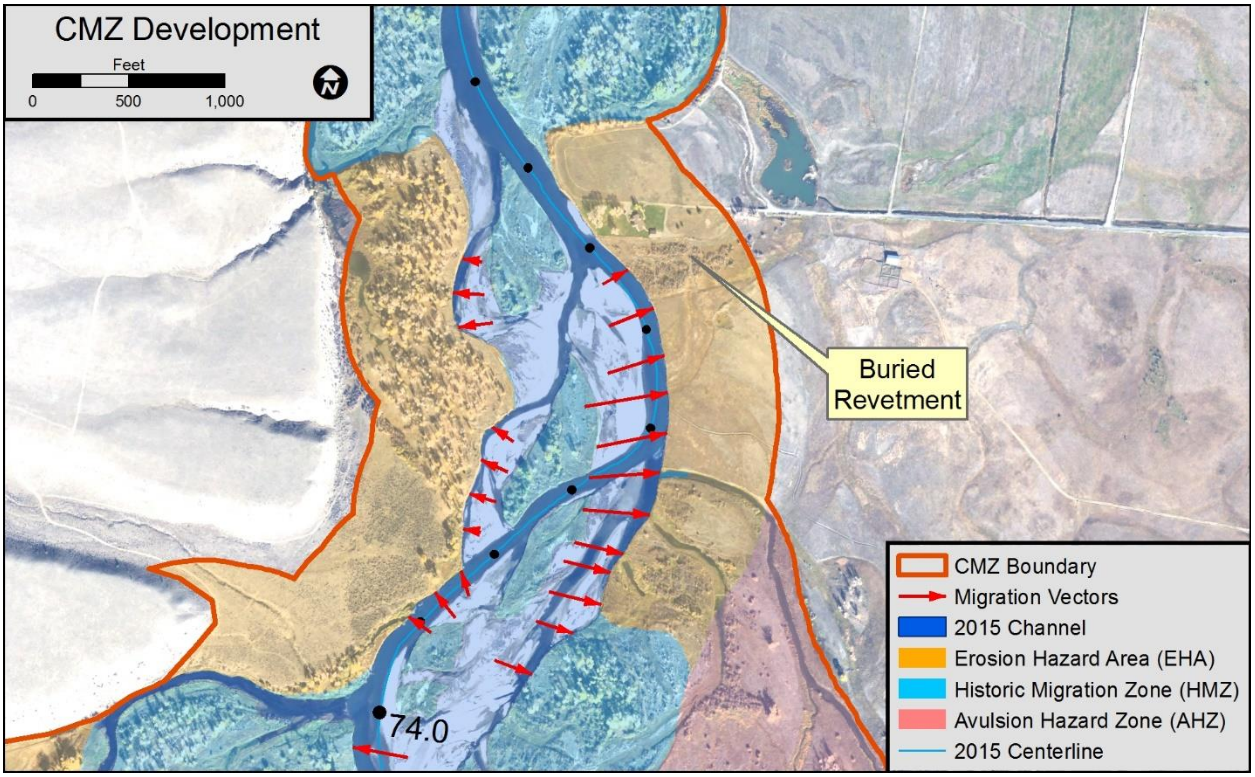

Figure 42. Example of CMZ development, Reach JR12.

5.2 Reach JR11

Reach JR11		
Upstream/Downstream RM	72.9	65.7
Length (miles)	7.2	
General Location	Below Cottonwood Creek to Primrose Lane	
Mean Migration Rate (ft/yr)	2.6	
Max 60-year Migration Distance (ft)	475	
100-year Buffer (ft)	260	

Reach JR11 is 7.2 miles long and extends from just below the mouth of Cottonwood Creek to Primrose Lane. It is a relatively straight reach and has about half the mean migration rate than Reach JR12 upstream. The reach is moderately confined by the left valley wall that is made up of sedimentary rocks of the Sixmile Creek Formation. Similar to Reach JR12 upstream, there has been some residential development within the Erosion Hazard Area (Figure 43). Bank armor is common, with about 12% of the bankline protected by some form of armor, which protects both structures and irrigated fields. At RM 71.8, there is flanked riprap in the channel (Figure 44), and at RM 68.8, rock has been piled on an eroding streambank, apparently as "launchable riprap" that will armor the bank as erosion proceeds. With a 100-year erosion buffer of 260 feet but a maximum measured 60-year migration distance of 475 feet, Reach JR11 has a strong potential to locally migrate beyond the mapped CMZ boundary over the next century.

There is notably less sediment storage and active channel migration in Reach JR11 relative to adjacent reaches. Sediment transport is clearly active in the reach. However, there is evidence that old side channels require dredging to keep them open and able to carry irrigation water to diversions on those channels, which in some cases were the main thread in the GLO mapping (Figure 45 and Figure 46). The Parrot Canal Diversion at RM 68.5 requires mid-channel berming for its operation (Figure 47).

Figure 43. View downstream of bank armor protecting home and field, RM 72.1, Reach JR11. (Kestrel)

Figure 44. Flanked left bank riprap in channel, RM 71.8L. (Kestrel)

Figure 45. View downstream of dredging at head of side channel that supplies irrigation water, RM 71.1 Reach JR11. (Kestrel)

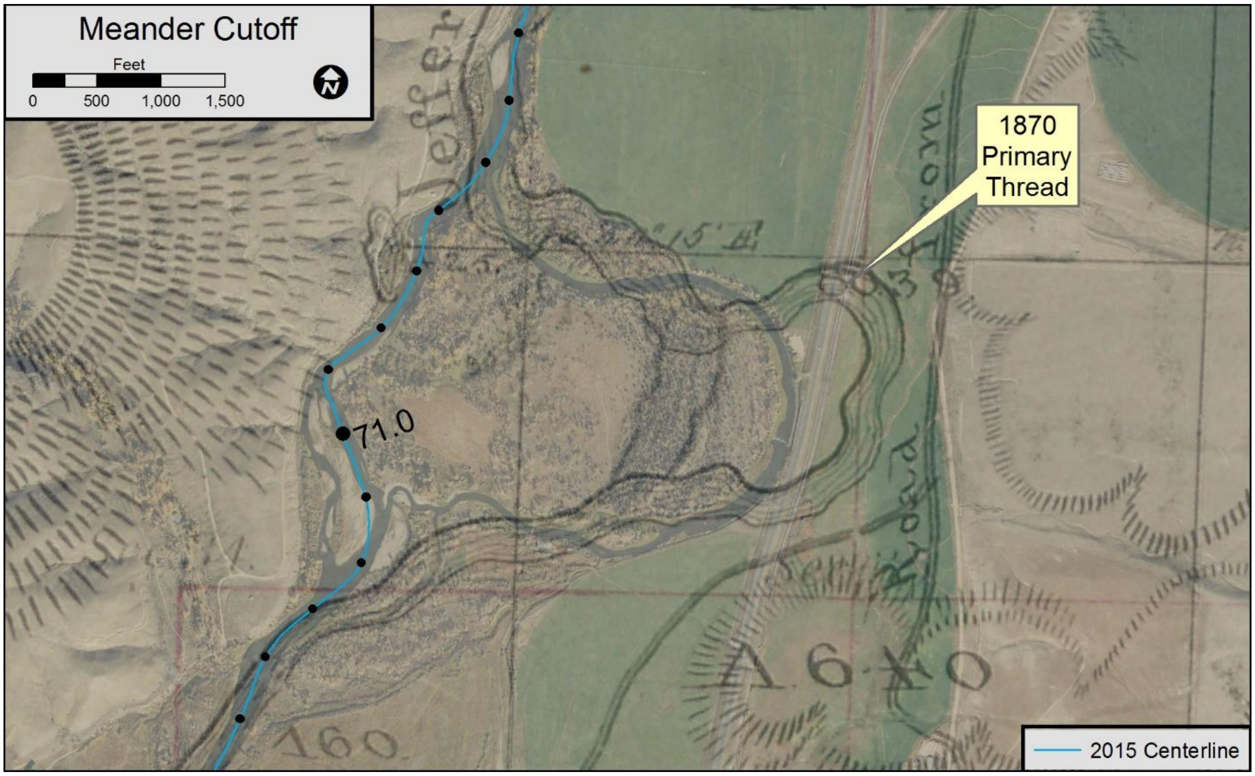

Figure 46. GLO map showing large meander cutoff and loss of main thread to support irrigation at RM 71.1.

