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Clarks Fork Yellowstone River & Rock Creek Channel Migration Zone Mapping



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Carbon County, Montana

Clarks Fork Yellowstone Partnership

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Executive Summary

This report contains the results of a Channel Migration Zone (CMZ) Mapping effort for approximately 72.6 miles of the Clarks Fork Yellowstone River (Clarks Fork) starting at the Montana/Wyoming border and ending with the confluence of the Yellowstone River near Laurel, Montana and 48 miles of Rock Creek starting at the US Forest Service boundary south of Red Lodge and ending with its confluence with the Clarks Fork. This study was funded through a pair of Montana Department of Natural Resources and Conservation (DNRC) Reclamation and Development Planning Grants RITP-23-0185 and RITP-25-0217. The contract was administered by Carbon County, Montana and work overseen by the Clarks Fork Yellowstone Partnership.

The goal of these Planning Grants was to generate new CMZ mapping so that it can be used as a tool to evaluate river channel migration and flood-related impacts in Carbon County, assist in emergency flood response preparation, and identify projects that will help mitigate future risks while also supporting healthy river functions such as floodplain connectivity, flood attenuation, natural channel movement and erosion / sedimentation processes, water quality, and in-stream fisheries habitat.

While the two waterways differ greatly in size and geomorphic character, they both form high on the Beartooth Plateau, are uncontrolled and are subject to similar runoff patterns. The Rock Creek watershed is a sub-watershed of the larger Clarks Fork watershed. Both were impacted by the June 10 to 16, 2022 flood event, resulting in markedly higher lateral migration rates in many areas. Continued development along the corridor has increased property values and placed additional infrastructure within the corridor that is at risk of both flooding and bankline migration.

The objective with the mapping and interpretations provided in this document is to assist river corridor landowners and other stakeholders in understanding the nature of the Clarks Fork Yellowstone River and Rock Creek lateral migration history, focusing not only on the challenges that channel migration creates but also the critical contributions that these processes provide towards long-term river health, resiliency, and ecological vibrancy. These waterways are critical for the economic health and character of Carbon County. Adoption of a CMZ approach to management of the river corridor represents an opportunity for the long-term vibrancy of Carbon County at a reduced cost to landowners.

The mapping and analysis presented in this report is not regulatory in nature and does not impact property rights. It is similar to over 1,500 miles of CMZ mapping completed throughout Montana.

This report, maps, and GIS data will be available from the Montana State Library on the Channel Migration Zone Resources web page (https://msl.mt.gov/geoinfo/data/montana_channel_migration_zones/resources). Additionally, the mapping data layers will be included on the State Library's CMZ web map. This can be used for exploring the CMZ data and creating maps of specific sites.

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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.

Avulsion Hazard Zone (AHZ) – Floodplain areas geomorphically susceptible to abrupt channel relocation. Defined as those areas that are within four vertical feet of the river's July 2021 surface water elevation.

Avulsion Node – The location where a river splits or relocates from an existing channel into an avulsion path.

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.

Bendway Core – The narrow strip of land enclosed within the loop of a meandering river.

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 through 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 (based on average annual migration rates).

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 Damage – Impacts to the floodplain and/or infrastructure due to elevated water levels resulting in over bank flows during a flood event.

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.

Geomorphic Change – An alteration in shape, form, or structure (e.g. channel bendway migration or avulsion)

Geographic Information System (GIS) – 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.

Median Value – The median is the middle number in a sorted list of numbers (either ascending or descending) that represents the "middle" value in the list.

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.

National Agriculture Imagery Program (NAIM) – 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.

Reclamation and Development Grants Program (RDGP) – Grant program administered by the 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 over 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

Channel Migration Zone (CMZ) mapping focuses on identifying potential river corridor hazards associated with the lateral migration of stream channels and avulsion into new or reactivated channel pathways. This is a separate risk from flood hazard - or FEMA mapping - but represents a serious risk to public and private infrastructure and safety.

Note: CMZ mapping is non-regulatory in Montana and the inclusion of the word "Zone" should not be interpreted as imparting any sort of regulation on land.

This effort reflects an assessment of river channel locations mapped from aerial photography between the mid-1950s and 2023, including impacts of the 2022 flood.

Note: All river mile references in this report are based on the Montana Fish Wildlife Parks river stationing that does not necessarily follow the current flow paths.

This report contains the results of a CMZ Mapping effort for approximately 73 miles of the Clarks Fork Yellowstone River (Clarks Fork) in Carbon County, Montana (note that the lower ~6 miles are in Yellowstone County) and 48 miles of Rock Creek in Carbon County. The Clarks Fork from the Montana/Wyoming Border to its confluence with the Yellowstone River near the city of Laurel, MT is largely rural in nature, with multiple bridge crossings that are critical for accessing emergency services, towns, businesses, agricultural operations and private residences property. While the corridor has not seen the development pressures seen along many of Montana rivers, its proximity to Billings makes future residential development likely. In contrast, Rock Creek between the US Forest Service boundary south of Red Lodge to its confluence with the Clarks Fork reflects a split character, with recreational and residential development pressures in the upper end associated with Red Lodge and a largely agricultural character on the lower end. Rock Creek has seen continued development pressures as land along the river is subdivided and developed. New development along river corridors generally increases property values and puts additional infrastructure at risk of both flooding and/or channel migration. The upper section of Rock Creek through Red Lodge was heavily impacted by the June 10 to 16, 2022 FEMA declared national disaster flood event, with markedly rapid lateral migration rates in areas that had not previously seen measurable erosion. While the Clarks Fork also experienced flooding and increased lateral migration from the flood event, the impacts were not nearly as severe.

The mapping was NOT developed to be regulatory in nature and does not create new requirements for landowners. It is intended to assess and present a specific river hazard type, to help individuals and entities associated with the river make educated decisions regarding development within the river corridor.

This project is based upon work supported by the DNRC under Agreement Nos. RITP-23-0185 and RITP-25-0217. The contract was administered by Carbon County, Montana and work overseen by the Clarks Fork Yellowstone Partnership.

1.1 Background and History

The approximately 2,800 square mile Clarks Fork Yellowstone River watershed is a major tributary to the Yellowstone River, contributing approximately four percent of the area. It originates high on the Beartooth Plateau near the Montana/Wyoming border and runs 141 miles east through Wyoming, then north through Montana and joining the Yellowstone River near Laurel, Montana. The headwaters for Rock Creek are just north of those for the Clarks Fork. The 323 square mile Rock Creek watershed accounts for approximately 11 percent of the full Clarks Fork Watershed. Rock Creek runs northeast from its alpine sources for 60 miles before joining the Clarks Fork south of Laurel. Neither waterway has any major dams or reservoirs on its mainstem.

There are numerous irrigation diversions on both waterways, supporting a diverse agricultural base. With no dams on the river or major tributaries and only a few significant diversions, the waterways behave as a snow melt system with a natural hydrograph that tends to peak during late spring and early summer months.

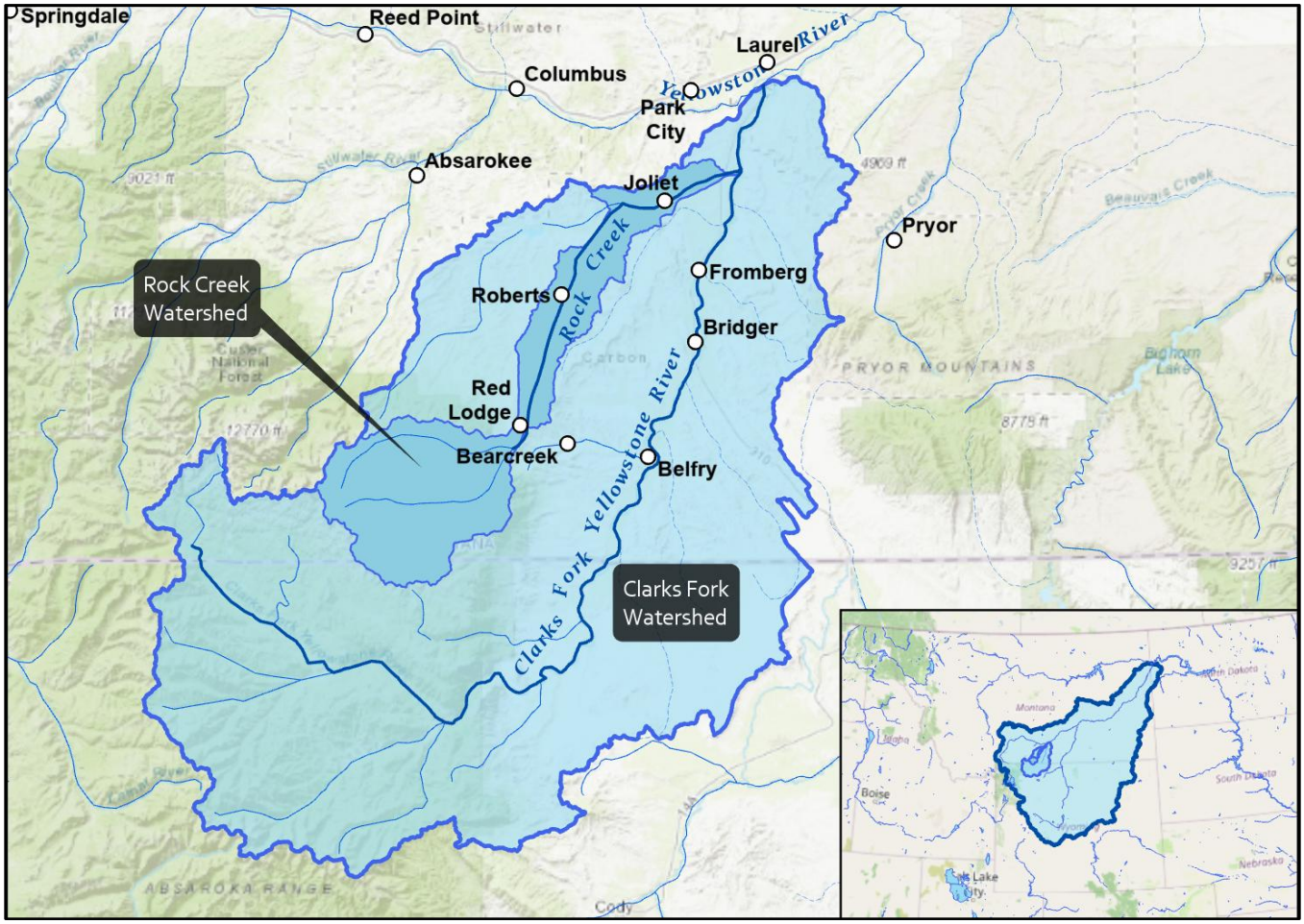


Figure 1. The Clarks Fork Yellowstone River watershed and Rock Creek sub-watershed, showing its position in the Yellowstone River watershed.

While both waterways have experienced moderate flood events over the past 90 years, the June 2022 flood event far surpasses any of the previous events. As the "flood of record", it presents a unique opportunity to see how the corridors responded to the event, what sort of impacts occurred, and what the long-term implications will be.

1.2 Relevant Studies

With the exception of the 2019 Clarks Fork Yellowstone River Assessment (Kellogg, 2019) noted below, most identified studies of these waterways are in association with the 2022 flood event. The key reports referenced in this CMZ study are listed below.

Red Lodge Emergency Flood Repair Project

https://www.mdt.mt.gov/pubinvolve/redlodge/?utm_source=chatgpt.com

Clarks Fork Yellowstone River Assessment – 2019 Warren Kellogg

In 2018 the Carbon County CD contracted Warren Kellogg of Stream & Watershed Consulting to perform a comprehensive river corridor assessment of the lower 45 miles of the Clarks Fork River. The goal was to develop a better understanding of conditions, management issues and restoration opportunities. The study area was divided into 5 reaches, with a total of 142 sites visited.

USACE Technical Team Damage Assessment

This study from July 2022 summarizes a site visit around Fromberg, MT to assess damages from the June 2022 flood. The primary issues noted were:

1. Damage to the upstream side of the East River Street bridge.
2. The city municipal water wells which lie adjacent to the Clarks Fork River were inundated by flood waters. Extensive gravels surrounding the well heads and distribution center were washed away.
3. A short section of irrigation canal culvert was damaged.

Final Waterway Debris Assessment, 4655DR-MT Flooding & Severe Storms, 10 October 2022

This report documents over 100 locations in Park, Stillwater, Carbon, and Yellowstone counties for flood-deposited debris that may be impairing river or bridge functions. Thirty-eight sites were in Carbon County, with the majority being in in the Red Lodge area.

Geotechnical Reconnaissance of the 2022 Southern Montana/ Yellowstone Floods

Approximately two weeks after the June 2022 flood, members of the Geotechnical Extreme Events Reconnaissance Association (GEER) visited sites reportedly impacted by the flood. This included several sites on Rock Creek in Red Lodge area, as well as Fromberg on the Clarks Fork River (Lemnitzer, et al., 2022).

Post-Flood Surveys and Hydraulic Analysis Flood of June 2022, Rock Creek (USACE, 2022)

> *"This report describes the technical assistance provided to the State of Montana, Carbon County and the City of Red Lodge through the U.S. Army Corps of Engineers (USACE) Emergency Operations Program of Public Law (PL) 84-99. The purpose was to determine the effects of the June 2022 flood on the flow capacity of Rock Creek through Red Lodge. This required collection of field survey data along Rock Creek and hydraulic analyses. This document describes the data collection, analysis and results of the study and provides recommendations regarding the expected future flood hazard along Rock Creek through the community. Data from pre-flood hydraulic analyses for Rock Creek were provided by the Montana Department of Natural Resources and Conservation (DNRC)." (USACE, 2022).*

1.3 The Project Team

The work for this project was performed by Tony Thatcher of DTM Consulting (DTM), Mike Sanctuary of Pinyon Environmental (Pinyon), and Jeannette Blank of Montana Freshwater Partners (MFP). The team has over 20 years of CMZ mapping experience, including developing Channel Migration Zone maps for over 1,500 miles of channel on numerous rivers in Montana, to provide rational and scientifically-sound tools for river management. It is the overall goal to facilitate the understanding of rivers regarding the risks they pose to natural resources and infrastructure, so that those risks can be managed and hopefully avoided. Furthermore, the project team believes the mapping supports the premise that managing rivers as dynamic, deformable systems contributes to ecological and geomorphic resilience while supporting sustainable, cost-effective development.

1.4 What is Channel Migration Zone Mapping?

The goal of CMZ mapping is to provide a cost-effective and scientifically based tool to assist land managers, property owners, agency personnel, 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 for river dynamics and changing site conditions. 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 2).

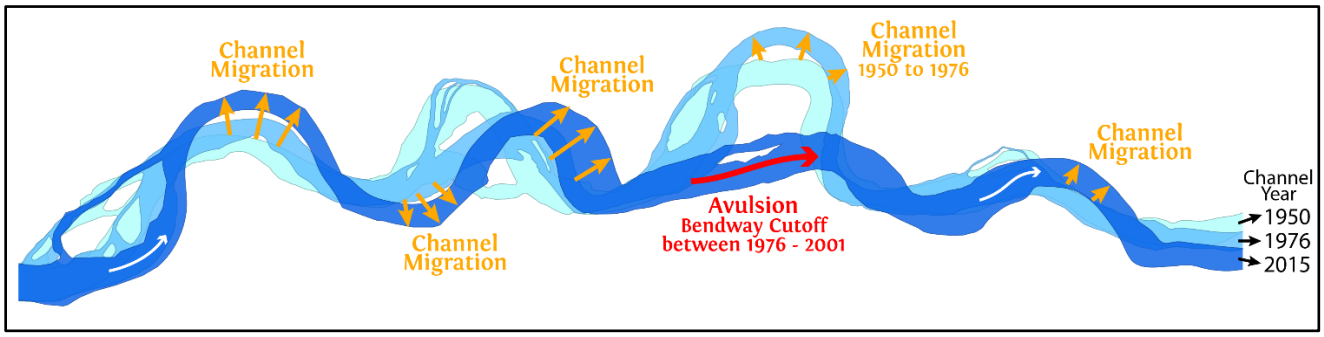


Figure 2. Typical patterns of channel migration and avulsion evaluated in CMZ development.

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 - based on average annual rates of movement. This is defined by first mapping historic channel locations to define the Historic Migration Zone, or HMZ (Figure 2, Figure 3). Using those mapped banklines, migration distances are measured

between suites of air photos to generate a migration vector distance dataset that is exported from the GIS project for analysis. The distance measurements are evaluated statistically to determine mean migration rates for any given river segment (reach). The mean rates are then 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 (Figure 3).

Although the mean migration rate is the most commonly used to develop the EHA, there may be substantial data outliers, unique physical or hydrologic conditions, or intended uses that would warrant using a different statistic to capture a wider range of potential risk (e.g. 90th percentile value).

Channel migration rates are affected by geomorphic influences such as geology, channel type, flood events, stream size, sediment volume, sediment 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. This is why the EHA buffers are developed at a reach scale, as it best addresses natural variability. To that end, 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. On the Clarks Fork, the reaches range from 6.8 to 19.0 miles long, while on Rock Creek they range from 1.5 to 15.6 miles. 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 2), historic side channels that may reactivate, and areas where the modern channel is perched above its floodplain. Avulsions can also occur due to channel blockages (ice, landslides, or debris), however those events are rare and impossible to predict.

The following map units collectively define a Channel Migration Zone map (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 Rappe and Abbe (2003) guidance for CMZ mapping includes the removal of the RMA from the CMZ such that areas that are “no longer accessible” by the river are not identified on the maps. In our experience,

identifying those areas that have become restricted due to human activities like levee building or bank armoring provides insight as to the extent of overall encroachment into the CMZ and highlights potential restoration sites where there may be opportunities for floodplain reconnection or CMZ restoration. It is also important to note that these restricted areas are not protected by fail-proof treatments. There are numerous examples of bank armor failure along the Yellowstone River in Park County that serve as a reminder that properties within the mapped CMZ will continue to have some level of risk despite efforts to control channel movement with bank stabilization treatments. 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 3).