Figure 47. In-channel berming and side work at head of Parrot Canal, RM 68.54. (Kestrel)

5.3 Reach JR10

Reach JR10		
Upstream/Downstream RM	65.7	53.2
Length (miles)	12.5	
General Location	Below Silver Star and Primrose Lane	
Mean Migration Rate (ft/yr)	4.3	
Max 60-year Migration Distance (ft)	601	
100-year Buffer (ft)	426	

Reach JR10 is a relatively long 12.5 mile river segment located below Silver Star. The reach is unconfined and dynamic, with actively migrating large meander bends common. The broad river valley is bound on both sides by older terraces and alluvial fans. The average migration rate in Reach JR10 is 4.3 feet per year, and the maximum migration distance measured since 1955 is 601 feet. About 10% of the banks are armored. The reach supports some long side channels which contribute to geomorphic complexity and instream habitat.

About 2.5 miles downstream of Silver Star, a series of bendways experienced two avulsions prior to 1979, and a third prior to 2015, showing how rapidly a channel course can change on the Jefferson River (Figure 48 and Figure 49). The reach also has a good example of bendway compression due to bank armoring on the downstream limb of a meander (Figure 50). There is flanked riprap in the channel at the upper avulsion site (RM64).

Similar to Reach JR11 upstream, the 100-year erosion buffer width (426 feet) is notable lower than the maximum migration distance measured in the reach over 60 years (601 feet), indicating that site-specific erosion rates can be very high, and local channel migration beyond the mapped CMZ boundary is likely over the next century.

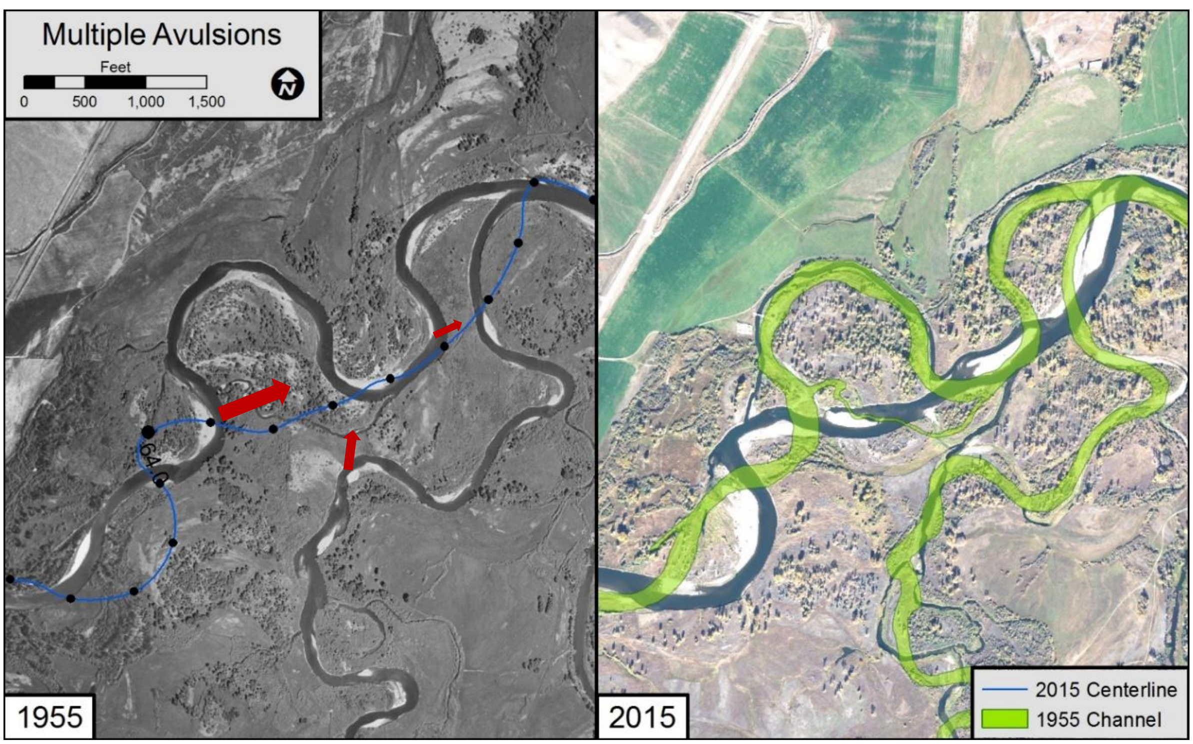

Figure 48. Imagery from 1955 (left) and 2015 (right) showing three avulsions and resulting channel straightening below Silver Star.

Figure 49. Post-avulsion channel widening, RM64. (Kestrel)

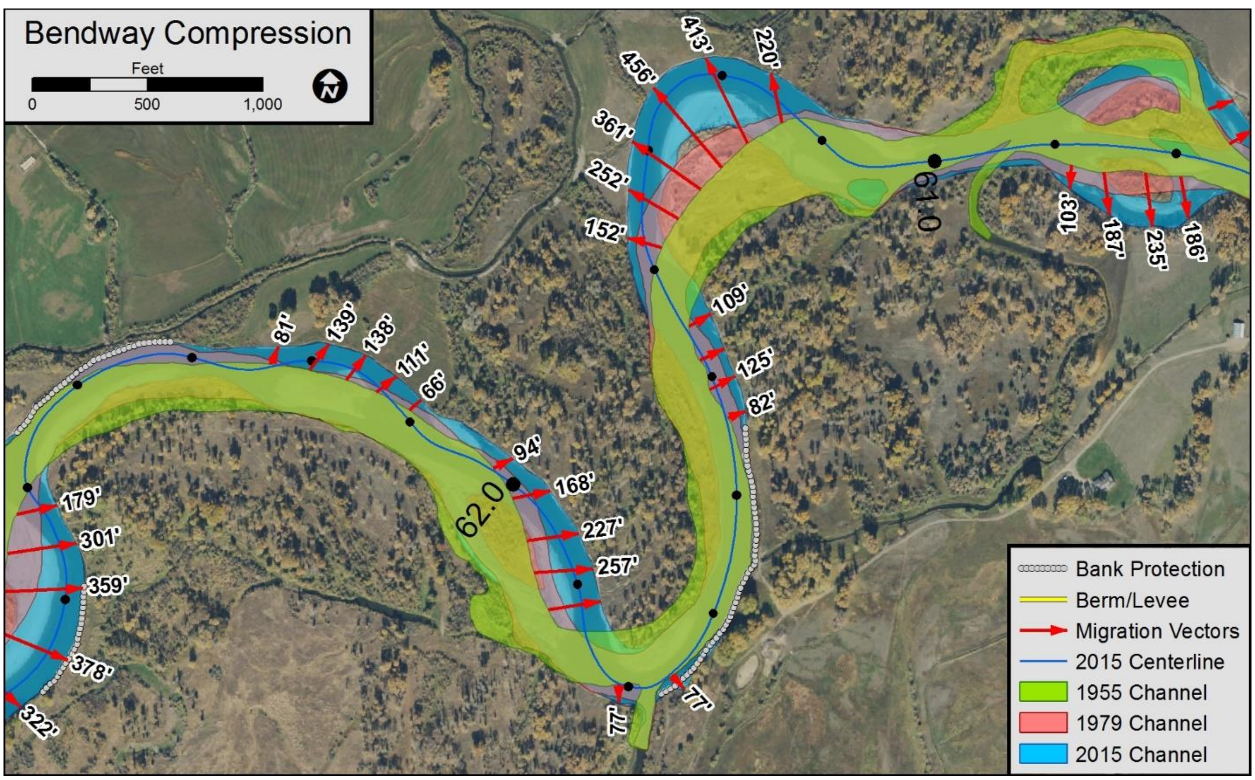

Figure 50. Meander compression on bendway "pinned" by bank armor (grey dots); flow is from left to right.

5.4 Reach JR09

Reach JR09		
Upstream/Downstream RM	53.2	48.2
Length (miles)	5.0	
General Location	Upstream of Renova Diversion	
Mean Migration Rate (ft/yr)	3.8	
Max 60-year Migration Distance (ft)	492	
100-year Buffer (ft)	379	

Reach JR09 is located upstream of the Renova Diversion, where the river follows the east valley wall along alluvial fans in the upstream portion of the reach and older sedimentary rocks closer to the Renova Diversion. Migration in the reach is active where the river is pulling away from the valley wall. The river is anomalously steep in this reach, which may be in part due to bedrock controls. The valley wall trends parallel to the Tobacco Root Fault which follows the base of the Tobacco Root Mountains, and Renova Hot Springs are on the mapped fault trace where it follows the river.

The Renova Diversion structure was constructed in response to the progressive abandonment of an old side channel that is used as a canal. In 1955, there was no diversion structure in the river. In 1979, berms were built to divert flow. By 1995 a small rock structure had been built, and that structure was expanded to a large, permanent composite structure by 2009 (Figure 52). This expansion of the structure was accompanied by the formation of a large island upstream of the diversion that drove erosion on both banks, essentially doubling the river width from 1955 to 2015 (Figure 53).

The Renova Diversion structure is a major part of the Jefferson Valley irrigation system. It conveys water through a complex series of sloughs, canals, and ditches throughout the valley, so there has been continued concern over its stability and long-term function. The mapping shows relatively high rates of migration just above the diversion as well as on a bendway upstream, creating both an additional erosion hazard as well as an avulsion hazard on the floodplain upstream of the diversion (Figure 54). This, in turn, has altered the river configuration at the diversion structure and will require careful monitoring. Based on historic migration patterns it is feasible that the river will continue to pull away from the bedrock valley wall on the eastern edge of the valley (Figure 55).

The side channels that come off of the Renova Diversion, including Slaughterhouse Slough, were mapped as overflow paths but were not mapped as demonstrable avulsion risks. The historic channel routes are substantially longer than the existing channel, have been decaying with time, and there is no compelling evidence to support mapping an avulsion risk. The side channel has been naturally degrading since the 1950s and would probably be closed off without the addition of diverted water. That said, assessing the avulsion risk at the Renova Diversion is complicated by the diversion structure itself as well as site management that will tend to promote the continued conveyance of flow through the side channel. An avulsion around the Renova Diversion and into the old side channels is a possibility if river management at the structure results in forcing flows into those side channels without maintaining sufficient conveyance down the main thread.

Figure 51. View downstream of right bank structures on an alluvial fan that are out of the CMZ. (Kestrel)

Figure 52. Renova Diversion Structure. (Kestrel)

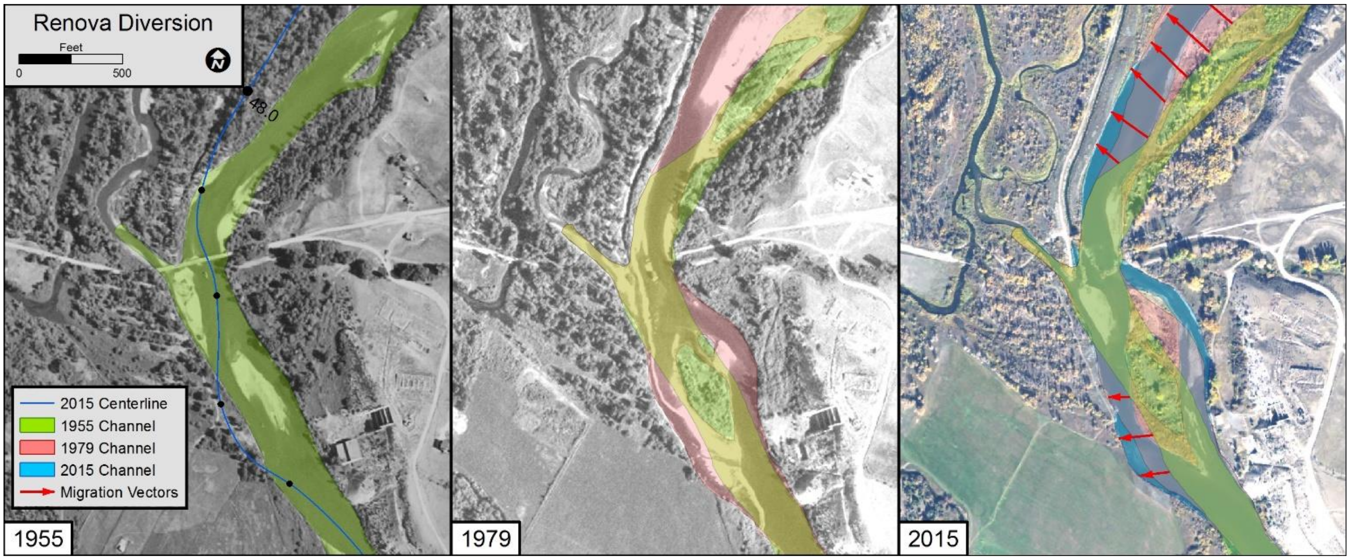

Figure 53. Renova Diversion site in 1955 (left), 1979 (middle) and 2015 (right).