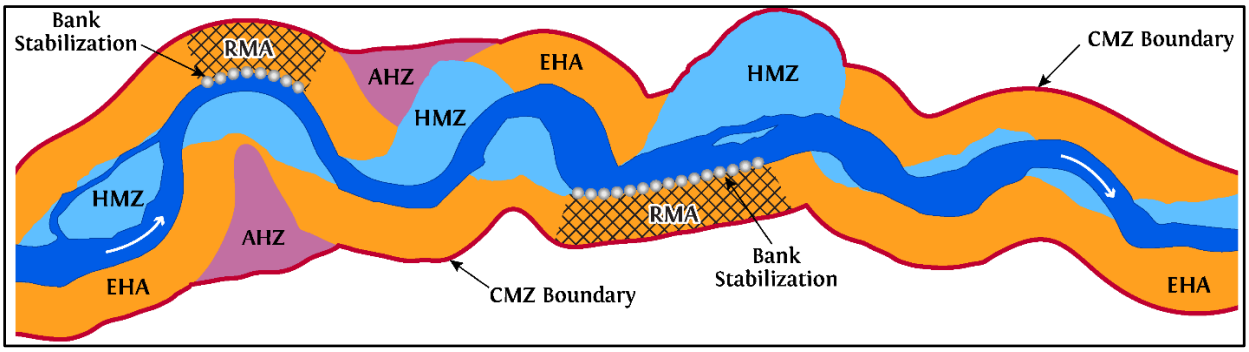


Figure 3. Channel Migration Zone mapping units.

Although the basic concept for CMZ mapping efforts is largely the same throughout the country, different approaches to defining and presenting 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 1954, 1981, 2015, 2021, and 2023 imagery (HMZ), and an 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).

1.5 Relative Levels of Risk

The natural processes of streambank migration and channel avulsion both create risks 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 allow some relative comparison of the type and magnitude of their risk. In general, the Erosion Hazard Area (EHA) 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 Zone (AHZ) 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, debris jams, landslides, or ice jams. 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 Uncertainty

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

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

The Clarks Fork Yellowstone River and Rock Creek show historic patterns of lateral migration and avulsions locally within a complex mix of geomorphic settings, including broad floodplains with a network of historic channels, high and low alluvial terraces, and confined canyons. With potential contributing factors such as woody debris jamming, sediment slugs, landslides, or ice jams, dramatic change could potentially occur virtually anywhere in the stream corridor or adjacent floodplain. As the goal of this mapping effort is to highlight those areas most prone to either migration or avulsion based on specific criteria, there is clearly the potential for changes in the river corridor that do not meet those criteria and thus are not predicted as high risk.

Uncertainty also stems from the general paradigm that "the past is the key to the future." As predicted future migration is based on an assessment of historic channel behavior, the drivers of channel migration over the past ~70 years – the span of the historic imagery - 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 structures could also affect map boundaries.

It should be noted that recent flood events on the Clarks Fork and Rock Creek, throughout Montana, the United States and globally point towards increased levels of uncertainty in terms of climate and the resulting hydrology, and the impacts associated with seemingly extreme, yet frequent events. Given this uncertainty and noting recent flood-related damages, it may be time to adopt more conservative approaches to living with river systems such as stepping back from the river's edge and allowing the corridor to adapt to an uncertain future.

1.7 Potential Channel Migration Zone Applications

Channel Migration Zone mapping is intended to support a range of applications, but the mapping should be primarily viewed as a tool to support informed management decisions throughout a river corridor. 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.
- Develop river corridor best management practices.
- Identify CMZ restoration opportunities in support of system resilience.
- Improve the understanding of the risks and benefits of channel movement.
- Facilitate productive discussion between regulatory, planning, and development interests active within the river corridor.
- Help communities and developers integrate dynamic river corridors into land use planning.
- Assist long-term residents in conveying their experiences of river process and associated risk to newcomers.
- Develop project priorities, timelines, and funding mechanisms.
- Assist realtors to convey existing property risks to potential buyers.

Note:

The CMZ mapping developed in this study was developed without any explicit intent of either providing regulatory boundaries or overriding site-specific assessments. Any future 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.

1.8 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 many hazards associated with river corridors. Flooding, ice jams, and landslides are other significant hazards associated with rivers like the Clarks Fork and Rock Creek.

1.8.1 Flooding

CMZ maps illustrate the historic channel locations and areas that are prone to future channel movement and erosion risks, while floodplain maps illustrate the areas that are at most risk of flooding and inundation during specific flood events. Together, CMZ maps and floodplain maps provide important information on the primary risks associated with the river: flooding, channel movement and erosion. The difference between mapped flood boundaries (i.e. FEMA floodplain maps) 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 4). 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 4). This is a common problem in Montana because of the extent of high glacial terraces that are above base flood elevations, but not erosion-resistant.

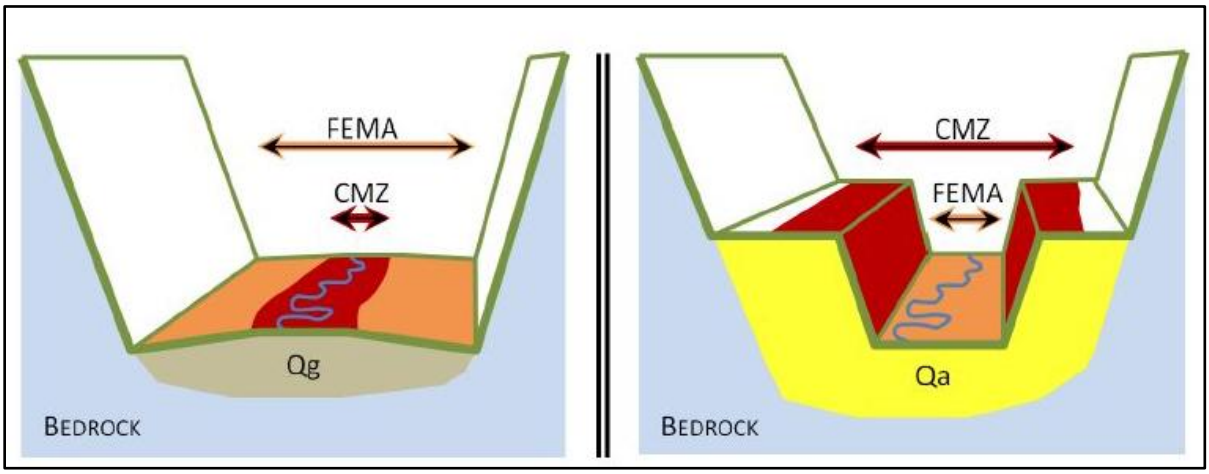


Figure 4. Schematic comparisons between CMZ and FEMA flood mapping boundaries (Washington Department of Ecology).

This has been a chronic problem in river management, as landowners assume that if their home is beyond the mapped floodplain margin, it is safe from all river hazards. Figure 5 shows flooded ranch buildings along the Clarks Fork Yellowstone during the June 2022 flood and Figure 6 shows the same location in 2023. While there was likely floodwater damage to some structures and scour through the corral areas, there was little impact due to lateral channel migration. In contrast, in 2005 after experiencing massive flood damages in St. George, Utah (Figure 7), 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 5. Flooding on the Clarks Fork during June 14, 2022. (Powell Tribune photo by Kevin Killough, June 14, 2022).



Figure 6. Google Earth 2023 imagery showing post-flood recovery.



Figure 7. Photos from a 2005 flood event in Saint George Utah, where homes several feet above the mapped floodplain were destroyed by channel migration (originally sourced from Utahfloodrelief.com).

Note: CMZ maps do not affect floodplain maps or flood insurance rates in Montana.

An example floodplain map for the City of Fromberg is shown in Figure 8. The floodplain boundaries cover much of the valley bottom, and the regulatory floodway, which is crosshatched in red, identifies the area of river and adjacent land areas that "must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height" (www.fema.gov). Communities are responsible for prohibiting encroachments including fill and new construction in floodway areas unless hydrologic and hydraulic analyses show that it will not increase flood levels in the community. The combined risks of flooding and channel migration on the Clarks Fork River and Rock Creek should both be considered threats to human health and safety.

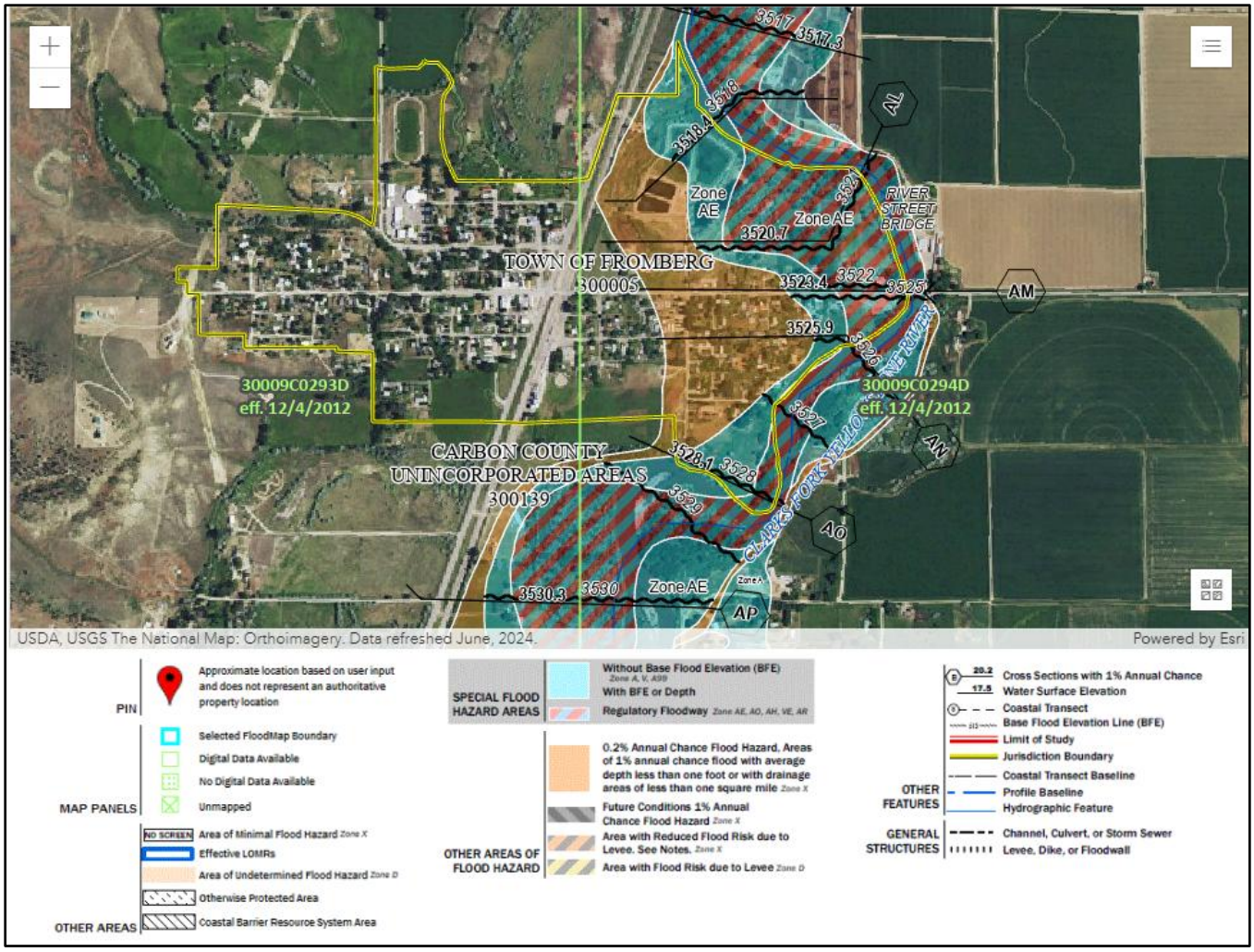


Figure 8. FEMA flood map in Fromberg, MT on the Clarks Fork Yellowstone River (fema.gov).

1.8.2 Ice Jams

Another serious river hazard, especially in Montana, is ice jamming. Over 4,563 ice jams records have been posted in the CRREL Ice Jam database for Montana since 1894, which is the most in the United States. Ice dams can cause flooding upstream due to backwatering, and downstream of the jam, ice chunks mobilized by breakups can cause damage. Breakups can occur rapidly, and it generally takes water that is almost two to three times the thickness of the ice to mobilize the jammed ice. Ice jams can also cause avulsions by entirely blocking channels and forcing flows onto the floodplain.

While ice jamming has been infrequent on the Clarks Fork River, with only 5 jams noted between 1959 and present, the impact of those jams can be severe. Although ice jams are most common in Montana during February and March, ice jam flooding has happened on the Clarks Fork River as early as November. One jam of note was on November 19, 1959:

Freeze-up jam resulting from extremely low air temperatures caused water to rise approximately 10 feet above normal stage. Town used dragline to construct by-pass channel through the ice. (CRRELL Ice Jam Database)

On Rock Creek flooding due to ice jamming does not appear to be a large concern. There are numerous records in the Ice Jam Database of increased water levels due to jamming downstream of the USGS gage near Red Lodge, but there were no notes of flooding related to these events. That said, recent posts on social media have documented numerous ice jamming events near Red Lodge. The ice breakup from one such event where near bank full flows were observed was captured on video on December 10, 2016 was captured on video by Tom and Cindy Millard (https://www.facebook.com/watch/?v=1548884635128443)(Figure 9).



Figure 9. Ice jam blowout on Rock Creek at Rotary Park in Red Lodge on December 10, 2016. (Tom and Cindy Millard, https://www.facebook.com/watch/?v=1548884635128443)

1.8.3 Landslides

While landslides are a common risk in areas with steep topography, the geology bounding the waterways in this study show limited landslide risk. There are several mapped landslide deposits in the Red Lodge area on Rock Creek, but these tend to be small, localized deposits with little systemic risk for new failure and subsequent damming of the waterway. Though no recent slide activity has impacted the river corridor, the potential for landslides is real if the conditions are appropriate. If any of these areas should fail, there is potential for either deflection of the river channel or damming of the river in the most severe case. The Yellowstone region is also known for earthquake risk. Earthquake activity, when combined with landslide potential can be catastrophic, as witnessed by the 1959 Hebgen Lake earthquake which triggered a massive landslide and formed Earthquake

Lake, nearby, on the Madison River. That said, even relatively small hillslope failures can deflect stream courses and create hazards that may exceed the boundaries of the mapped CMZ.

1.9 Disclaimer and Limitations

The boundaries developed on the CMZ 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, nearby bank armor, and land use on channel migration, and an analysis of the site-specific potential for channel blockage or perching that may drive an avulsion.

1.10 Acknowledgements

We would like to extend our gratitude to the following individuals for their assistance and input on this project.

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- Katie Young, Trout Unlimited
- Aimee Bailey, Carbon County CD Administrator
- Jeff DiBenedetto, Karen Walmsley, and Scott Hancock, Carbon County Resource Council
- Ben Bailey, Montana Fish Wildlife Parks

2 Physical Setting

The following section contains a general description of the geographic, hydrologic, and geologic influences in the project area, to highlight how those influences affect stream corridor morphology. The size and shape of the river bottoms are largely controlled by project area geology and alluvial deposition, creating a high degree of variability in stream corridor width. Human development, including extensive river corridor transportation infrastructure and floodplain development, is superimposed on that natural variability to create channel migration corridors that range from largely unconfined to virtually locked in place.

2.1 Geography

The Clarks Fork Yellowstone River and Rock Creek are significant hydrologic features in south-central Montana near the town of Red Lodge. Both drain the northeastern slopes of the Beartooth Mountains and contribute to the broader Yellowstone River watershed. Their courses reflect high topographic relief and diverse geomorphologic processes from the steep mountain slopes of their headwaters and transitioning to the broad alluvial valleys once leaving the mountain canyons.

2.1.1 Clarks Fork Yellowstone River

The Clarks Fork Yellowstone River (Clarks Fork) originates in the Beartooth Mountains at the confluence of perennial headwater streams near Fisher Creek and Lady of the Lake Creek in Park County, Montana. From its headwaters, the river flows south into Wyoming, turning northeast and re-entering Montana near Chance, Montana (Figure 1 and Figure 10).

The mainstem of the Clarks Fork extends approximately 141 miles from its source to its confluence with the Yellowstone River near Laurel, Montana (Wikipedia, 2025). The Clarks Fork Yellowstone River watershed corresponds to Hydrologic Unit Code (HUC) 10070006 in the United States Geological Survey watershed hierarchy and covers approximately 2,890 square miles.

2.1.2 Rock Creek

Rock Creek near Red Lodge originates just north of the Clarks Fork headwaters in high alpine basins of the Beartooth Mountains, with major tributaries such as West Fork Rock Creek and Lake Fork Rock Creek collecting drainage from steep headwater slopes (Figure 1 and Figure 10).

2.2 Geology and Geomorphology

The project area is located near Red Lodge, Montana and is situated along the northeastern margin of the Beartooth Mountains, a major Laramide uplift within the northern Rocky Mountains (Figure 10 and Figure 11). The Beartooth uplift exposes extensive Precambrian crystalline basement rocks, including granitic and gneissic lithologies that represent some of the oldest rocks in North America. These rocks dominate the high-elevation terrain southwest of Red Lodge and form the headwaters of Rock Creek. Uplift of the Beartooth block occurred primarily during the Late Cretaceous to early Paleogene Laramide Orogeny, producing a steep mountain front and adjacent sedimentary basins (USGS, 1961).