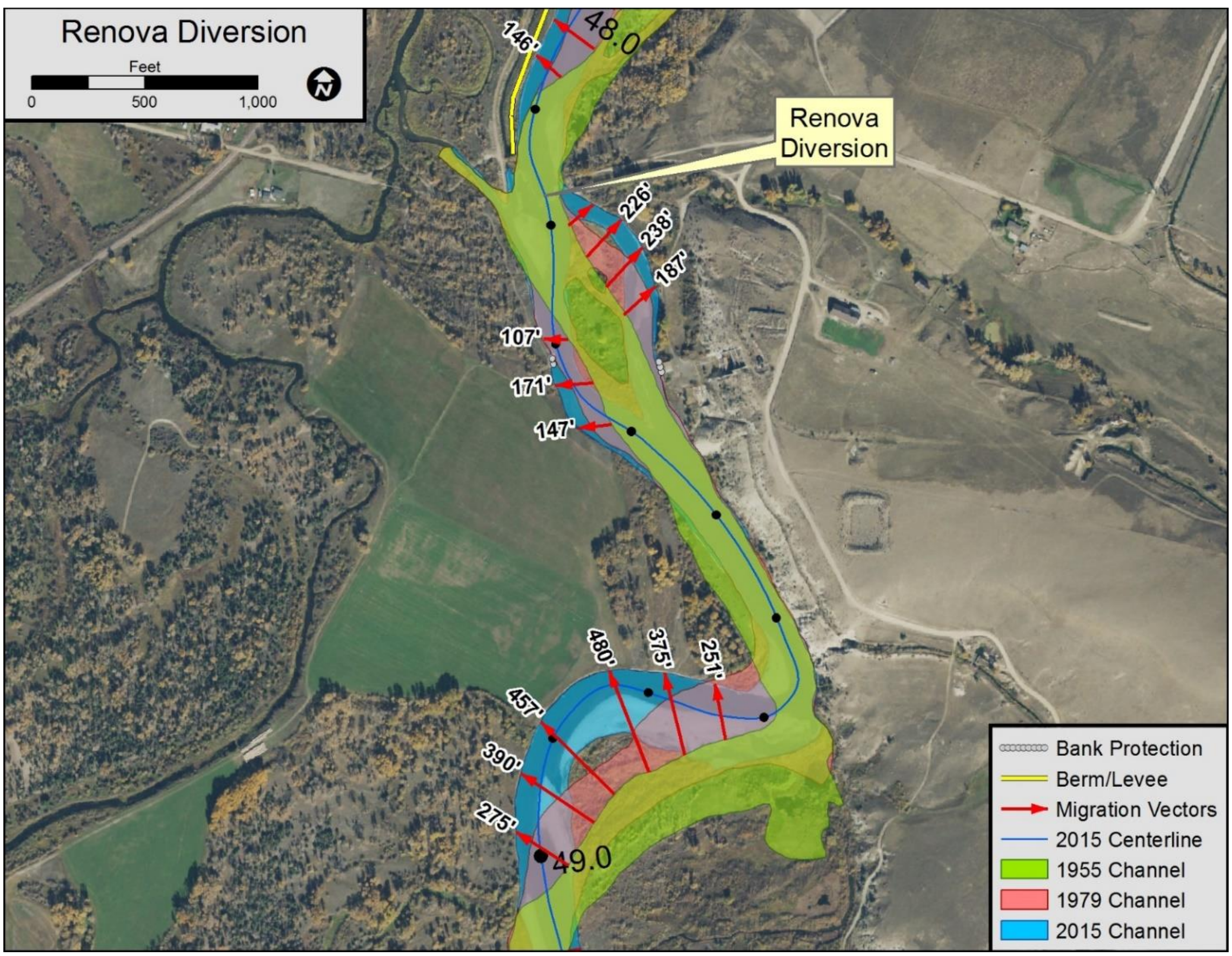

Figure 54. Channel migration upstream of Renova Diversion.


Figure 55. View downstream towards Renova Diversion (upper left) showing channel migration away from right valley wall. (Kestrel)

5.5 Reach JR08

Reach JR08		
Upstream/Downstream RM	48.2	43.3
Length (miles)	4.9	
General Location	Renova Diversion to Kountz Road	
Mean Migration Rate (ft/yr)	5.5	
Max 60-year Migration Distance (ft)	532	
100-year Buffer (ft)	554	

Reach JR08 begins at the Renova Diversion and extends about 5 miles downstream to the Kountz Road Bridge. The mean migration rate for the reach is 5.5 feet per year, and the 100-year EHA buffer is 554 feet wide. This reach is fairly remarkable in that it is the product of a very large avulsion that occurred since the GLO maps were made in the 1870s. At that time, the main thread of the Jefferson River flowed over a mile to the north in what is now Slaughterhouse Slough (Figure 56). At what is now the Slaughterhouse Slough diversion, the river split into two forks in 1880, the "Right Fork" and "Left Fork". The "Left Fork" is now Jefferson Slough and the "Right Fork" is Slaughterhouse Slough. Historically, these two major threads did not rejoin until near Cardwell on the eastern edge of the valley. In 1880 the current river course did not exist. Currently the river is shifted south and those historic sloughs receive water from the Jefferson Canal and Renova Diversion. In Reach JR08 about 10.5% of the bankline is armored, hosting large bendways that commonly abut irrigated fields (Figure 57). Armoring is especially dense in the lower end of the reach at the approach to Kountz Road Bridge (Figure 58).

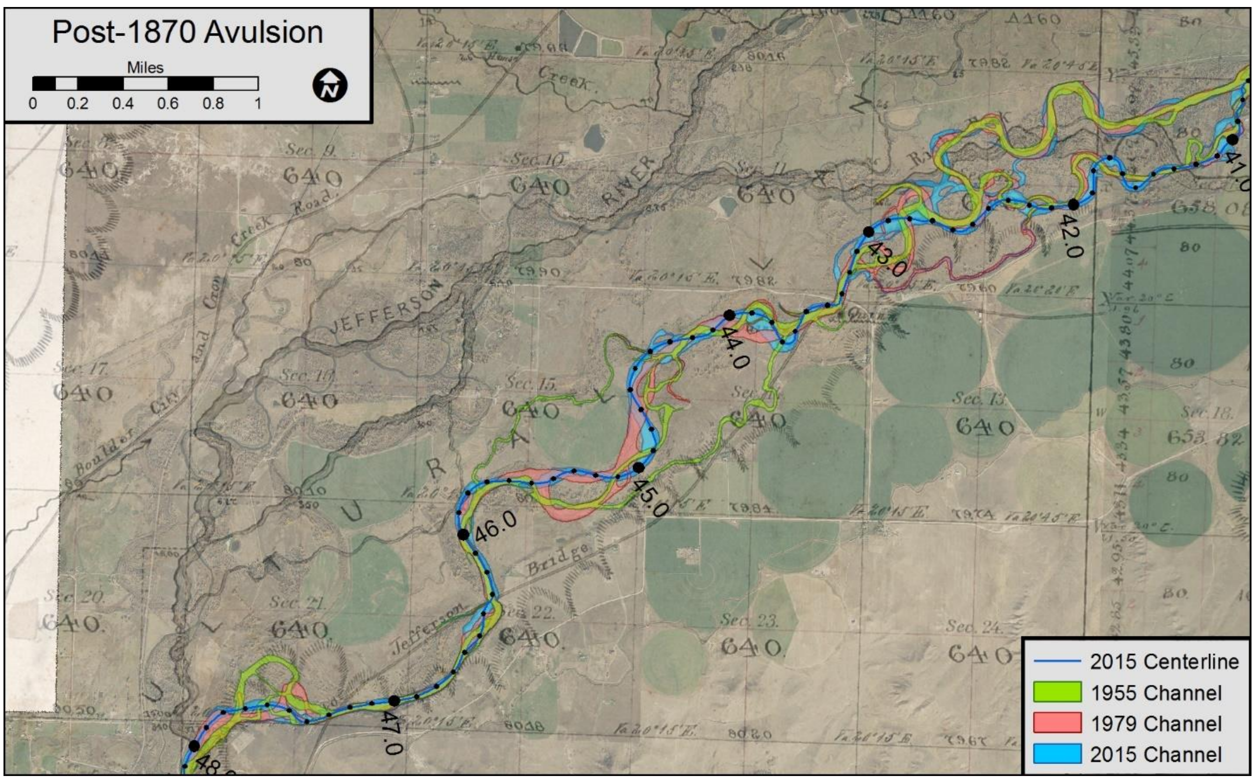

Figure 56. 1870 GLO map showing major 1870-1955 avulsion in which the river relocated over a mile south.

Figure 57. View downstream of Reach JR08 showing meander core irrigation and left bank armor. (Kestrel)

Figure 58. View downstream of Kountz Road Bridge showing dense armor on approach. (Kestrel)

5.6 Reach JR07

Reach JR07		
Upstream/Downstream RM	43.3	34.6
Length (miles)	8.7	
General Location	Kountz Road to LaHood	
Mean Migration Rate (ft/yr)	5.9	
Max 60-year Migration Distance (ft)	858	
100-year Buffer (ft)	588	

Reach JR07 lies in the eastern edge of the Jefferson Valley, extending about 6 miles from Kountz Road to the head of Jefferson Canyon at LaHood. Within much of this reach the river follows the historic "Right Fork" of the Jefferson River. This reach has been notably dynamic, with a maximum measured migration distance of 858 feet since 1955. The reach shows a substantial loss of riparian cover since 1979. Development in the CMZ is common, and about 12% of the banks are armored (Figure 59). At RM39 a high amplitude bendway has a distinct chute channel through its core that will likely form an avulsion in coming years, shortening the river along a more efficient path (Figure 60). Reach JR07 has six mapped avulsions, five of which occurred between 1955 and 1979.

There has been a dramatic loss of woody riparian vegetation on the right (south) floodplain just below Cardwell Bridge, and this loss has happened over the last few years (Figure 61 and Figure 62).

Figure 59. View downstream of CMZ development, Reach JR07. (Kestrel)

Figure 60. View downstream impending cutoff avulsion, RM 39.0. (Kestrel)

Figure 61. View downstream degraded riparian area on far side of Cardwell Bridge. (Kestrel)

Figure 62. Riparian decay downstream of Cardwell Bridge between 2011 (left) and 2015 (right).

5.7 Reach JR06

Reach JR06		
Upstream/Downstream RM	34.6	22.2
Length (miles)	12.4	
General Location	LaHood to Sappington Bridge (Jefferson River Canyon)	
Mean Migration Rate (ft/yr)	0.5	
Max 60-year Migration Distance (ft)	39	
100-year Buffer (ft)	53	

Reach JR06 extends through the Jefferson River Canyon between LaHood and Sappington Bridge. It is 12.4 miles long, and throughout this reach the Jefferson River is tightly confined by erosion resistant bedrock canyon walls and nested infrastructure within that canyon. The geology of the canyon is notable in that it exposes over a billion years of geologic history. The rocks become progressively younger from the west to the east sides of the canyon, with the LaHood Formation on the western end of the canyon reaching over a billion years in age. About a mile and a half of the canyon walls are Madison Limestone, which hosts Lewis and Clark Caverns.

William Clark recorded seeing the canyon on July 26, 1805. In 1890 the Northern Pacific built a spur from its main line east of Three forks to Butte, to get coal from Red Lodge to Butte. Around 1900, Dan Morrison opened a limestone quarry in the canyon that operated almost continuously until 1935. Some gold dredging gook place near the quarry in 1906. The dredge washed downstream during a flood in 1907, getting hung up on Sappington Bridge. It was eventually dynamited. The Milwaukee Line was built in 1908 on the south side of the river; and was abandoned in the 1980s (Montana Bureau of Mines and Geology). The highway in Jefferson Canyon was built with the Montana Department of Transportation rerouted Highway 10 through the canyon in 1928. This highway was then bypassed by I-90 in 1968. As would be expected, migration rates in the canyon are low and limited to a narrow alluvial fringe on the channel margin. Although the 100-year buffer is 53 feet, most of the CMZ in this reach was clipped out because the buffer extended into non-erodible rocks.

Figure 63. View downstream of Jefferson Canyon. (Kestrel)

5.8 Reach JR05

Reach JR05		
Upstream/Downstream RM	22.2	18.9
Length (miles)	3.3	
General Location	Sappington Bridge to Williams Bridge Road	
Mean Migration Rate (ft/yr)	2.0	
Max 60-year Migration Distance (ft)	254	
100-year Buffer (ft)	200	

JR05 is a short transitional reach at the lower end of Jefferson Canyon. Migration rates are higher than those of the canyon, but less than reaches further downstream where the floodplain broadens dramatically towards Three Forks. Within JR05, Madison Limestone continues to limit channel movement, and the rail line encroaches into the historic floodplain (Figure 64). This reach has the highest concentration of floodplain dikes and levees in the project area, with 7% of the bankline armored. The Old Hale Ditch Diversion is a prominent feature in the reach, forming a full span diversion dam and large canal (Figure 64). All of the armor in the reach is protecting either the canal or rail line.

Figure 64. View downstream Reach JR05 showing Old Hale Diversion and floodplain encroachment by rail line. (Kestrel)

5.9 Reach JR04

Reach JR04		
Upstream/Downstream RM	18.9	11.0
Length (miles)	7.9	
General Location	Williams Bridge Road to just below Milligan Canyon	
Mean Migration Rate (ft/yr)	5.9	
Max 60-year Migration Distance (ft)	792	
100-year Buffer (ft)	588	

Reach JR04 extends from Williams Bridge Road to just below Milligan Canyon near Three Forks. It is 7.9 miles long, and migration rates are relatively high with an average annual bank erosion rate at migrating sites of 5.9 feet. The maximum migration distance measured in Reach JR04 is 792 feet. This section of river can be described as a "response reach" downstream of Jefferson Canyon, where high transport rates and low deformability in the canyon abruptly transition to a zone of sediment storage and bank migration. Because of active bank migration coupled with the residential development, this reach has the most extensive bank armoring of any reach on the Jefferson River. About 12,120 feet of bank line is armored, which is about 14.4% of the total bankline. Barbs are commonly used, however erosion between the barbs is common (Figure 65). In some cases homes adjacent to the river experienced substantial flooding in 2011 (Figure 66 and Figure 67).

Active channel movement can be seen at RM 13 where a chute channel has formed across a meander core, showing the early stages of an avulsion (Figure 68). Natural meander movement has been impeded to protect bridges. This "pinning" of meanders with bank armor can cause accelerated erosion upstream and drive an eventual cutoff (Figure 69). A total of four avulsions were mapped in Reach JR04, three of which occurred since 1979.