Erosion of the uplifted Beartooth Mountains supplied large volumes of sediment to these basins, establishing the stratigraphic framework of the foothills and lowlands east and northeast of Red Lodge. The distribution of bedrock units, structural features, and surficial deposits in the Red Lodge area is documented in detail on geologic maps prepared by the Montana Bureau of Mines and Geology (MBMG), particularly the *Geologic Map of the Red Lodge Area* (MBMG, 2005).

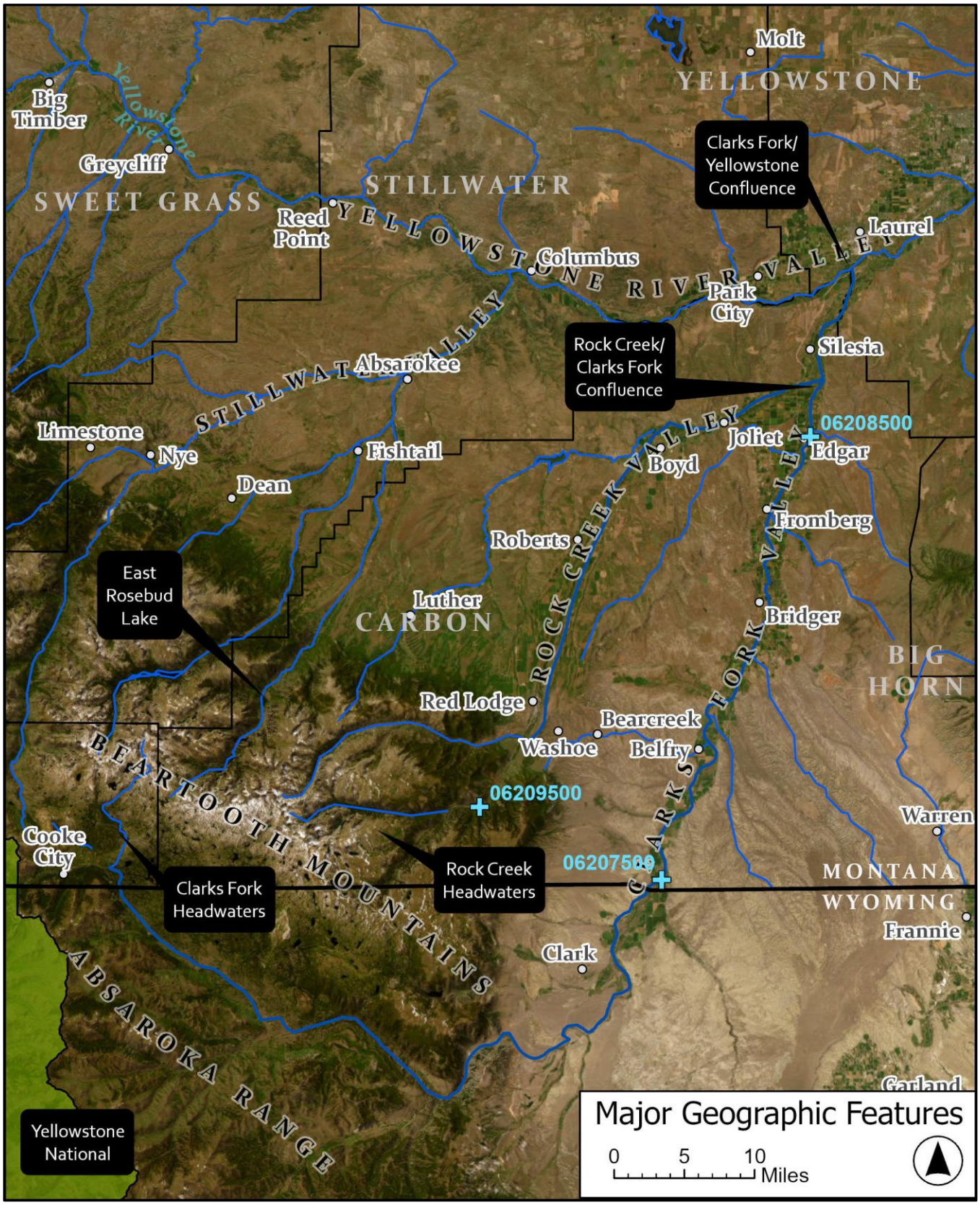


Figure 10. Major geographic features and USGS gauge stations of project area.

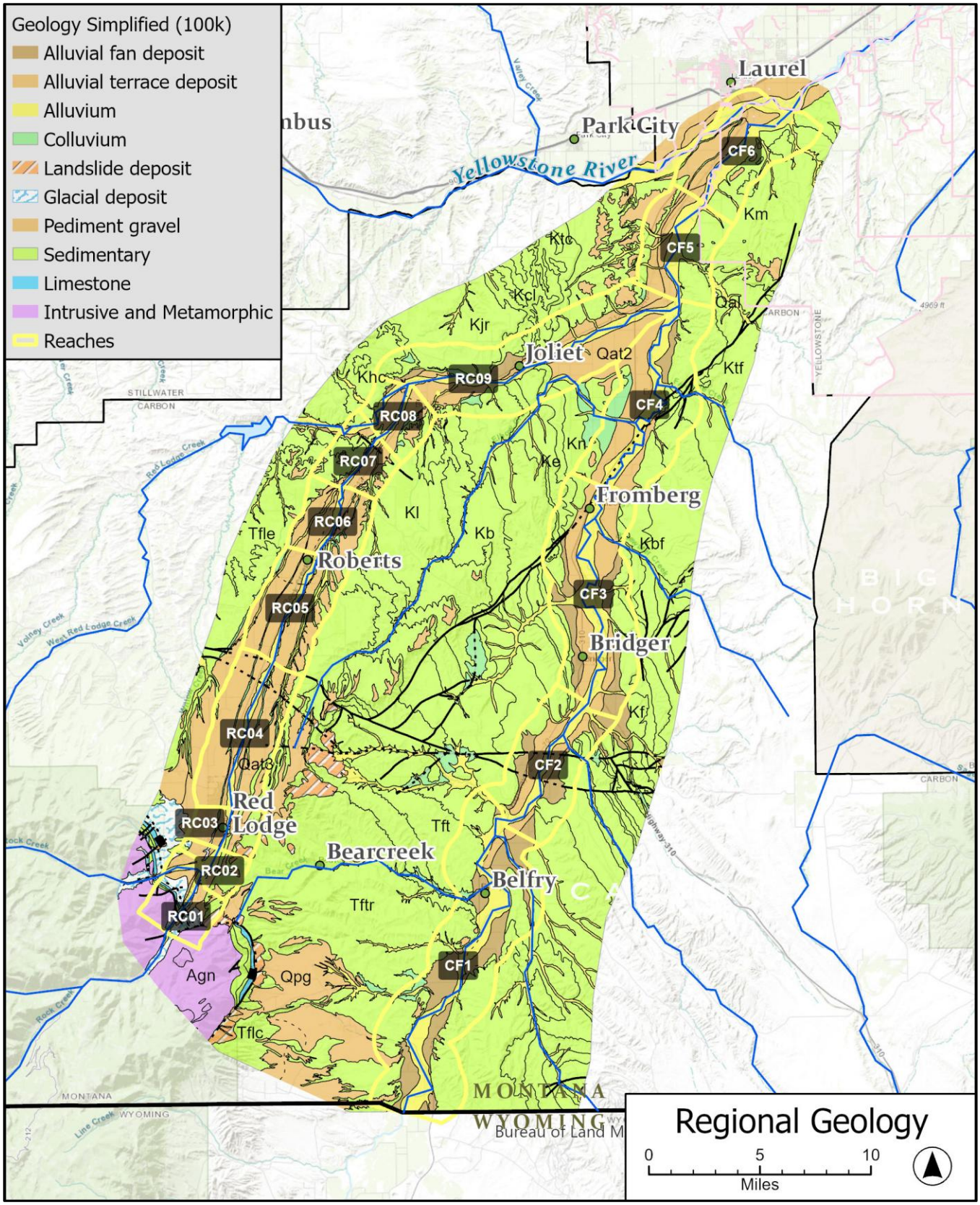


Figure 11. Simplified geologic map of the project area. Note that the project reaches are described in Section 3.4.

2.2.1 Rock Creek Valley Geology and Geomorphology

Rock Creek drains the northeastern flank of the Beartooth Mountains and flows northeastward through the town of Red Lodge before joining the Clarks Fork Yellowstone River. In its upper reaches, Rock Creek occupies a narrow, steep-walled canyon incised into Precambrian bedrock (Figure 12). Glacial till and other Pleistocene deposits are present in portions of the upper valley, reflecting alpine glaciation that affected the Beartooth Mountains during the Quaternary (USGS, 1961).

Downstream of Red Lodge, Rock Creek emerges from the mountain front and flows across a widening valley characterized by extensive alluvial deposits and multiple terrace levels within a mature cottonwood corridor (Figure 13). These terraces consist of gravel, sand, and silt derived from both the crystalline uplands and erosion of Tertiary sedimentary rocks. The presence of multiple terrace surfaces indicates episodic incision and aggradation related to changes in base level, sediment supply, and climate during the late Cenozoic.

Near Boyd, the river turns east and the gradient lessens (Figure 14). The waterway shows increased turnover within the wooded valley bottom. Cleared agricultural fields often form the edges of the active corridor. Migration rates increase as the bedload is deposited and reworked. Avulsions are common but generally contained within the historic channel footprint. The exception is near the confluence with the Clarks Fork where the modern channel is located around a quarter of a mile north of its location around 1900.



Figure 12. View upstream from the East Side Road bridge (December 16, 2025).



Figure 13. View upstream from the Fox East Bench Road bridge (December 16, 2025).



Figure 14. Access site below Joliet bridge looking downstream. Granite Road is on the right (May 19, 2026)

2.2.1 Clarks Fork Yellowstone River

The Clarks Fork Yellowstone River detailed in this study flows east of Red Lodge in a broad, low-gradient valley that contrasts with the more confined Rock Creek valley (Figure 15). The Clarks Fork valley is underlain by thick accumulations of Quaternary alluvium overlying Tertiary sedimentary rocks, primarily the Fort Union Formation (Figure 16). Compared to Rock Creek, the Clarks Fork exhibits fewer well-preserved terrace remnants, suggesting a longer history of lateral channel migration and floodplain development (USGS, 1961).

Rock Creek contributes significant sediment to the Clarks Fork at their confluence, influencing channel morphology and sediment distribution downstream (Figure 17). The broader valley geometry and sustained discharge of the Clarks Fork reflect its role as a major regional drainage within the Yellowstone River basin.



Figure 15. View downstream from the Chance Road bridge near the Montana/Wyoming border (December 16, 2025).



Figure 16. View downstream near Wolf Creek Road (December 16, 2025).



Figure 17. View downstream from the Cottonwood Road bridge (December 16, 2025).

2.2.2 Terraces and Landscape Evolution

A prominent geomorphic feature between Rock Creek and the Clarks Fork is Mesa Bench, an elevated terrace formed by ancestral Rock Creek. Mesa Bench stands several hundred meters above the modern Clarks Fork valley floor and records an earlier phase of valley development prior to significant downcutting. This feature provides evidence for changes in drainage configuration and regional base level during the late Cenozoic (USGS, 1961).

Differences in terrace development between Rock Creek and the Clarks Fork reflect contrasts in drainage area, sediment load, and erosional history. These terrace surfaces are key indicators of long-term landscape evolution in the Red Lodge area.

2.2.3 Surficial Deposits and Active Processes

Modern surficial processes continue to modify the Rock Creek and Clarks Fork valleys. Active floodplains are composed of unconsolidated alluvium that is periodically reworked during high-flow events. Post-glacial slope processes, including small landslides, debris flows, and colluvial deposition, contribute sediment to both river systems and influence valley margins. These processes reflect ongoing geomorphic adjustment to tectonic uplift, climatic variability, and hydrologic events.

2.3 Flood History

The following sections detail the flood history of the two waterways, along with a detailed description of the June 2022 flood.

2.3.1 Introduction

Rock Creek and the Clarks Fork Yellowstone River both have their headwaters in the Beartooth Mountains along the Montana/Wyoming border. Rock Creek is located on the north side of the ridge and flows generally north and west until its confluence with the Clarks Fork Yellowstone River. The Clarks Fork Yellowstone River begins on the south side of the ridge and heads southwest before turning north and joining the Yellowstone River. With headwaters in the high mountains, these two channels maintain a natural spring snowmelt hydrograph which typically peaks in mid-June.

The floods described as Q10, Q50, and Q100 ("100-year flood") have a 10%, 2%, and 1% probability of occurring in any given year, respectively.

There are several USGS stream gages on both channels (Figure 10). Only one gage on Rock Creek is currently active, gage #06209500 near Red Lodge. On the Clarks Fork Yellowstone River there are two gages in Montana that are currently active, gage #06207500 near Belfry, which is located near the Montana/Wyoming border, and gage #06208500 at Edgar. The annual peak flow records for all three gages show very different historic flooding patterns. For all three gages, however, the flood of record occurred in June 2022. Along the Clarks Fork Yellowstone River, the 2022 flood was greater than a 500-year event. At the Rock Creek gage, the 2022 flood was just over a 200-year event. The Rock Creek gage is located upstream of the confluence with the West Fork Rock Creek which had an estimated greater than 500-year event in 2022.

Other major floods recorded on the Clarks Fork Yellowstone River are shown in Figure 18 and Figure 19. There have been five events recorded near Belfry and only one at Edgar greater than a 10-year event in the last 100 years. The gage at Edgar has no record between 1970 to 1986, therefore the 1981 flood event was not recorded. Annual peak floods for Rock Creek are shown in Figure 20. There have been four events greater than a 10-year event in the last 25 years recorded near Red Lodge. Prior to 1986 there were two events greater than a 10-year event on Rock Creek recorded at a discontinued gage above Maurice Creek which is just downstream from the current gage.

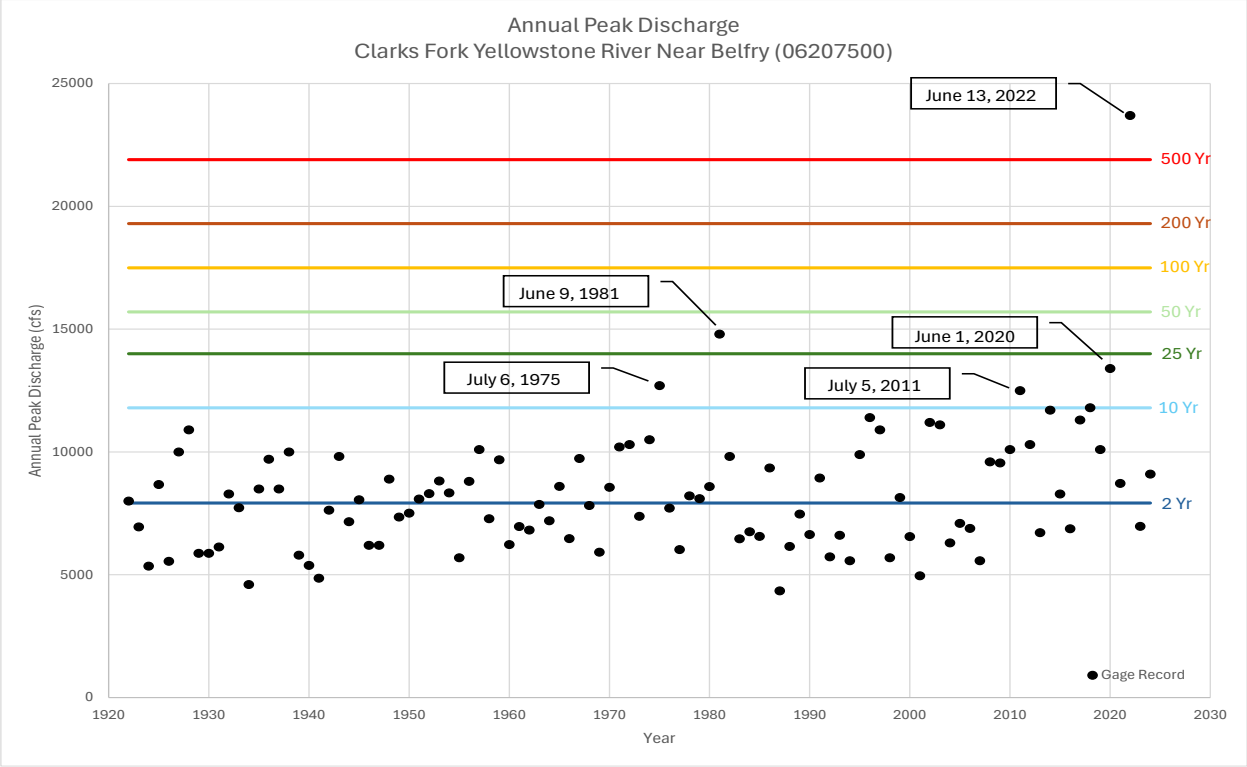


Figure 18. Annual peak floods for USGS 06207500 Clarks Fork Yellowstone River near Belfry (near Montana/Wyoming border) with floods greater than an estimated 10-year event labeled.