Figure 65. View downstream Reach JR04 showing left bank barbs with erosion between structures. (Kestrel)

Figure 66. View downstream Reach JR04 showing CMZ development on right (east) floodplain. (Kestrel)

Figure 67. Flooding at house shown in Figure 66 (www.jeffersonriver.org). (Kestrel)

Figure 68. View downstream Reach JR04 chute cutoff formation in meander core. (Kestrel)

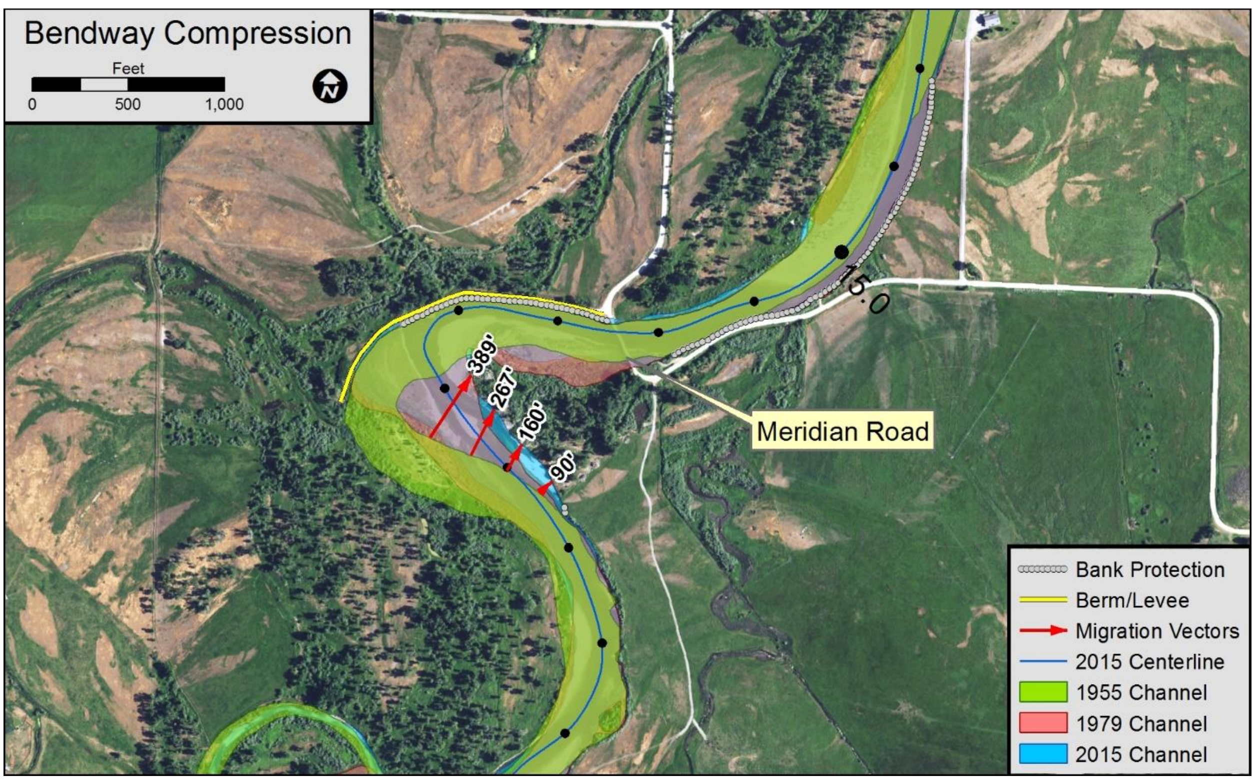

Figure 69. Jefferson River at Meridian Road Bridge showing "pinned" bendway compression on armored meander bend. (Kestrel)

5.10 Reach JR03

Within Reach JR03 the Jefferson River follows the west valley wall which consist of Cambrian age limestone and younger sandstone and claystone. This reach has fairly continuous road access to the river, and CMZ development is common. Many homes are on a bluff and out of the CMZ, but some are in low floodplain areas surrounded by historic swales (Figure 70 and Figure 71).

Reach JR03		
Upstream/Downstream RM	11.0	8.3
Length (miles)	2.7	
General Location	Below Milligan Canyon to Three Forks Road	
Mean Migration Rate (ft/yr)	4.1	
Max 60-year Migration Distance (ft)	459	
100-year Buffer (ft)	411	

Reach JR03 has no mapped avulsions, and about 10% of the banks are armored with rock riprap.

Figure 70. View downstream Reach JR04 showing residence in CMZ. (Kestrel)

Figure 71. 2011 flooding around home within CMZ shown in Figure 70.

5.11 Reach JR02

Reach JR02		
Upstream/Downstream RM	8.3	5.0
Length (miles)	3.3	
General Location	Three Forks Road to I-90	
Mean Migration Rate (ft/yr)	5.0	
Max 60-year Migration Distance (ft)	886	
100-year Buffer (ft)	503	

Reach JR02 extends from the Three Forks Road Bridge to the I-90 crossing. It is 3.3 miles long and is less confined and more dynamic than Reach JR03 upstream. This reach experienced a major avulsion sometime after 1871, where the whole river relocated westward, creating a new channel complex on the west side of the river valley (Figure 72). Channel migration has created some challenges at the I-90 bridge crossing due to split flow and poor channel orientation to the bridge (Figure 74). Reach JR02 has about 2,300 feet of mapped rock riprap, which covers about 6.6 % of the total bankline. The maximum measured migration distance in Reach JR02 is almost 900 feet.

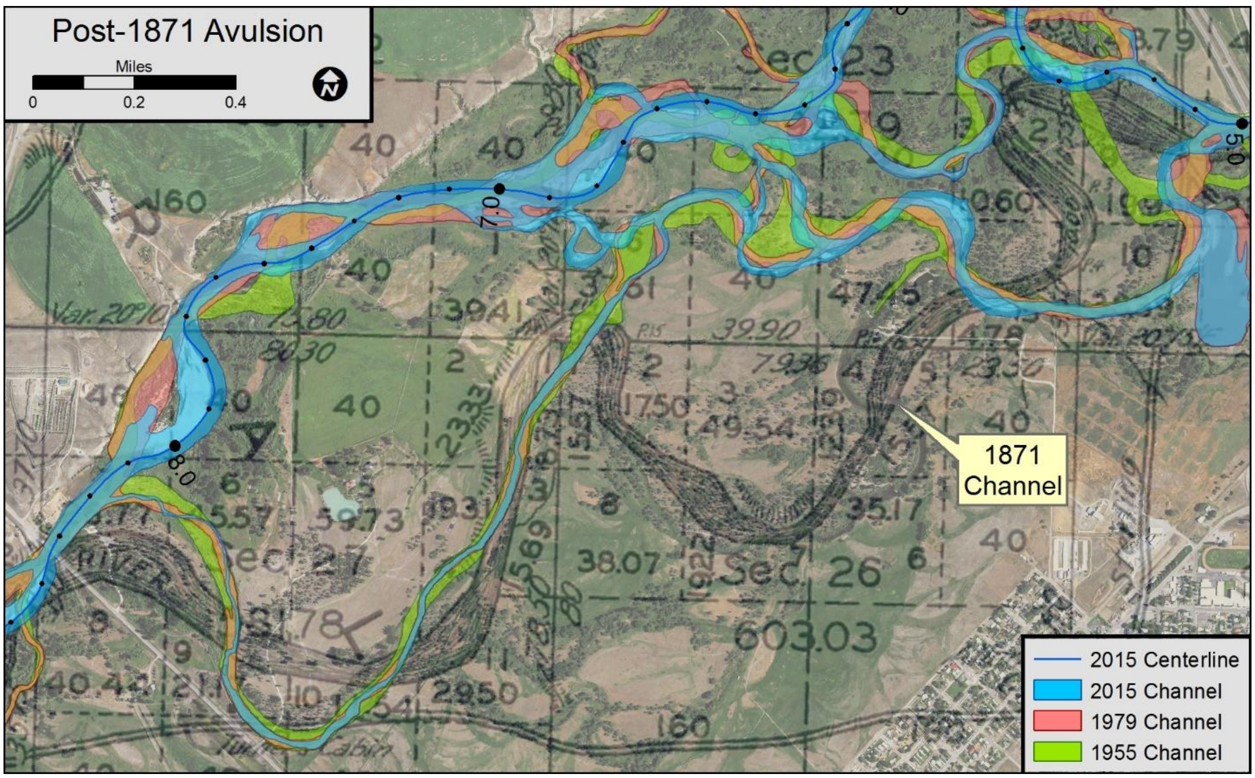

Figure 72. Post-1871 channel avulsion in Reach JR02, showing GLO mapped trace in black and white and modern traces in color.