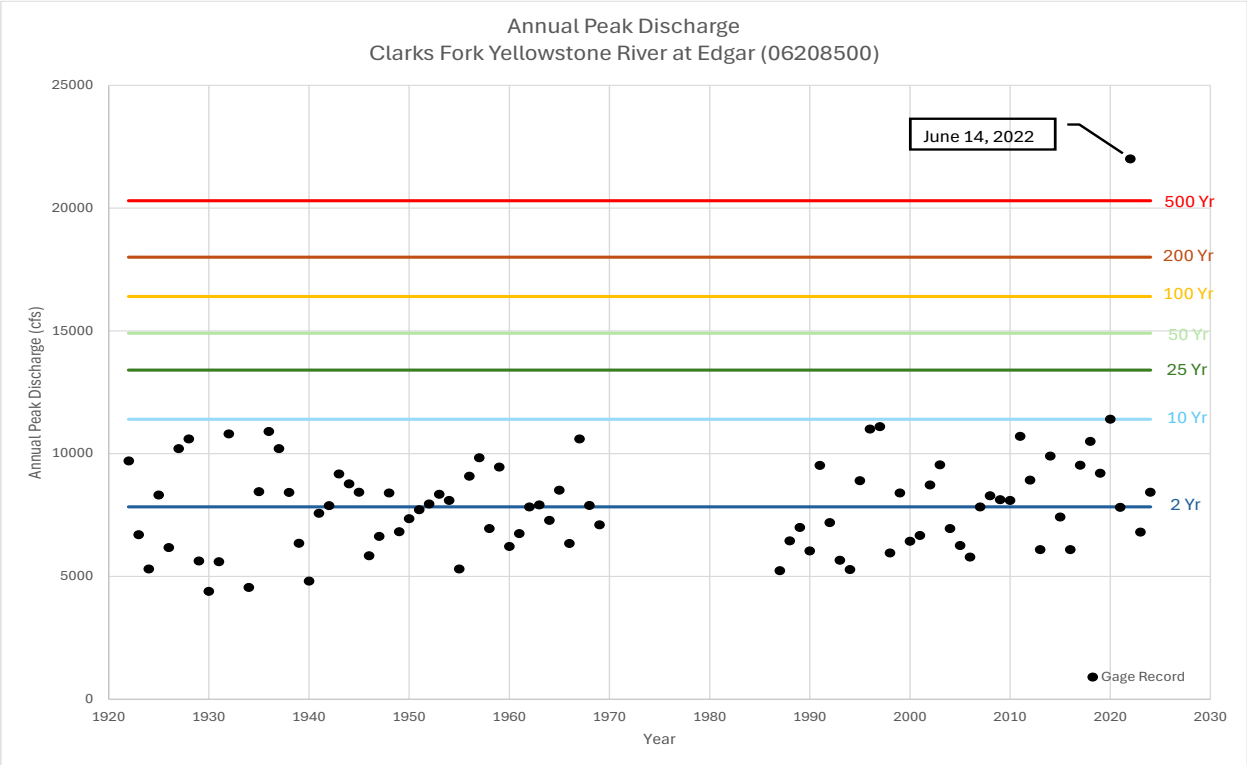


Figure 19. Annual peak floods for USGS 06208500 Clarks Fork Yellowstone River at Edgar with floods greater than an estimated 10-year event labeled.

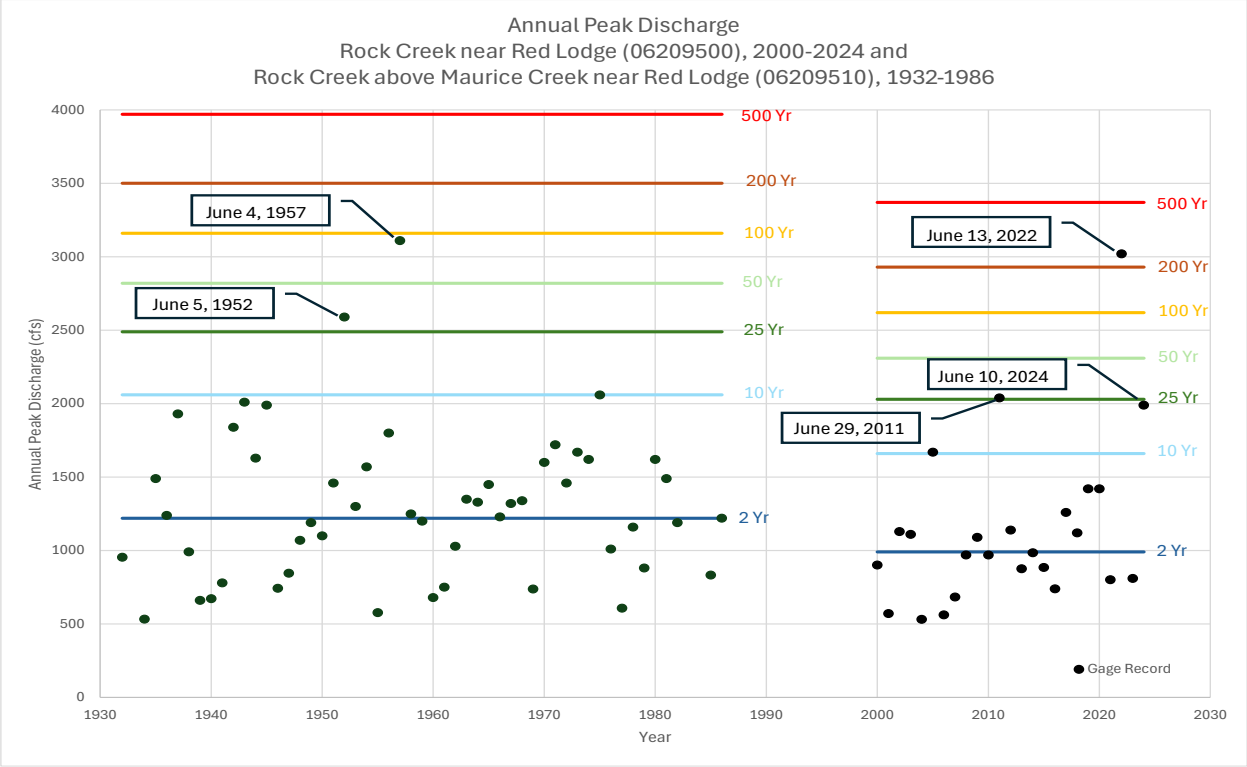


Figure 20 Annual peak floods for Rock Creek near Red Lodge and above Maurice Creek with floods greater than an estimated 10-year event labeled.

2.3.2 2022 Flood

In late May and early June of 2022, an atmospheric river that had soaked the Pacific northwest dropped several inches of rain in southern Montana and northern Wyoming. The rainfall event coincided with a warm spell that sped up snowmelt. The Absaroka and Beartooth Ranges received up to 5 inches of rain, which was combined with up to an additional 5 inches of snow water equivalent coming off saturated soils (nasa.gov). On Monday, June 13, 2022, the stage of the Rock Creek and Clarks Fork Yellowstone River gages rose rapidly. At Belfry, the stage of the Clarks Fork Yellowstone River reached a record elevation that was about 2.7 feet higher than the previous record set in 1981, and the peak discharge was estimated by the USGS to be 23,700 cubic feet per second (cfs). Near Red Lodge, the stage of Rock Creek was only about 0.2 feet higher than the previous record set in 2011, and the peak discharge was estimated by the USGS to be 3,020 cfs.

Clarks Fork Yellowstone River

Although the 2022 event was extreme, it was also short, with flows exceeding 14,000 cfs for about a day on the Clarks Fork. Whereas the instantaneous peak on June 13 was 23,700 cfs, the mean daily flow value on that day was 20,800 cfs. Figure 21 shows mean daily flow hydrographs at Belfry for all the major floods since 1975; the very sharp rise and fall of flows during 2022 was unusual, as can be seen by the shapes of the hydrographs. A similar short duration peak occurred in 1981, but the peak flow was much lower.

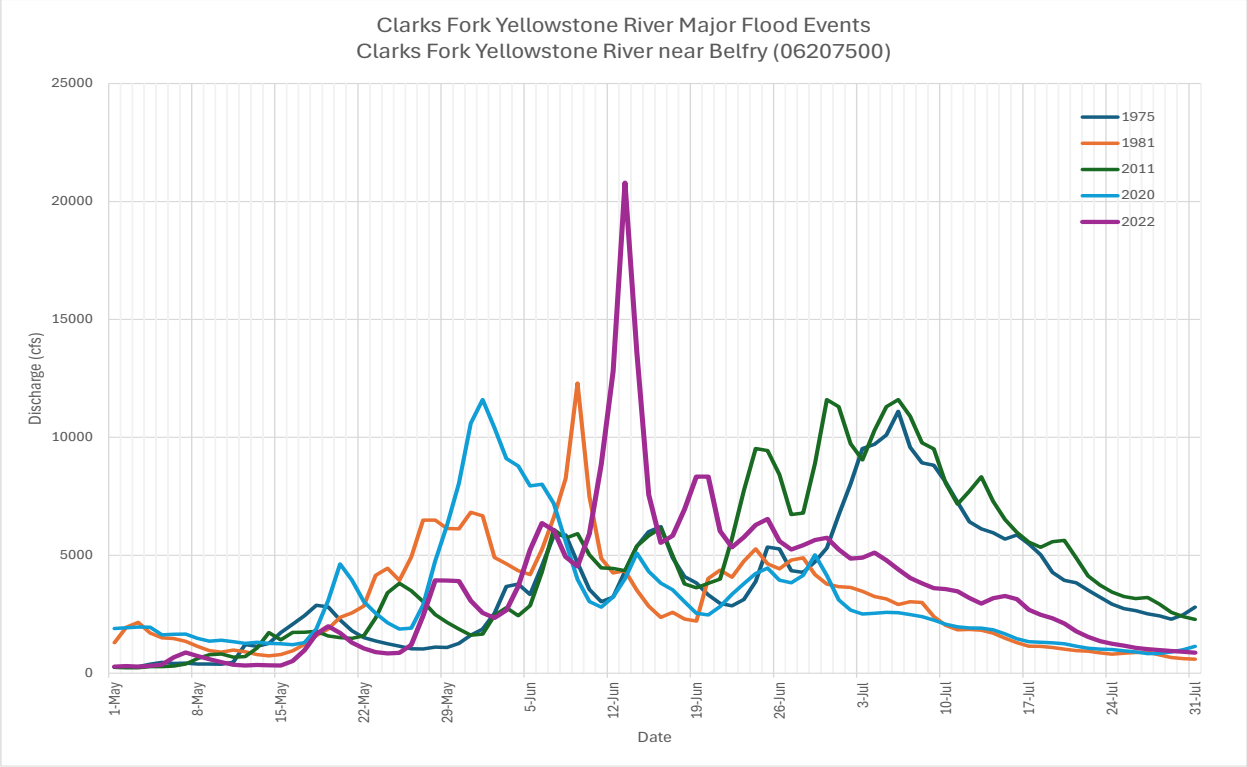


Figure 21. Flood hydrographs for the Clarks Fork Yellowstone River at Belfry. Flows are mean daily values.

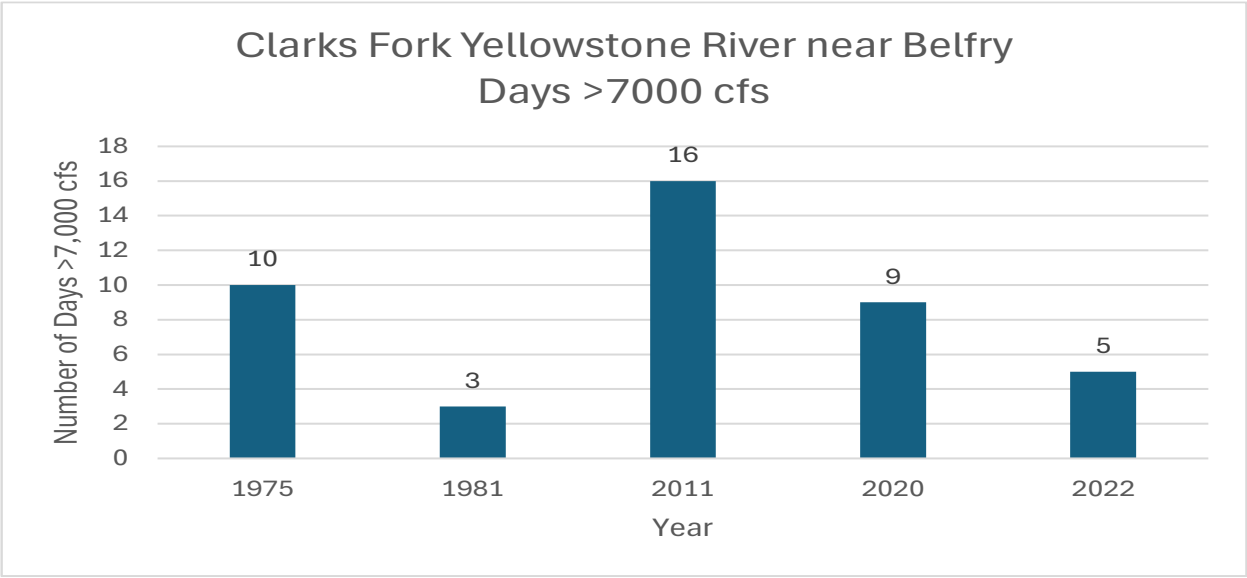


Figure 22. Number of days that mean daily flows exceeded 7,000 cfs near Belfry for major flood events.

Although the 2022 event was extreme, it was also short, with flows exceeding 1,700 cfs for about a day on Rock Creek. Whereas the instantaneous peak on July 13 was 3,020 cfs, the mean daily flow value on that day was 2,630 cfs. Figure 23 shows mean daily flow hydrographs near Red Lodge for all the major floods since 2011; the very sharp rise and fall of flows during 2022 was extremely unusual as can be seen by the shapes of the hydrographs.

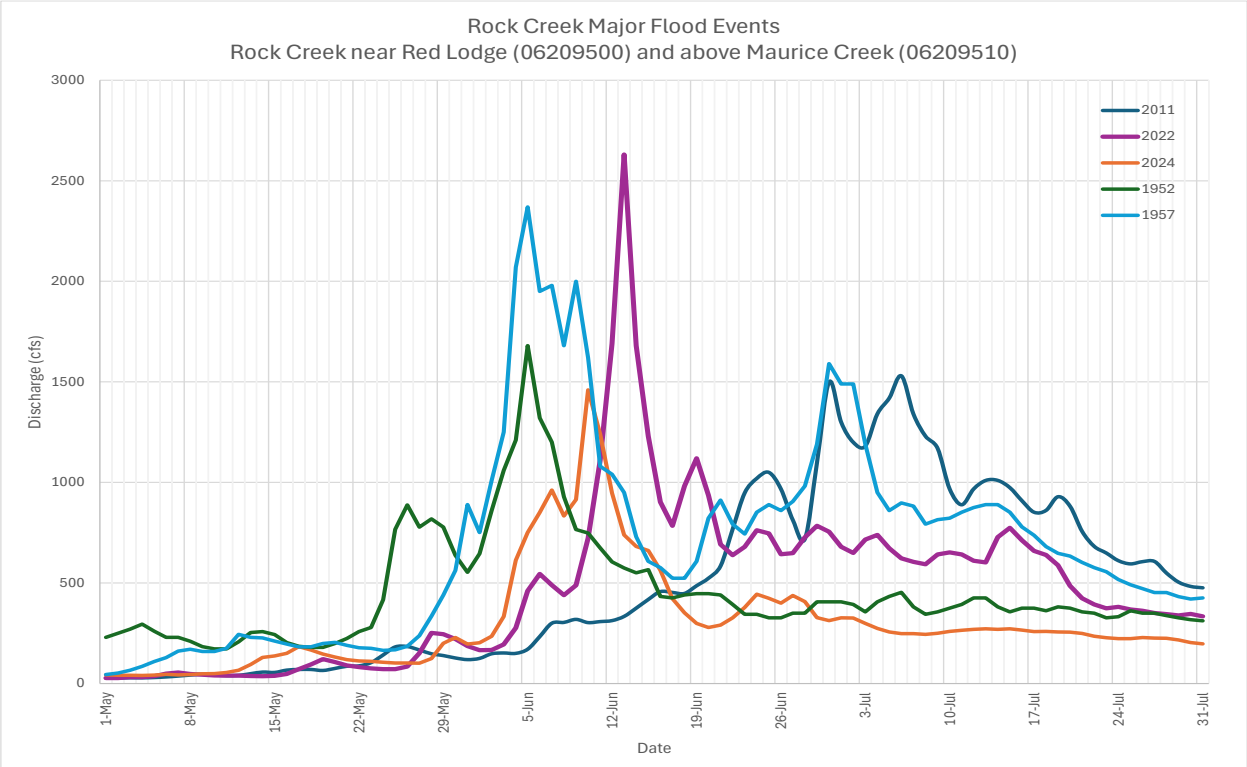


Figure 23. Flood hydrographs for Rock Creek near Red Lodge. Flows are mean daily values.

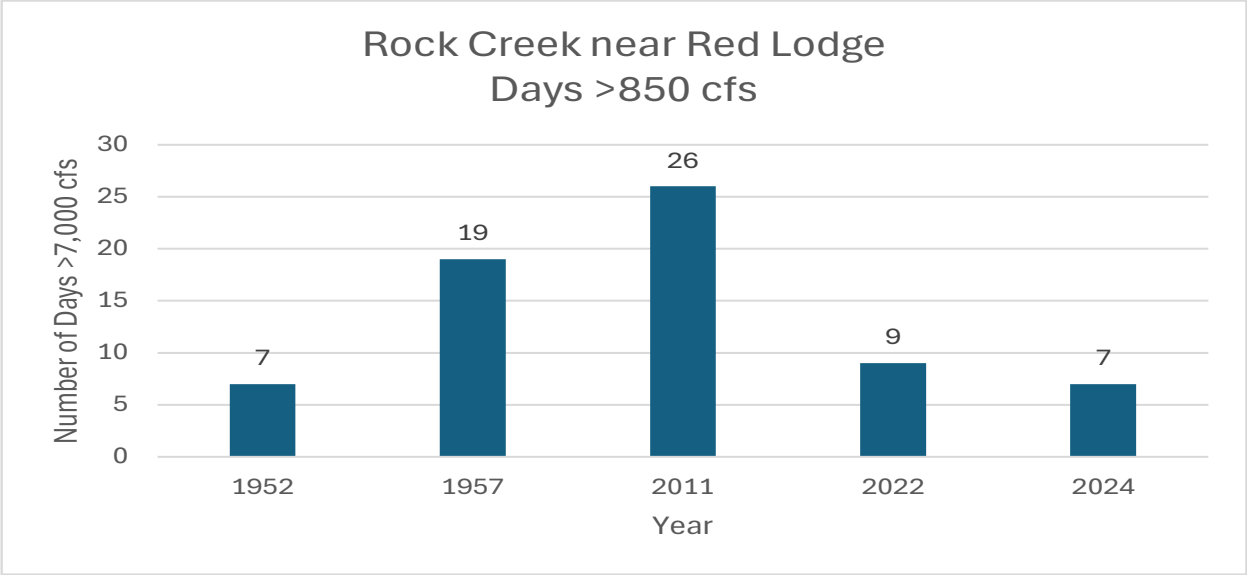


Figure 24. Number of days that mean daily flows exceeded 850 cfs near Red Lodge for major flood events.

The short duration of the 2022 flood made it a different type of event than the previous floods. While the magnitude of the flood event is important for evaluating rates of channel change, it is also important to put the duration of the events into perspective (Figure 22 and Figure 24). For example, a 25-year flood that lasts for weeks may result in more geomorphic changes (i.e. channel migration, avulsions) than a more extreme but short duration event that may primarily cause flood damage (Figure 25 and Figure 26). In 2011, a three-week runoff event on the Musselshell River resulted in 59 avulsions and 37 mile shortening of the river, completely changing its geomorphic form (width, slope, pattern). In 2011, the Clarks Fork Yellowstone River stayed above 7,000 cfs on the Belfry USGS gage for just over two weeks, causing extensive bank erosion and channel movement. The June 2022 event peaked quickly before dropping back down, only exceeding a mean daily flow of 7,000 cfs for 5 days. In 2011, Rock Creek stayed above 850 cfs at the Red Lodge USGS gage for almost four weeks. The June 2022 event by contrast only exceeded a mean daily flow of 850 cfs for 9 days. Bank erosion was common along both channels, but a longer duration flood would have created much more damage. That said, the rapidly rising flows created extensive floodplain damage due to high volumes of wood and sediment entering in the river. That material will continue to be reworked in coming years, creating a potentially long adjustment period post-2022.



Figure 25. Flooding at mouth of the Clarks Fork Yellowstone Canyon, June 17, 2022 (George Moncure, YouTube https://www.youtube.com/watch?v=7kpZSA0ANV0).



Figure 26. Clarks Fork River flooding near Lovers Lane. (Cowboy State Daily, June 14, 2022).

Although the short duration 2022 flood did not completely alter the form of the river system-wide, the very high peak caused different processes to occur, creating major changes in certain areas. One of the most striking changes was where Rock Creek flowed through Red Lodge (Figure 27 and Figure 28). Through town, the sheer volume of water was able to move large boulders and damage structures as it overtopped the confined channel entering Red Lodge. Although the 2022 event was relatively short, its extreme magnitude caused that material to mobilize, destabilizing those banks which resulted in extensive erosion, channel widening, and downstream sediment delivery.

2.4 Physical Features

Physical structures such as bridges, road beds, bank armor, and irrigation structures are often the largest impacts to any naturally flowing waterway. While investments in transportation, agricultural, municipal and residential structures are important economic drivers, the disruption of the natural geomorphic processes that allow a stream to adapt to changing inputs often leads to unintended consequences. To our knowledge, there is no formal inventory of physical features along either the Clarks Fork River or Rock Creek. The exception to this would be the Clarks Fork Yellowstone River Assessment (Kellogg, 2019) that inventoried structures on the lower 45 miles of the Clarks Fork from the Clarks Fork River FAS (Bridger, MT) to the confluence with the Yellowstone. To address this, an informal inventory of physical features within the study area was compiled primarily from an interpretation of 2023 NAIP aerial photography and more current Google Earth imagery for the entire study area. The 2019 Kellogg report helped to identify some “hidden” bank protection on the Clarks Fork. No on-the-ground mapping or assessment of features was performed for this study, so the mapped features likely underestimate the total amount of armor within the system on current and active channels. Additionally, some of the armor has failed since the mapping and that “lost” armor has not been completely removed from the data set compiled for this report.



Figure 27. Photo courtesy Kevin Kinzley for the Tribune (Powell Tribune, June 14, 2022).



Figure 28. Red Lodge flood debris. Photograph taken by Seth Siefken, U.S. Geological Survey, on June 29, 2022. (Chase et al, 2024).

2.4.1 Bank Armor

The 2019 Kellogg report brings to light the degree that historic bank armoring efforts plays a role in the geomorphic changes in the Clarks Fork River. In the lower 44.7 miles of the Clarks Fork River 12.4 miles of armor were mapped. This included bendway weirs, rock and concrete armor, car bodies, abandoned farm equipment, and other debris. This indicates that 28% of the channel length has been armored in one way or another (one side only, 14% if considering all banklines, or ~2x the channel length). Highest concentration is from Bridger to Edgar with up to 34% of the bankline armored. Much of this is not visible in aerial photographs as it is obscured by vegetation. The remote inventory used in this study identified approximately 9.6 miles of armor on 72 miles of the Clarks Fork River in the study, or 13% (one side of river). If looking at Reaches CF3-CF6 (approximately the same area used in the Kellogg study), we mapped ~7 miles of armor, or ~16% of the channel (one side of river), so at least on the Clarks Fork, the data compiled for this CMZ study definitely underrepresents the amount of armor on the channel. The same is likely true for Rock Creek, where dense vegetation likely hides much of the armor present on the channel.

2.4.2 Bridges

Bridges are critical infrastructure for both day-to-day activities, as well as providing key access during emergencies. There are 14 existing bridges on the Clarks Fork and at least 23 on Rock Creek (note that this count may not reflect recently replaced bridges or those obscured by bankline vegetation). Up to six bridges were lost on Rock Creek due to the 2022 flooding. Many others were damaged and required repairs. For the most part, the bridges on both waterways appear to be functioning as designed with adequate conveyance and good alignment with the river channel. Some of the bridges that were either damaged or lost during the floods may have not been appropriately designed to handle a flood of that magnitude.

2.4.3 Irrigation Infrastructure

Both the Clarks Fork and Rock Creek have extensive irrigation infrastructure associated with them and has resulted in extensive in-channel and bankline features to maintain conveyance into the associated canals. There are at least 19 large diversions on the Clarks Fork and 20 on Rock Creek. Managing water delivery to the canals along geomorphically active channels can be challenging. On both waterways, a variety of permanent and seasonal diversion dams and structures are used to ensure proper water delivery.

3 Channel Migration Zone Mapping Methods

The development of the Clarks Fork River and Rock Creek 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 over 1,500 miles of rivers in Montana to date.

3.1 GIS Project Development

All project data was compiled using ESRI's ArcGIS Pro Geographic Information System (GIS) utilizing a common coordinate system - Montana State Plane NAD83 Meters. Orthorectified air photos provide the basis for Channel Migration Zone mapping. Other existing datasets included roads, 2023 LiDAR elevation data, flood studies, scanned General Land Office Survey Maps obtained from Bureau of Land Management, and geologic maps produced by the United States Geological Survey. Stream stationing at tenth-of-a-mile increments produced by the Montana Fish Wildlife and Parks is used for all river mile locations.

This report, maps, and GIS data will be available from the Montana State Library on the Channel Migration Zone Resources web page (https://msl.mt.gov/geoinfo/data/montana_channel_migration_zones/resources). Additionally, the mapping data layers will be included on the State Library's CMZ web map. This can be used for exploring the CMZ data and creating maps of specific sites.

3.2 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.

This project relied on five primary imagery datasets to define river locations through time and develop annual channel migration rates. All of the aerial imagery is publicly available for either download or streaming. The earliest imagery is from the early to mid-1950s (mainly 1954) and available statewide through a web service. The data set is comprised of USDA black and white aerial photography that were orthorectified by the University of Montana. Color natural color and infra-red USGS National High Altitude Imagery Program (NHAP) from 1981 was orthorectified for the State of Montana by Aero-Graphics and are available through data streaming. The remaining imagery (2015, 2021 and 2023) are all from the USDA National Agricultural Imagery Program (NAIP). NAIP is generally flown every two years in Montana on odd numbered years. Additional NAIP and Digital Orthophoto Quad (DOQ) imagery was referenced on an as needed basis to better understand channel development.

Table 1. Aerial photography used for the River Channel Migration Mapping Study.

Year	Source	Scale	Image Date(s)	Notes
1954	USDA	~1:20,000	Summer 1954	Orthorectified, black and white
1981	NHAP	1-meter	August 24, 1987	Orthorectified, color
2015 NAIP	USDA	1-meter	July 4 & 29, August 10, 2015	Digital Download, Compressed County Mosaics (color)
2021 NAIP	USDA	1-meter	June 11, 2021	Digital Download, Compressed County Mosaics (color)
2023 NAIP	USDA	1-meter	August 11, 2023	Digital Download, Compressed County Mosaics (color)

Figure 29 to Figure 33 provide imagery examples at the same location along with the associated digitized bankfull channel boundaries.

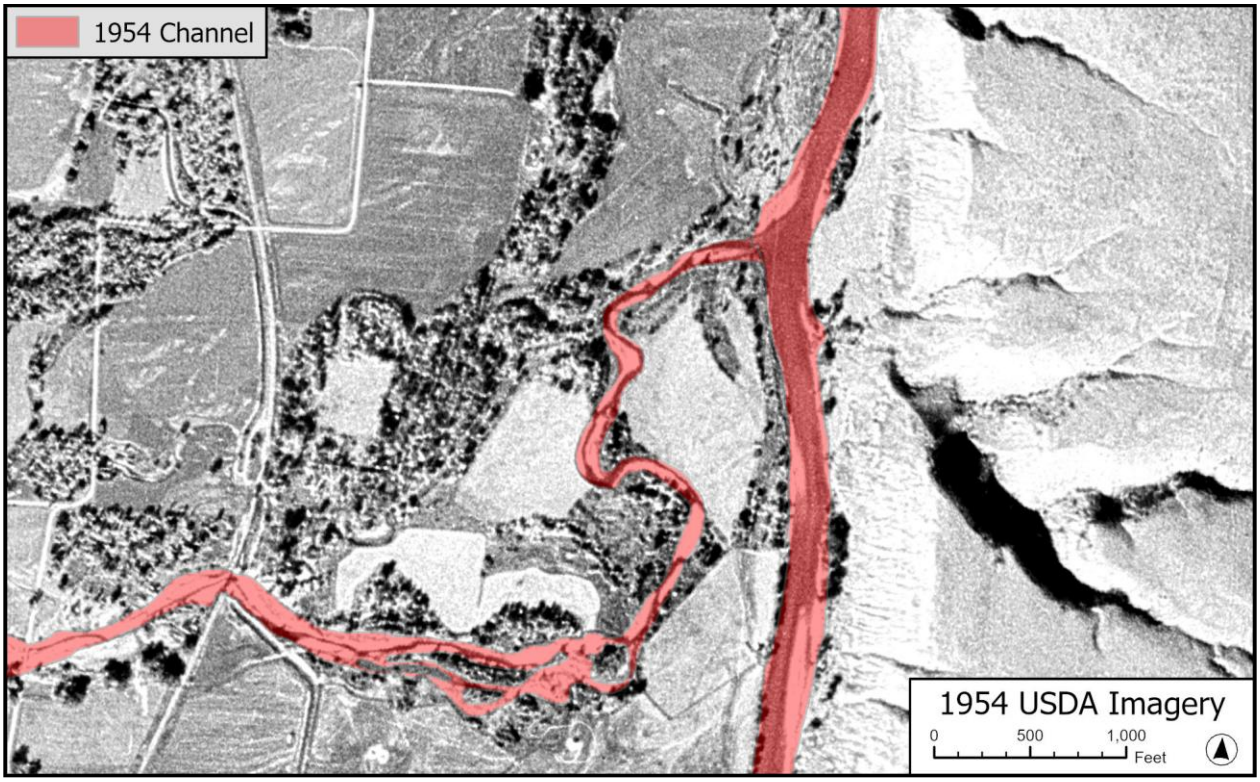


Figure 29. Example NAIP imagery from 1954 USDA showing the Clarks Fork River and Rock Creek confluence.

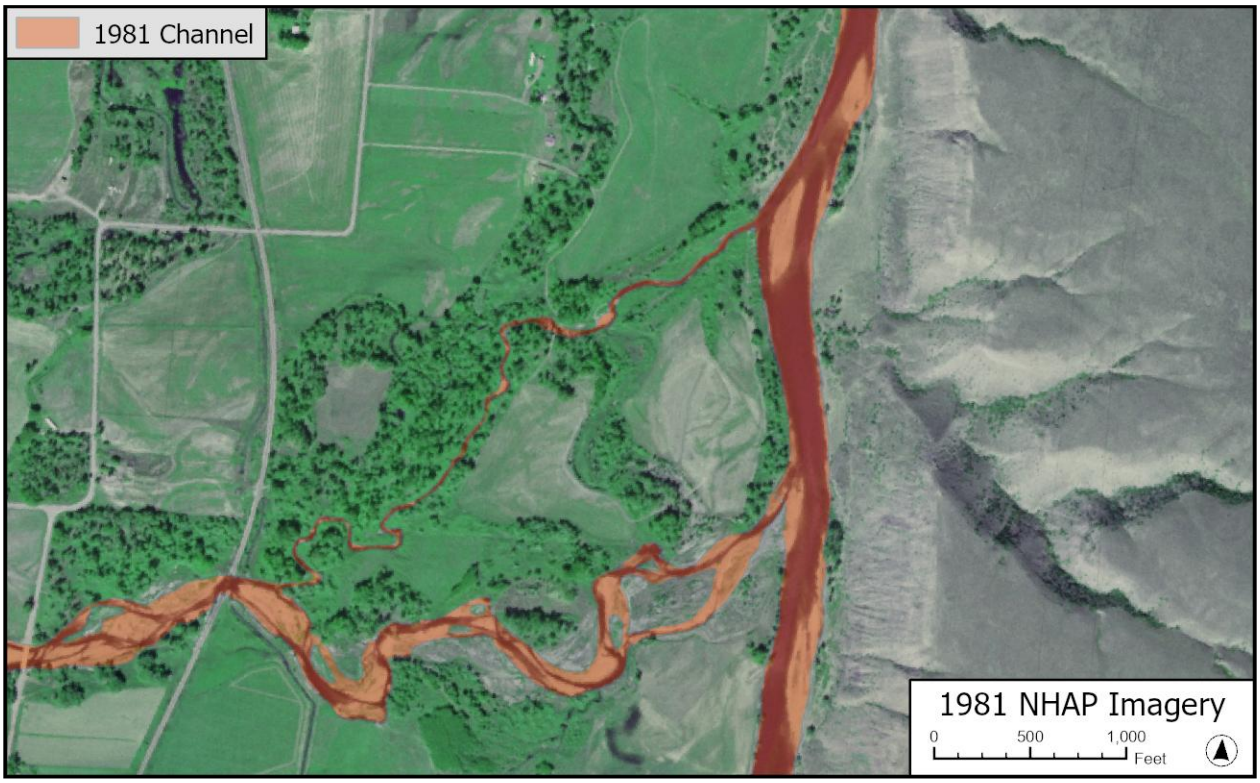


Figure 30. Example National High Altitude Imagery Program (NHAP) imagery from 1981 showing the Clarks Fork River and Rock Creek confluence.

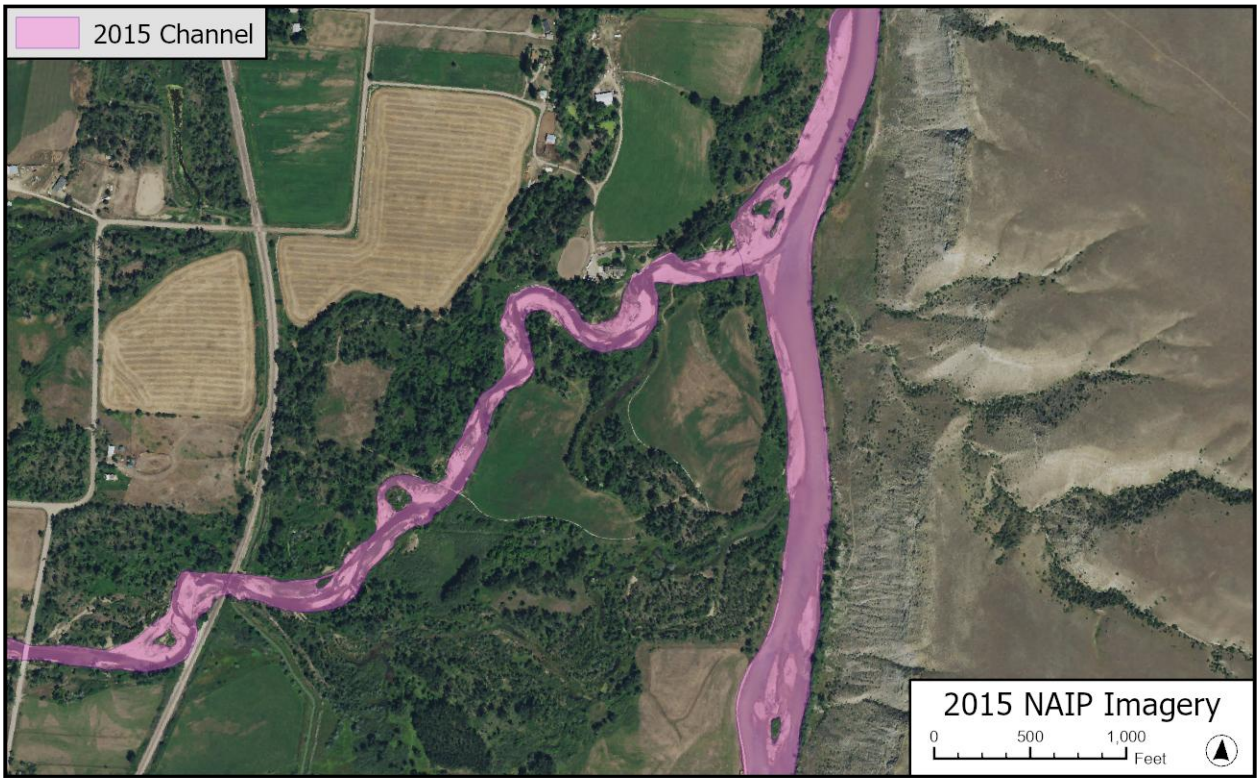


Figure 31. Example NAIP imagery from 2015 showing the Clarks Fork River and Rock Creek confluence.