Figure 73. View down valley showing post-1871 channel complex, Reach JR02. (Kestrel)

Figure 74. View down valley showing Jefferson River crossing at I-90 in foreground; Madison River is in distance. (Kestrel)

5.12 Reach JR01

Reach JR01		
Upstream/Downstream RM	5.0	0.0
Length (miles)	5.0	
General Location	I-90 to Mouth	
Mean Migration Rate (ft/yr)	7.4	
Max 60-year Migration Distance (ft)	919	
100-year Buffer (ft)	744	

Reach JR01 extends from the I-90 Bridge crossing near Three Forks to the mouth of the Jefferson River in Headwaters State Park. Within this reach the river enters a broad composite floodplain formed between the Madison and Jefferson Rivers, with a myriad of active and remnant channels that flow between the two systems. This reach has the highest mean migration rate in the project area (7.1 feet per year). The maximum 1955-2015 migration distance was 919 feet.

In 1955, the Jefferson River water flowed into the Madison River through a major side channel that is now blocked by debris (orange thread in Figure 75). This crossing still has a railroad bridge. In all of Reach JR01 the railroad line bisects the composite floodplain of the Madison/Jefferson Rivers, dampening the interaction between those two river systems and creating long-term risk to the railroad on both sides of the embankment. Similarly, managing channel migration has been challenging at bridge crossings in Reach JR01, with channel movement creating high angle, hydraulically-complex bridge approaches (Figure 76 and Figure 77).

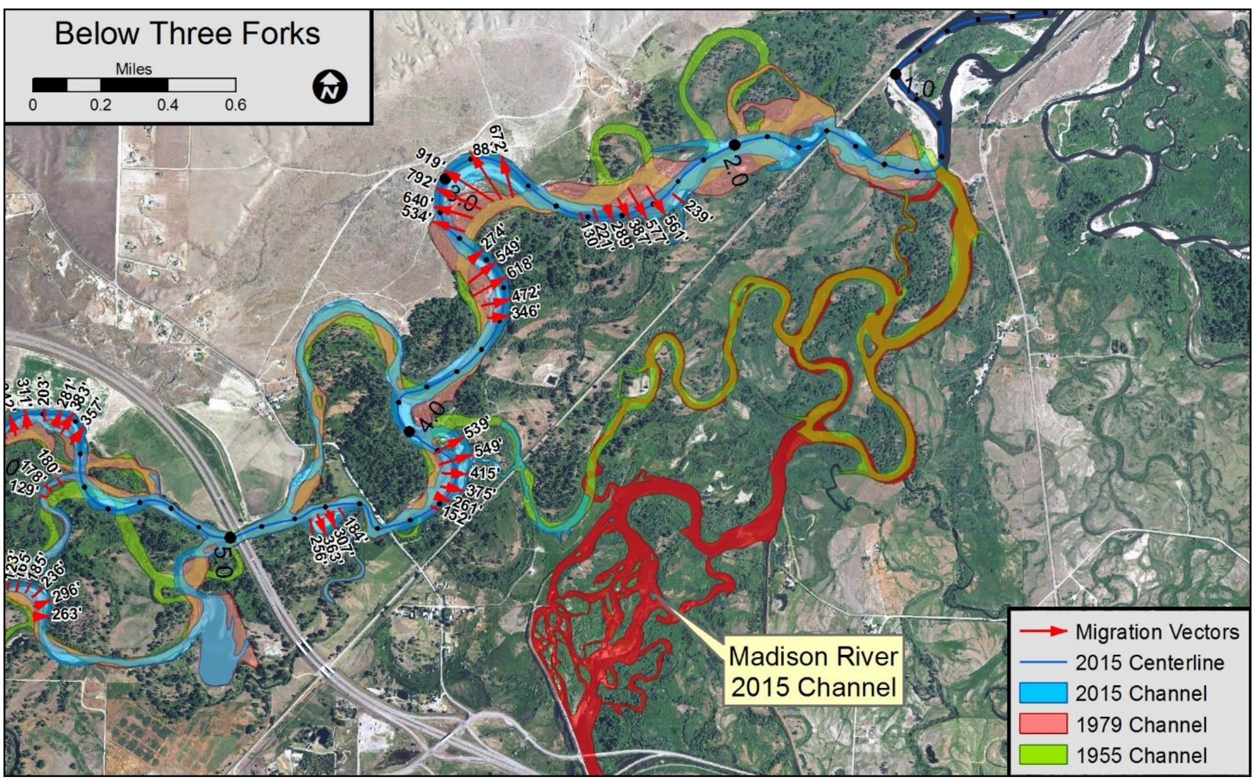

Figure 75. Mapped banklines of Jefferson River and 1965 Madison River channel (red).

Figure 76. View downstream showing poor river alignment and bank armoring at Old Town Road Bridge over Jefferson River. (Kestrel)

Figure 77. View down valley showing rail grade orientation to river corridor; Madison River is to right. (Kestrel)

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Appendix A: Reach and Site Migration Statistics