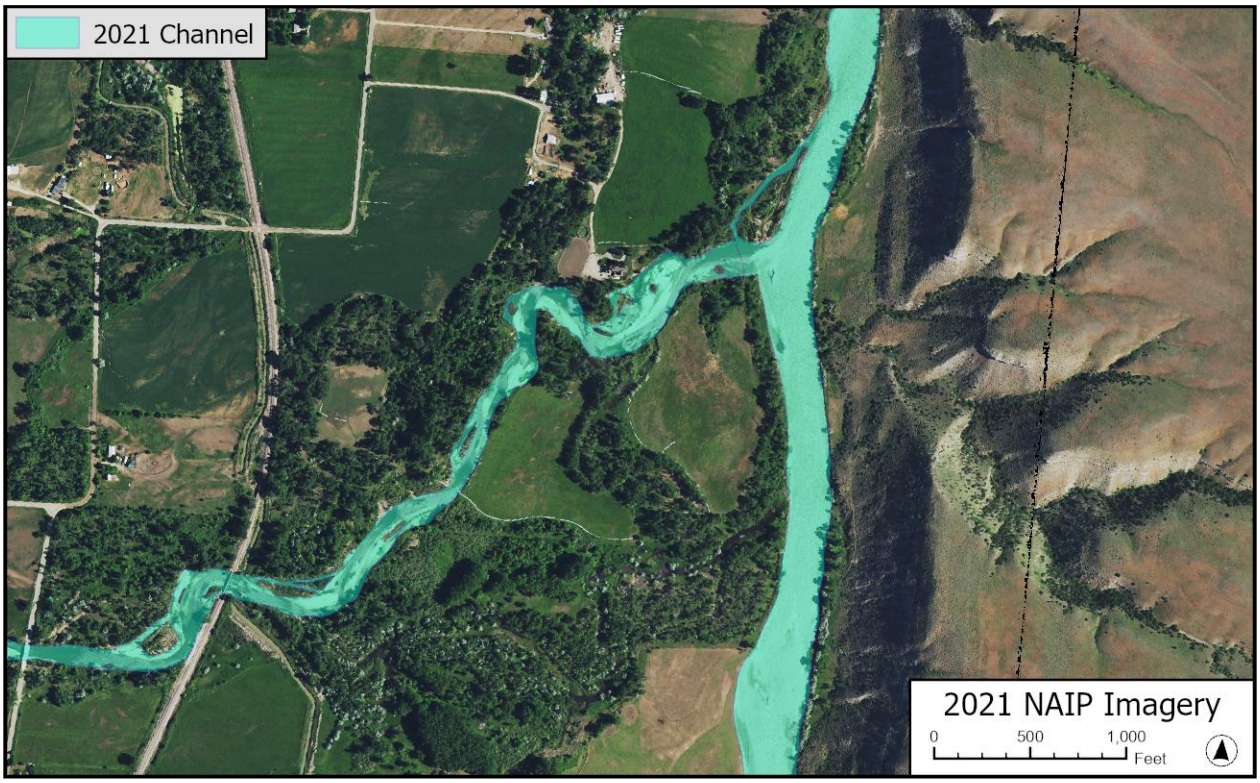


Figure 32. Example NAIP imagery from 2021 showing the Clarks Fork River and Rock Creek confluence.



Figure 33. Example NAIP imagery from 2023 showing the Clarks Fork River and Rock Creek confluence.

3.3 Bankline Mapping

Bankline mapping was developed for each suite of imagery to approximate bankfull conditions. All banklines were digitized at a scale of ~1:3,000 for the Clarks Fork River Rock Creek below Roberts and ~1:2,000 on Rock Creek above Roberts where the channel is narrower and more difficult to see on the imagery. 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 due to more frequent bed scouring. 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 and geomorphic processes, allow for consistent bankline mapping through time and across different types of imagery.

Examples of the bankline mapping from the confluence of the Clarks Fork River and Rock Creek can be found in Section 3.2.

The cumulative footprint of the mapped banklines creates the Historic Migration Zone (HMZ)(Figure 34). The HMZ closely represents the active channel area that the river has a high likelihood of occupying in the future. All island areas are included in the HMZ.

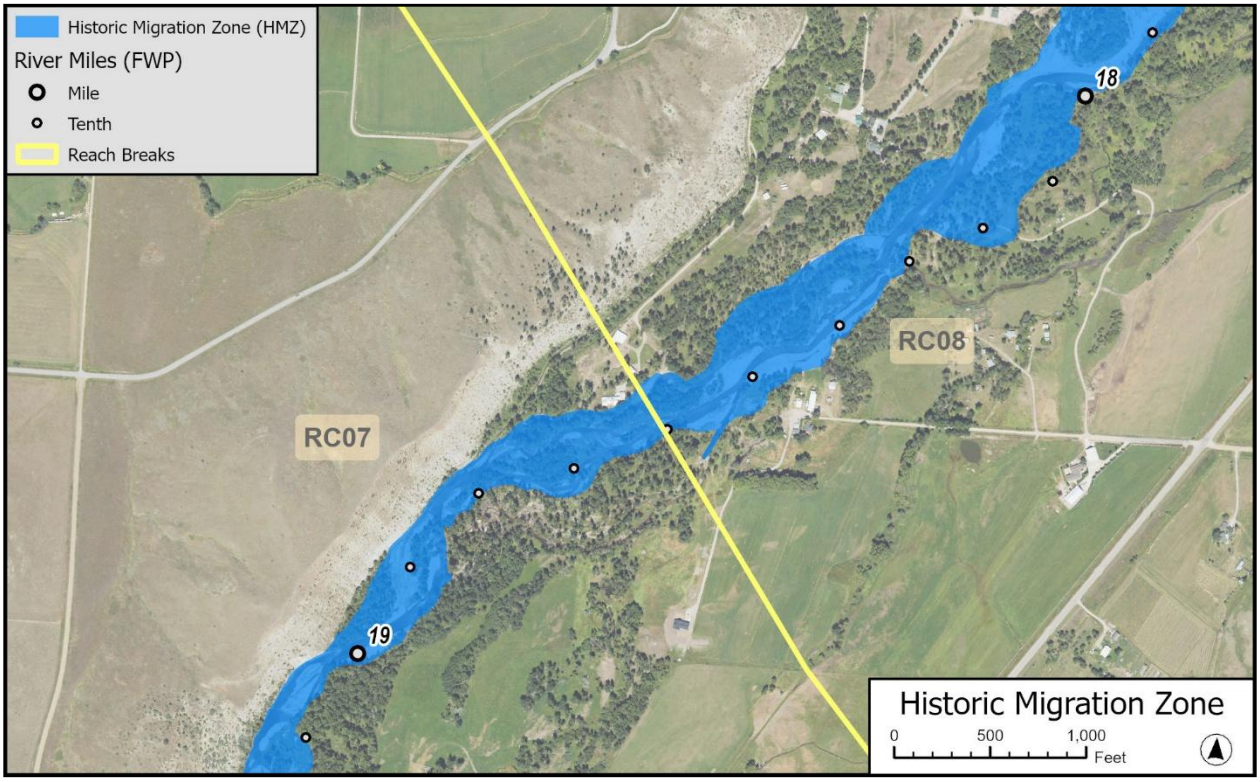


Figure 34. The Historic Migration Zone (HMZ) is the cumulative footprint of all mapped banklines.

3.4 Project Reaches

Since the approach to CMZ mapping used here includes a reach-scale evaluation of channel migration rates, the project was subdivided into reaches based on fundamental aspects of geomorphology including valley type, geologic controls, river pattern, and rates of change (Table 2 and Figure 35). These reaches differ from those defined in the Clarks Fork Yellowstone River Assessment (Kellogg, 2019) that used landmarks such as bridges to define reach breaks. For this study, there are six reaches defined for the 71 miles of the Clarks Fork River and nine reaches for the 45.8 miles of Rock Creek. The reaches are numbered from upstream to downstream for each river.

Table 2. Clarks Fork River (CF) and Rock Creek (RC) CMZ project reaches.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)
CF01	Montana/Wyoming Border to Dry Creek (Hwy 72 Bridge).	70.9	52.0	18.9
CF02	Dry Creek (Hwy 72 Bridge) to Hwy 310 Bridge.	52.0	44.6	7.4
CF03	Hwy 310 Bridge to 1.5 miles below Fromberg.	44.6	30.0	14.6
CF04	1.5 miles below Fromberg to the Rock Creek confluence.	30	15.6	14.4
CF05	Rock Creek confluence to near Evergreen Drive.	15.6	8.8	6.8
CF06	Evergreen Drive to the Yellowstone River confluence.	8.8	0.9	7.9
RC01	US National Forest boundary to the West Fork Rock Creek confluence.	45.8	42.5	3.3
RC02	West Fork Rock Creek confluence to just upstream of Hwy 308 Bridge in Red Lodge.	42.5	41.0	1.5
RC03	Just upstream of Hwy 308 Bridge in Red Lodge to Beartooth Lane, Red Lodge.	41.0	39.1	1.9
RC04	Beartooth Lane, Red Lodge to slope change at RM31.3.	39.1	31.3	7.8
RC05	Slope change at RM31.3 to just below Roberts.	31.3	25.5	5.8
RC06	Just below Roberts to Dry Creek confluence.	25.5	21.7	3.8
RC07	Dry Creek confluence where the river pulls away from the west valley wall.	21.7	18.7	3
RC08	Where the river pulls away from the west valley wall to Red Lodge Creek confluence.	18.7	15.6	3.1
RC09	Red Lodge Creek confluence to Clarks Fork River confluence.	15.6	0.0	15.6

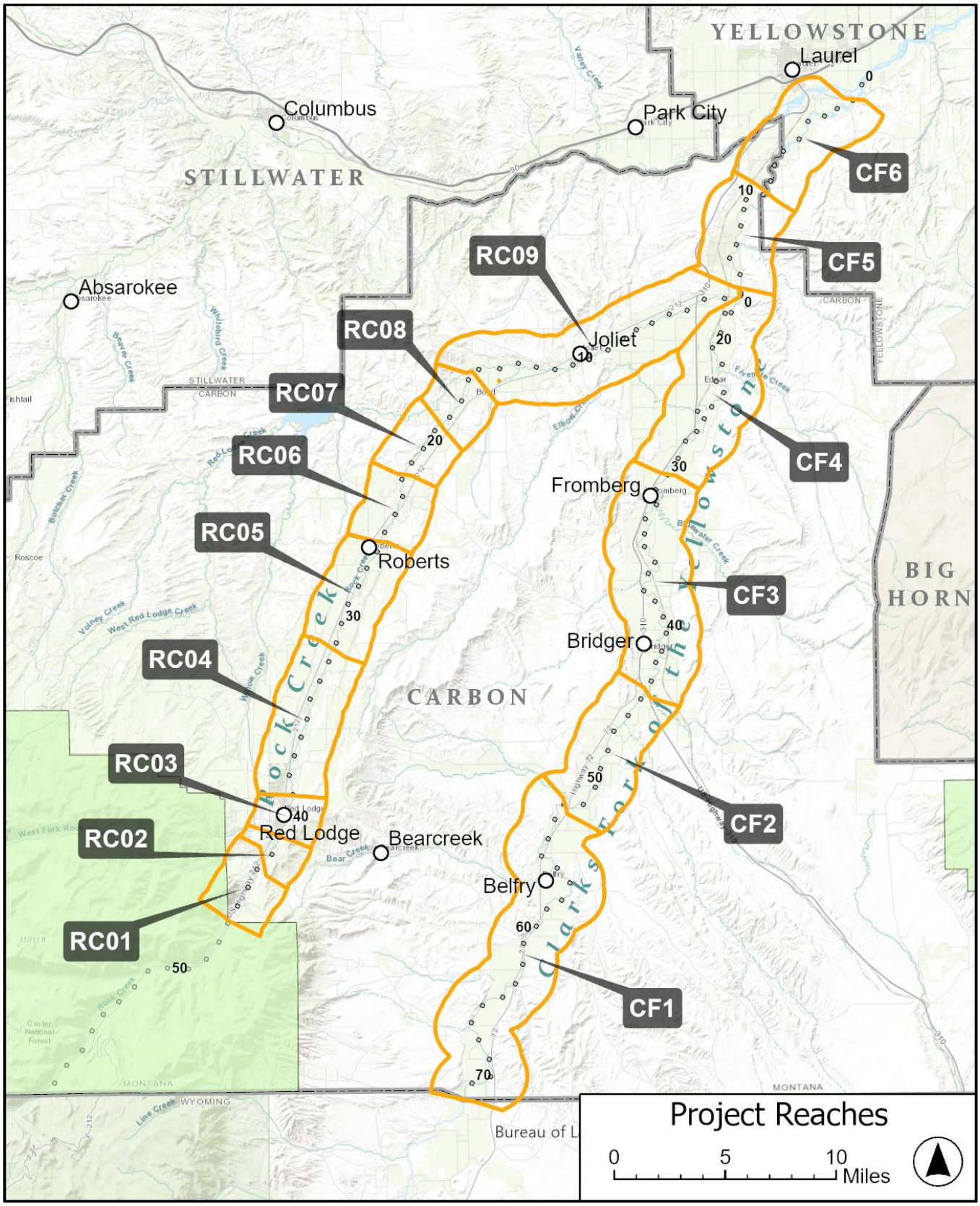


Figure 35. Clarks Fork Yellowstone and Rock Creek CMZ Mapping project reaches.

3.5 Migration Rate Measurements and the Erosion Hazard Area (EHA)

Once the banklines were digitized, they were evaluated in terms of discernable channel migration between the early 1954 and 2023. 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 made in the GIS approximately every 400-600 feet on the Clarks Fork and every 200-300 feet on Rock Creek (Figure 36). A total of 1,051 measurements were made along the length of the two waterways, 668 on the Clarks Fork and 383 on Rock Creek. These measurements were then summarized by reach and then used to define a reach-scale erosion buffer width to allow for likely future erosion.

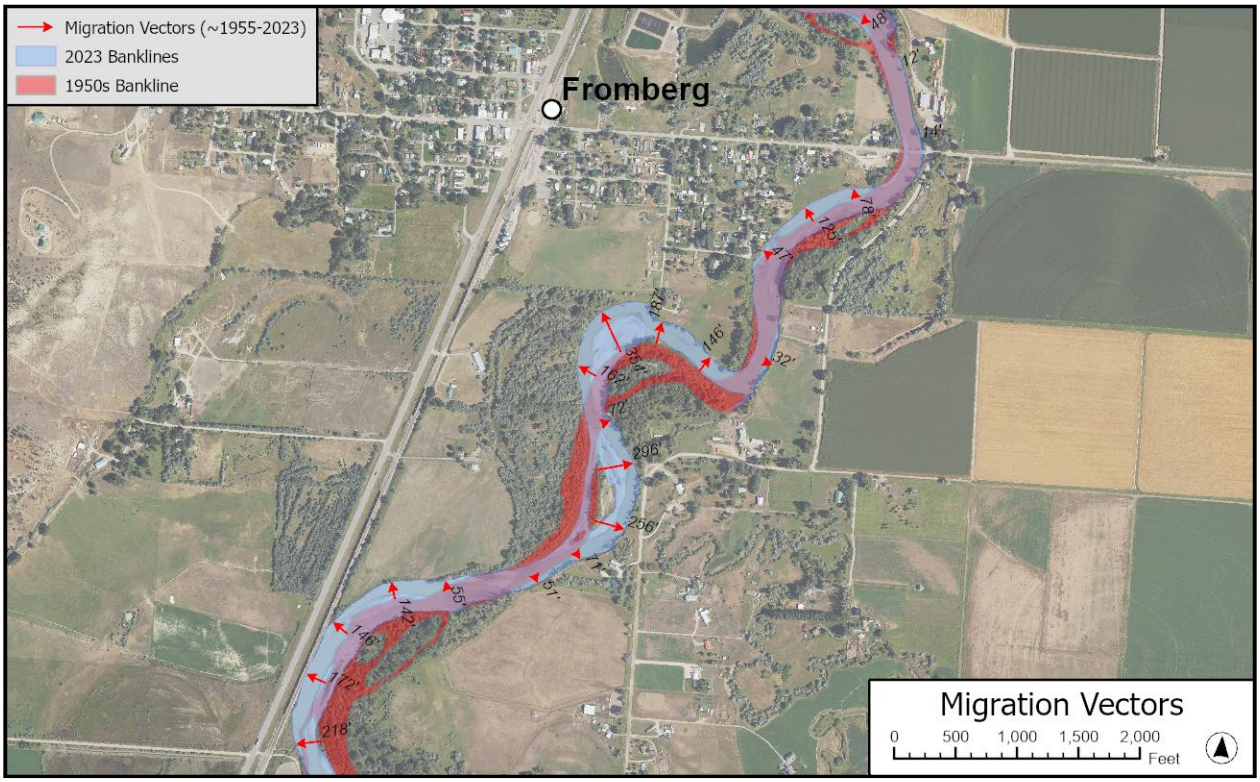


Figure 36. Example of migration measurements between the early 1950s and 2023 (migration distance in feet).