The Channel Migration Zone Mapping for the Jefferson River resulted in 634 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)
JR01				
MSID-JR-2.35	7	343	130	577
MSID-JR-2.98	6	740	534	919
MSID-JR-3.37	5	452	274	618
MSID-JR-4.19	6	382	152	549
MSID-JR-4.71	4	278	184	363
JR02				
MSID-JR-5.52	3	162	129	180
MSID-JR-5.82	8	290	168	383
MSID-JR-6.1	6	211	123	296
MSID-JR-6.51	5	179	92	283
MSID-JR-6.81	6	370	215	498
MSID-JR-7.15	4	198	167	224
MSID-JR-7.36	4	249	147	388
MSID-JR-7.92	6	618	305	886
JR03				
MSID-JR-10.3	3	120	100	145
MSID-JR-10.4	3	154	132	172
MSID-JR-8.47	5	284	157	354
MSID-JR-8.69	5	121	79	159
MSID-JR-9.1	3	142	132	148
MSID-JR-9.61	5	347	244	459
JR04				
MSID-JR-11.2	4	305	229	397
MSID-JR-11.26	5	252	149	363
MSID-JR-11.39	3	244	224	258
MSID-JR-11.51	3	338	240	387
MSID-JR-11.98	4	338	292	380
MSID-JR-12.16	7	130	61	174
MSID-JR-12.79	8	283	137	392
MSID-JR-13.32	7	142	88	185
MSID-JR-13.69	3	126	71	169
MSID-JR-13.88	4	145	93	211
MSID-JR-14.11	10	196	130	292
MSID-JR-14.49	5	180	85	255
MSID-JR-15.57	4	227	90	389
MSID-JR-16.21	5	522	329	792
MSID-JR-16.67	3	385	317	478
MSID-JR-17.05	5	325	168	521
MSID-JR-17.52	7	311	124	495
MSID-JR-17.85	7	508	195	726
MSID-JR-18.2	4	184	146	208
MSID-JR-18.66	7	215	132	300
JR05				
MSID-JR-19.14	5	88	74	103
MSID-JR-20.71	3	206	157	254
MSID-JR-21.25	5	100	62	128
JR06				
MSID-JR-24.01	4	28	14	39
JR07				
MSID-JR-34.87	5	516	286	759
MSID-JR-35.41	1	183	183	183
MSID-JR-36.41	5	463	336	636
MSID-JR-36.8	9	246	131	311
MSID-JR-38.17	4	268	187	315
MSID-JR-38.84	5	638	243	858
MSID-JR-39.42	10	223	104	349
MSID-JR-40.62	3	181	137	230
MSID-JR-41.3	3	137	125	150
MSID-JR-41.68	5	203	157	251
MSID-JR-41.7	3	159	119	208
MSID-JR-42.1	5	135	87	165
MSID-JR-42.4	4	251	204	280
MSID-JR-42.48	5	191	158	243
MSID-JR-42.82	3	291	185	380
MSID-JR-42.95	4	205	149	273
JR08				
MSID-JR-43.43	4	135	127	151
MSID-JR-43.68	4	252	119	348
MSID-JR-43.88	5	342	165	532
MSID-JR-44.44	6	167	109	226
MSID-JR-44.93	6	366	194	531
MSID-JR-45.42	5	266	167	381
MSID-JR-45.81	10	191	79	295
MSID-JR-46.19	5	94	74	116
MSID-JR-46.42	5	277	226	328
MSID-JR-46.79	2	67	62	72
MSID-JR-47.07	2	97	84	109
MSID-JR-47.65	4	272	228	318
MSID-JR-47.91	9	292	146	442
JR09				
MSID-JR-48.23	4	199	143	238
MSID-JR-48.34	3	142	107	171
MSID-JR-48.88	6	371	251	480
MSID-JR-49.11	3	116	57	157
MSID-JR-49.93	3	268	201	315
MSID-JR-50.22	4	234	187	269
MSID-JR-50.62	6	381	161	492

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-JR-50.86	4	183	124	230
MSID-JR-51.13	2	76	73	79
MSID-JR-51.26	2	74	71	77
MSID-JR-51.62	3	171	152	204
MSID-JR-52.44	3	137	110	159
JR10				
MSID-JR-53.74	6	383	242	513
MSID-JR-54.04	6	250	134	381
MSID-JR-54.16	3	78	72	85
MSID-JR-54.47	5	144	94	173
MSID-JR-54.76	4	134	99	159
MSID-JR-56.11	7	204	155	286
MSID-JR-56.28	3	167	139	216
MSID-JR-56.66	5	215	108	317
MSID-JR-57.04	4	214	182	250
MSID-JR-57.31	5	219	125	312
MSID-JR-57.7	5	348	216	472
MSID-JR-58.35	3	106	91	132
MSID-JR-58.65	6	412	236	601
MSID-JR-59.03	6	359	163	437
MSID-JR-59.68	7	155	93	196
MSID-JR-60.76	2	116	115	117
MSID-JR-60.83	4	178	103	235
MSID-JR-61.29	6	309	152	456
MSID-JR-61.49	4	109	82	125
MSID-JR-61.79	2	77	77	77
MSID-JR-61.94	5	195	94	257
MSID-JR-62.18	5	107	66	139
MSID-JR-62.69	9	257	137	378
MSID-JR-63.33	4	279	196	328
MSID-JR-64	3	336	237	424
MSID-JR-64.26	5	451	212	593
MSID-JR-64.5	4	175	149	192

Site ID	Count	Avg (ft)	Min (ft)	Max (ft)
MSID-JR-64.68	2	75	71	79
MSID-JR-64.86	2	260	238	282
MSID-JR-65.05	5	256	146	318
JR11				
MSID-JR-65.8	2	90	77	102
MSID-JR-66.25	3	72	63	80
MSID-JR-67.1	3	123	112	136
MSID-JR-67.37	4	181	141	224
MSID-JR-67.59	2	146	118	173
MSID-JR-67.96	4	110	61	139
MSID-JR-68.45	2	131	126	135
MSID-JR-70.38	4	99	72	125
MSID-JR-70.7	3	144	78	190
MSID-JR-71.02	5	188	164	206
MSID-JR-71.17	4	352	207	449
MSID-JR-71.48	2	393	311	475
MSID-JR-71.97	3	130	112	165
MSID-JR-71.99	2	99	98	100
MSID-JR-72.5	2	75	72	77
MSID-JR-72.6	2	74	69	79
JR12				
MSID-JR-72.91	2	196	140	252
MSID-JR-72.95	2	170	133	206
MSID-JR-73	3	201	162	251
MSID-JR-73.36	3	150	104	181
MSID-JR-73.67	12	288	152	440
MSID-JR-73.75	4	134	97	153
MSID-JR-73.88	3	151	136	172
MSID-JR-74.12	5	285	181	382
MSID-JR-74.66	5	382	315	416
MSID-JR-74.86	1	173	173	173
MSID-JR-75.01	5	363	288	495
MSID-JR-75.38	5	339	159	464

Appendix B: Bridge Photos

Figure 78. Iron Rod Bridge on July 12, 2016. (Kestrel)

Figure 80. Waterloo Road bridge on July 12, 2016. (Kestrel)

Figure 79. Primrose Lane Bridge on July 12, 2016. (Kestrel)

Figure 81. Railroad bridge downstream of Waterloo Road on July 12, 2016. (Kestrel)

Figure 82. Kountz Road bridge on July 12, 2016. (Kestrel)

Figure 84. Cardwell Bridge on July 12, 2016. (Kestrel)

Figure 83. Mayflower Road bridge on July 12, 2016. (Kestrel)

Figure 85. Railroad bridge at Sappington on Sept. 30, 2016. (Kestrel)

Figure 86. Sappington Bridge on Sept. 30, 2016. (Kestrel)

Figure 87. Williams Road bridge on Sept. 30, 2016. (Kestrel)

Figure 88. Meridian Road bridge on Sept. 30, 2016. (Kestrel)

Figure 89. Hwy 2 bridge (Three Forks Frontage Road) on Sept. 30, 2016. (Kestrel)

Figure 90. Bridge grouping at Three Forks (I-90, Old Town Road) on July 21, 2016. (Kestrel)

Figure 91. Railroad bridge below Three Forks on Sept. 30, 2016. (Kestrel)

Appendix C: Irrigation Infrastructure Photos

Figure 92. Creeklyn Ditch, July 12, 2016 (Kestrel).

Figure 93. Parrot Canal diversion (canal exits to the right), July 12, 2016 (Kestrel).

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Figure 94. Diversion at RM 61.6, July 12, 2016 (Kestrel).

Figure 95. Jefferson Canal, July 12, 2016 (Kestrel).

Figure 96. Parrot/Castle Diversion, July 12, 2016 (Kestrel).

Figure 98. Diversion and canal at RM 14.7, Sept. 30, 2016 (Kestrel).

Figure 97. Old Hale Diverison, Sept. 30, 2016 (Kestrel).

Appendix D: Reach Maps