Figure 37 and Figure 38 show the distribution of measurements for each reach on the Clarks Fork and Rock Creek. On these plots, the "box" is defined by the 25th and 75th percentile values. The median value is a horizontal line in the box, and the average is denoted by an "X". Statistical outliers are shown as individual dots above the box and whisker section of the plot. The results show that all the reaches on the Clarks Fork and several reaches on Rock Creek have individual areas of markedly high migration rates that show up as outliers on the plot. Each of these locations were reviewed to ensure that they capture actual channel migration and not a large avulsion. So, while the average migration rate ("X" on the plot) may be relatively low, there are areas such as flooding, debris jams, erosion beyond the densely wooded corridor, or failed bank armor.

This provides an indicator of the maximum migration rates each reach has experienced in the past so that landowners and agencies alike can account for typical (median) rates and/or extreme rates of movement when appropriate.

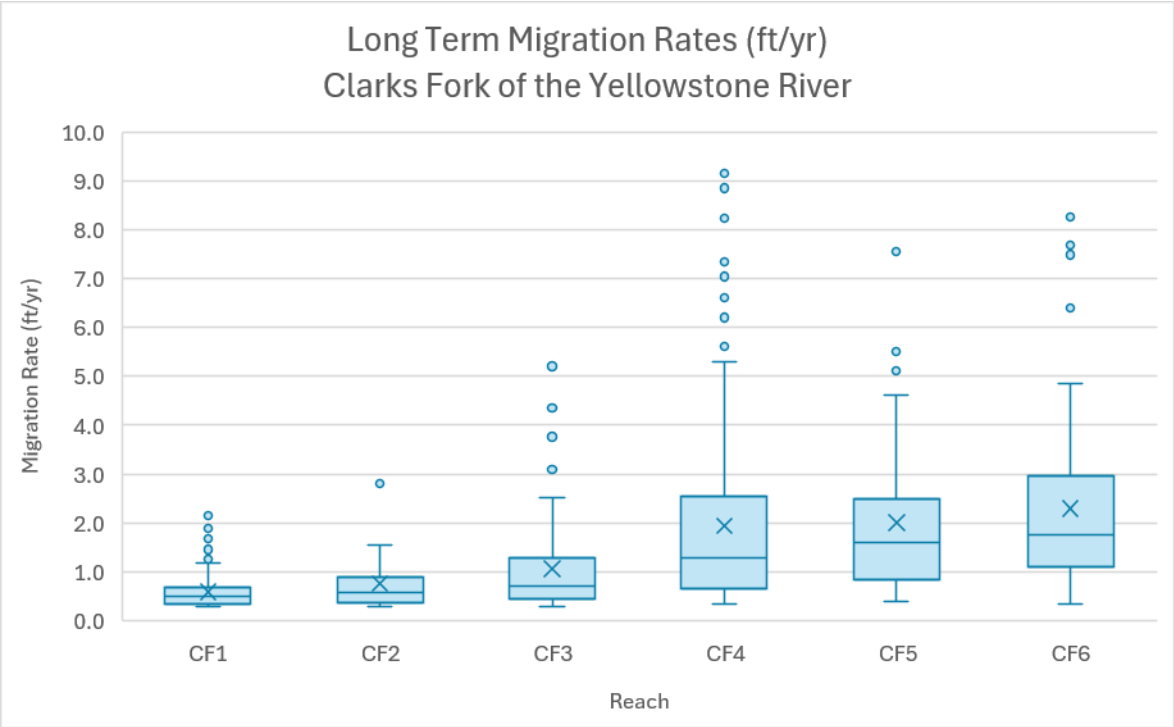


Figure 37. Annual long term migration rate box and whisker plots for Clarks Fork Yellowstone River.

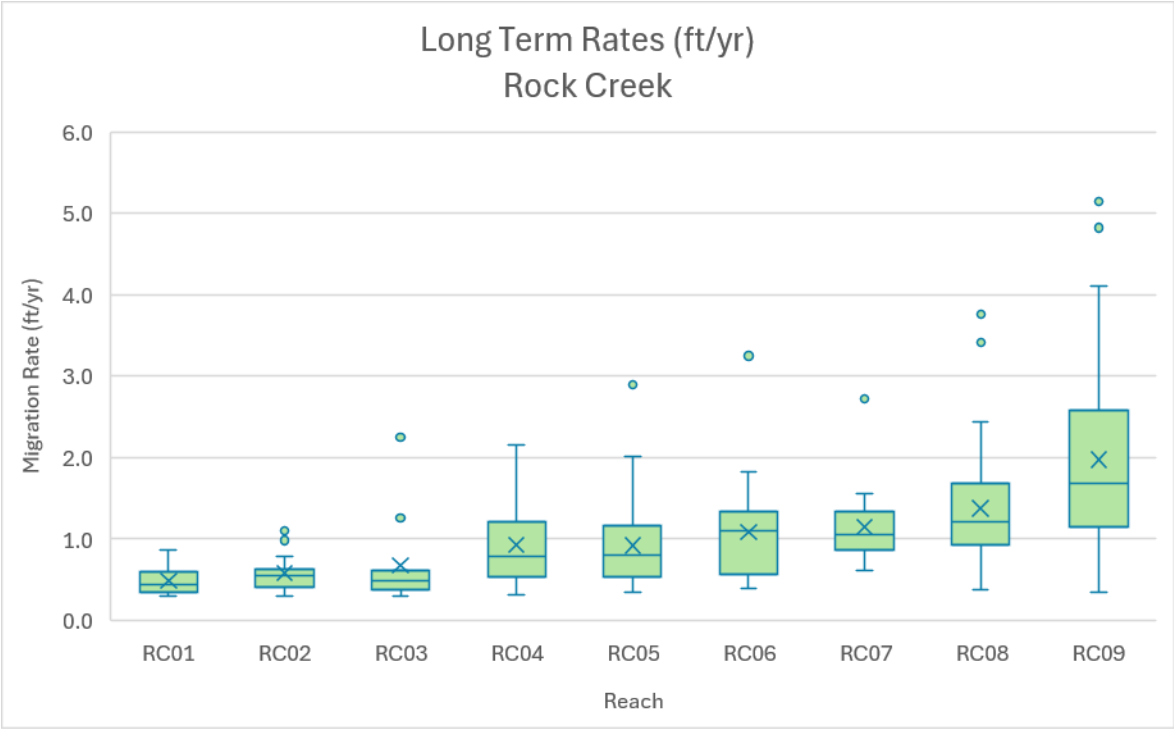


Figure 38. Annual long term migration rate box and whisker plots for Rock Creek.

The objective of the migration rate analysis is to generate an empirical value that can be used to define the erosion buffer for each reach; that is, the distance the river is reasonably expected to migrate in a defined future time period – generally 100 years. Note that the 100-year erosion buffer distance is based on the Mean Annual Migration Rate for each reach. If a larger migration distance such as the 90th Percentile or Maximum Migration Distance, the Erosion Hazard Area Buffers would be much larger and would skew management decisions such as

structure placement to be much more conservative. Conversely, if a smaller value were chosen, the resulting 100-year buffers would be much smaller and potentially place infrastructure at risk of lateral channel migration in a relatively short period of time. By using the Mean Annual Migration Rate one can fully expect that there will be a few locations along the river corridor that will erode beyond the EHA buffer. So, as part of assessing the EHA buffer values, we use the calculated 100-year buffer values to buffer the earliest (1954) banklines. We then assess whether the most current banklines (2023) that have nearly 70 years of movement are approaching or even eroding beyond the buffered 1954 channel.

Table 3 shows the resulting calculated 100-year erosion buffer distance values for each reach on each river. On the Clarks Fork they range from 60 feet in the more confined reaches, to 229 feet in less confined reaches as you progress downstream. On Rock Creek the buffer widths also increased as you move downstream and the corridor width widens, starting with 49 feet on the upper end to nearly 200 feet near the Clarks Fork confluence. These buffer widths were placed on the landward edge of the 2023 banklines and are shown as "Erosion Hazard Area" on the CMZ maps. If the buffer is partly or fully within the Historic Migration Zone (HMZ), it is trumped by the HMZ map unit and thus underlies it. As a result, the buffer is not always visible on the maps.

Table 3. Mean migration annual rate, maximum migration distance and 100-year EHA buffer by reach.

Reach	Number of Measurements	Mean Annual Migration Rate (ft/yr)	Max Migration Distance (ft)	100- Year Buffer Width (ft)
Clarks Fork				
CF1	150	0.6	146	60
CF2	47	0.8	191	76
CF3	131	1.1	354	106
CF4	124	1.9	623	194
CF5	52	2.0	514	201
CF6	62	2.3	562	229
Rock Creek				
RC01	29	0.5	59	49
RC02	15	0.6	75	58
RC03	15	0.7	153	68
RC04	106	0.9	155	93
RC05	75	0.9	197	92
RC06	21	1.1	221	108
RC07	20	1.1	185	115
RC08	35	1.4	256	137
RC09	47	2.0	350	198

Since the location and intensity of bank erosion shifts with time on dynamic rivers, 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), and has been used for all of the CMZ mapping in Montana.

An example of EHA mapping is shown in Figure 39. 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 can be discontinuous along the river. Once the buffers are placed on the 2023 banklines, areas of bedrock geology are clipped out (Figure 40) to reflect the likely lack of lateral channel migration in those areas during the 100-year life of the CMZ.

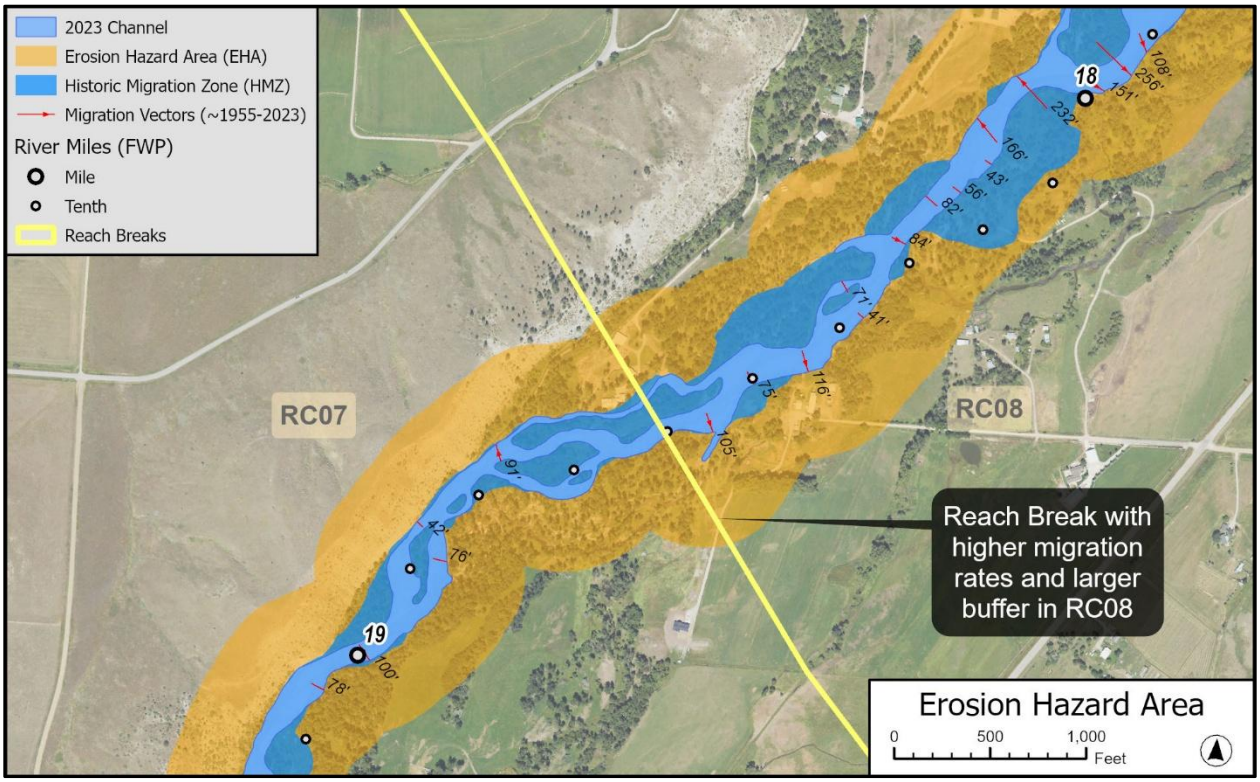


Figure 39. The Erosion Hazard Area (EHA) is a buffer placed on the 2023 banklines based on 100 years of channel migration for the reach.

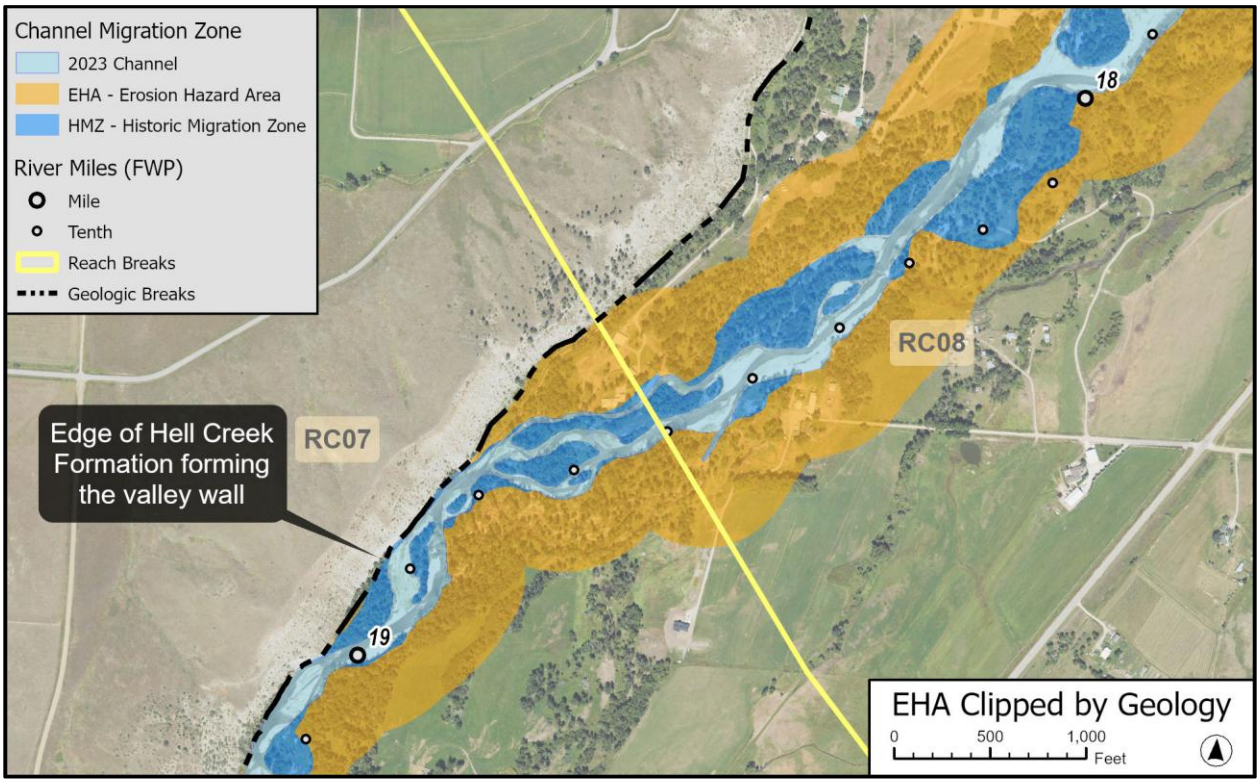


Figure 40. 100-year migration buffers clipped for geology and erosion resistant terraces.

3.6 Avulsion Hazard Mapping

The avulsion hazard mapping captures areas beyond the core CMZ (HMZ + EHA) that show some propensity for developing new active channels in floodplain areas. This typically happens at meander cores or along continuous abandoned channels. It does not imply that the entire river will be captured by these channels, just that they could become more geomorphically active in the event of channel migration into a given area, intense flooding, or due to flow deflections out of the main channel due to wood or ice jams. In a broad sense, avulsions 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 reflect an increased potential for floodplain channel activation. These criteria include:

- Potential flow paths on the floodplain that are substantially steeper than the existing channel slope. This commonly occurs through the cores of meander bends, where the potential flow route through the meander is shorter and steeper than the route along the longer channel course.
- Floodplain swales that are vertically connected to the river; typically, no more than three to four feet above the LiDAR water surface elevation.
- Well-defined continuous flow paths that intersect the core CMZ (HMZ and EHA) boundaries where continued erosion may “connect” the upper end of the flow path and thus capture flow.

Below are some general observations regarding avulsion potential along these waterways:

- Upper Clarks Fork is bound by terraces, with limited avulsion potential.
- Middle Clarks Fork often has one side of the river with a wider floodplain that contains remnant river channels that could support an avulsion.

- Below Fromberg the Clarks Fork floodplain is broad and characterized by frequent avulsions of bendway cores – the narrow strip of land enclosed within the loop of a meandering river. There are also a number of pre-1954 avulsions, both natural and human caused.
- Upper Rock Creek through Red Lodge is largely bound by terraces consisting of glacial outwash. There are some potential avulsion pathways, but they largely lie within the historic river bottom.
- Below Red Lodge a cottonwood riparian corridor shows frequent avulsions throughout the entire floodplain.
- Below Roberts the floodplain continues to widen and is only intermittently within a dense riparian forest or bounded by the valley wall or terraces. Avulsions are common throughout this section of river.

The Avulsion Hazard Zone (AHZ) includes the areas of the river landscape, such as relic channels and swales that are at risk of channel occupation outside of the Historic Migration Zone (HMZ). These areas are identified using a Relative Elevation Model derived from the 2023 hi-resolution LiDAR elevation collected after the 2022 flood in the summer of 2023. REM models depict the elevations adjacent to the river channel and are critical for identifying potential avulsion pathways. Figure 41 shows an example of the REM on the Clarks Fork between Fromberg and Edgar. Historic river channels show up as dark blue pathways in the floodplain, with warmer colors (yellows and reds) indicating areas above the river channel. Potential flow paths are shown in dashed lines.

The AHZ is defined by the outermost flow pathway that has potential connectivity to the main channel either by overtopping the bank or by erosion through the bank to connect to the swale. A minimum difference in elevation of four feet between the river and the head of the swale was required to define a potential avulsion path. The AHZ is placed beyond any Erosion Hazard Area (EHA) buffer (Figure 42).

While the risk of avulsion is somewhat unpredictable and likely a lower risk than channel migration, it is still fairly common on both the Clarks Fork and Rock Creek. An avulsion could either run through a structure or leave it stranded on an island. As such, locating infrastructure within the AHZ should be avoided if possible.

3.6.1 Clarks Fork Avulsion Discussion

The Clarks Fork has a long history of avulsions, especially on the river downstream from Fromberg. Starting at RM 29.0 and continuing downstream to the confluence with the Yellowstone River there have been at least 15 large avulsions that have shortened the river by ~5.3 miles (18.7%) from the ~1900's channel noted in the GLO maps. Some of these are recent bendway avulsions indicating that it is continuing to adjust and recover length. A couple of large avulsions are being maintained in the original channel to route water to large irrigation diversions. Several of the avulsions in the lower river were the result of the construction of the rail line from Laurel to Bridger that effectively rerouted the river. The extensive history of the rail construction to support the coal mining boom at turn of the 20th century is detailed in the Clarks Fork Yellowstone River Assessment (Kellogg, 2019).

Upstream of RM29.0 there are essentially no avulsions noted from the 1900s to present.

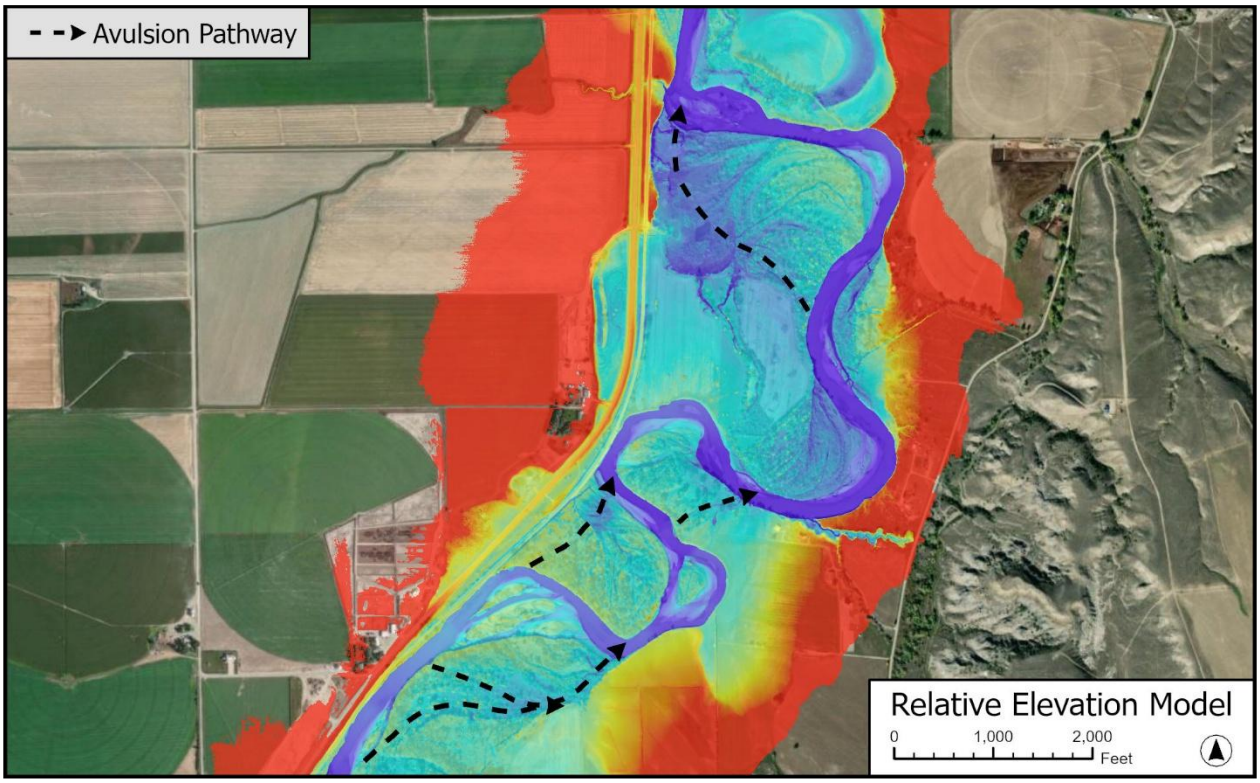


Figure 41. Example Relative Elevation Model and potential avulsion pathways on the Clarks Fork between Fromberg and Edgar.

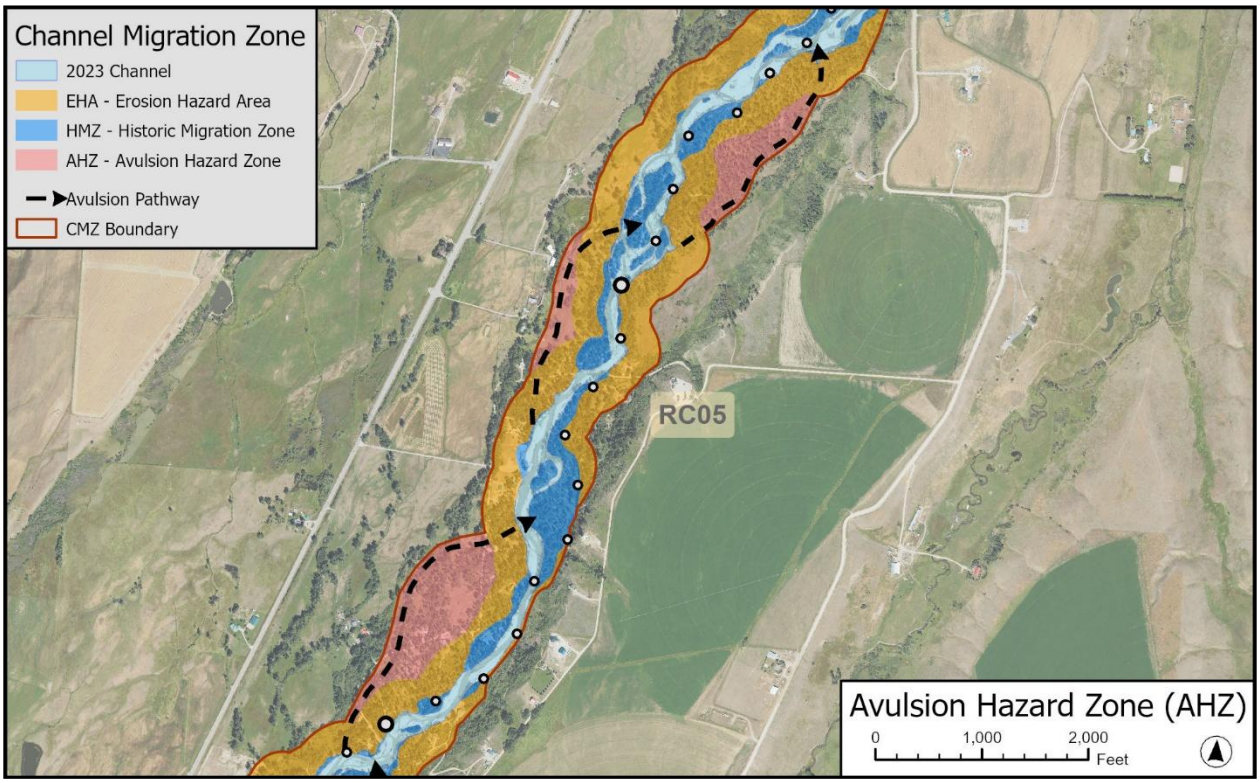


Figure 42. Example avulsion pathways and the resulting Avulsion Hazard Zone upstream from Roberts.

3.6.2 Rock Creek Avulsion Discussion

Avulsions within the Rock Creek drainage are generally associated with floodplain turnover caused by the resorting of floodplain deposits (erosion and deposition) within the boundaries of the active channel area. Avulsions are numerous and often reoccupy historic active channels. There were no notable locations where avulsions occurred either historically or during the 2022 floods that created wholesale new river channels.

The exception to this is at the mouth of Rock Creek where the lower two miles of channel has shifted approximately a quarter of a mile northward of the channel shown in the 1900s GLO mapping.

3.7 Composite Map

The composite map integrates all elements of the Channel Migration Zone map (Figure 43). This image demonstrates all the key concepts of CMZ mapping. The 2023 channel is in light blue. The historic river footprint from ~1954 to 2023 (HMZ) is in dark blue. The orange areas represent the area of erosion risk over the coming 100 years, with a larger erosion buffer in reach CF3 due to higher measured erosion rates in that reach. Areas of avulsion risk are in red, with potential avulsion flow pathways shown by black dashed lines. Areas where bedrock valley walls intercept CMZ are excluded from the CMZ. And finally, the Restricted Migration Area (RMA), areas behind bank protection, road grades, bridge, etc. that provide some protection from channel migration, is included as a red hatched overlay on the full CMZ. The RMA areas are not excluded from the CMZ as the level of protection of any physical feature is unknown and may fail given the right conditions.

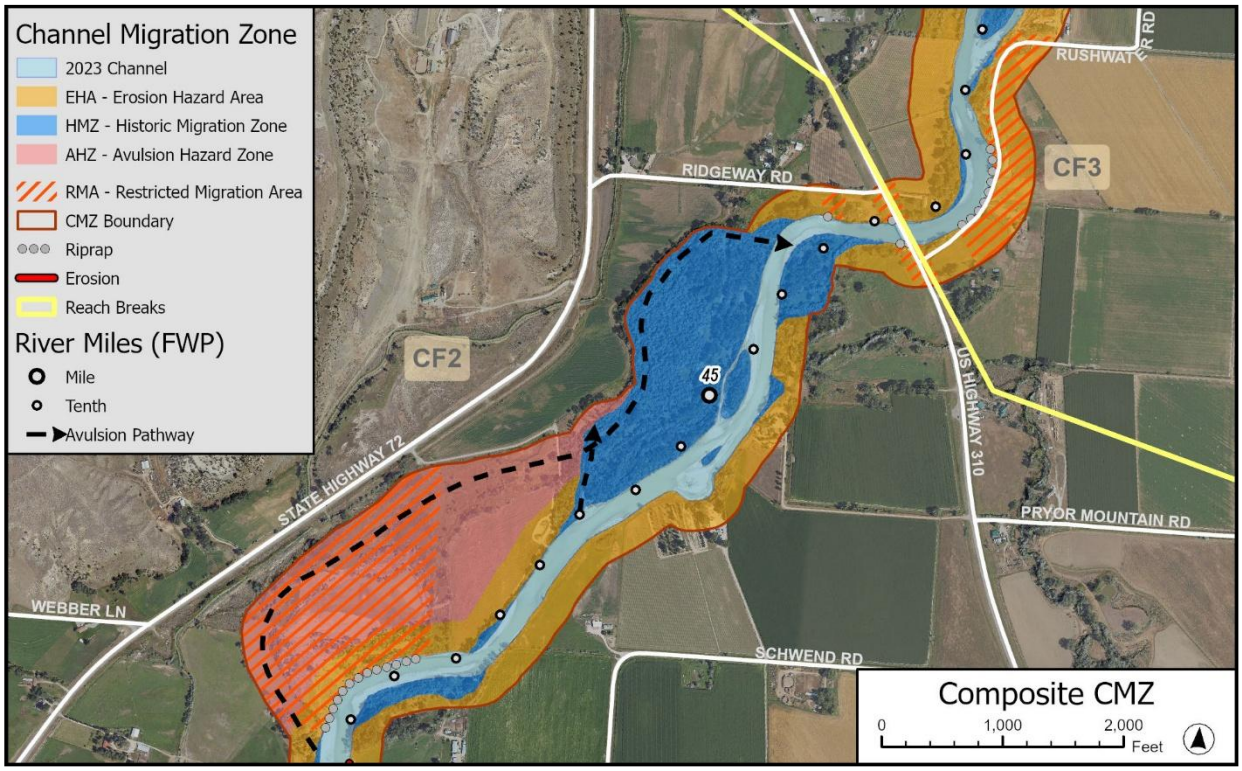


Figure 43. The composite CMZ map of the Clarks Fork River at the Hwy 310 Bridge.

4 Channel Migration Concerns and Potential Projects

The original intent of this section was to provide a Projects Database of sites that could be advanced to the Preliminary Engineering Report (PER) phase for future grant funding. While there are sites that should be addressed in the near future, much of the important immediate work resulting from the 2022 flood has already been completed or is in progress.

With that in mind, the following sections describe areas of concern on the Clarks Fork River and Rock Creek identified in this study due to recent or likely future channel migration. The descriptions are organized by waterway, from upstream to down. Several of the areas of concern identify specific locations identified through interviews with interested parties and public outreach, though the majority of the sites were identified through review of the CMZ mapping data. This discussion is not all inclusive, rather it demonstrates areas of concern and typical river processes that are impacting other sites to various degrees. It can be used to further discussion on management priorities and needs.

In general, both of these waterways performed well in terms of absorbing the intensity of the major flood event that occurred in June 2022. This is due to a number of factors:

- This was a high magnitude, but short-term flood event.
- Extensive existing bank protection on the Clarks Fork (Kellogg, 2019) likely effectively stabilized many banks that would have otherwise experienced increased erosion.
- With the exception of the area upstream from Red Lodge, both waterways have strong floodplain connectivity, allowing flood waters to spread out across the adjacent land and dissipate flood energy.
- Downstream of Red Lodge, the mature cottonwood gallery creates an ideal environment for the river to expend flood energy through avulsions, scour, and overbank flow.
- In general, most bridges are sized appropriately, allowing flood waters and debris to pass through without damaging the structure.
- There is limited encroachment into the active river corridor in terms of public infrastructure (bridges, treatment facilities, etc.) and private development (homes, outbuildings, corrals, etc.). Thus, where the river has moved laterally, it largely avoided areas of development. Note that the reach through Red Lodge is the exception, thus resulting in increased flooding and damage.

The discussion below details locations along Rock Creek and the Clarks Fork that show some risk for lateral channel migration or avulsion. Many were chosen because the issues at the site present a higher risk of damage to important infrastructure – irrigation diversions, transportation, ranch operations, bridges, etc. A location, Type of Concern and Notes are included for each site. Table 5 and Table 6 in the following sections list only those sites deemed “High” priority for assessment and potential future projects. High priority indicates that historic and flood-related channel migration at the site is such that there is a noted elevated risk to infrastructure due to channel migration or avulsion. A full list of identified sites can be found in Appendix A and all sites are noted in the maps found in Appendix B. Many of the sites along the Clarks Fork were noted in Warren Kellogg’s 2019 report, in which case the Priority noted in that report is included.

Note: All references to River Miles (RMs) reflect the Montana Fish Wildlife and Parks river stationing. 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, “RM 62.4R” refers to the right streambank located 62.4 miles upstream

of the river's mouth (the Yellowstone River confluence for the Clarks Fork and the Clarks Fork confluence for Rock Creek).

Table 4. Types of Concern

Type of Concern	Description
Bank Erosion	Location shows accelerated lateral channel migration, especially post-2022 flood.
Bank Stabilization	Location has mapped bank protection
Bridge	Bridge site with either alignment issues or noted damage.
Critical Infrastructure	Mainly water treatment facilities.
Development	Residential development in the CMZ.
Irrigation	Irrigation diversions or canals.
Transportation	Roads and railroads.

4.1 Clarks Fork Concerns

Table 5 lists sites along the Clarks Fork that were identified with High-Priority CMZ issues based on historic channel migration and likely future channel migration.

Table 5. CMZ concerns on the Clarks Fork Yellowstone River.

RM	Name	Type of Concern	Notes	Priority	Prior_Kellogg	Kellogg_ID
60.6L	Hwy 72	Bank Erosion	Recent short term erosion towards roadway.	High		
59.6	Lovers Lane	Bank Erosion	Recent erosion towards road where bank protection ends.	High		
45.1		Bank Erosion	Localized scour pocket, 191 ft migration.	High	Medium	1.2
43.5	Orchard Canal Diversion	Irrigation	Key irrigation diversion on an avulsed channel. Extensive efforts to keep water delivered to the diversion.	High	High	1.9
35.7		Bank Erosion	Over 100' of flood related erosion and overland flow through corrals. Scour of inside bendway.	High		
32.7		Bank Erosion	Accelerated erosion into ag field.	High		
32		Bank Stabilization	Point bar is rapidly developing. Erosion into Kellogg "gauge" continues and threatens buildings.	High	Medium	2.32
30.7		Bank Stabilization	Bankline appears to have some new migration at the upstream end towards the BNSF rail line. Section along ranch buildings is stable.	High	Low	3.4
30.2		Bank Erosion	60+ ft erosion into ag operations.	High		
27.3		Bank Erosion	Increased recent erosion below bank protection. Future avulsion.	High		
26		Bank Stabilization	Upstream bendway is a concern, but does not show any short-term movement from the flood.	High	High	3.16
23.4		Bank Erosion	Flanked riprap into irrigated field.	High		
22.6		Bank Stabilization	Likely site of an upcoming bendway avulsion. Neck is very narrow now.	High	Medium	3.27
18.1	White Horse Canal	Irrigation	Diversion study looking at headgate/diversion replacement and fish passage.	High	High	4.17
16.4		Bank Erosion	120+ ft of recent erosion into grazing fields. Rapid development of bendway. Continued erosion potential extremely high.	High		
12.9		Bridge	West abutment showed undermining in Kellogg study. Was this work done?	High	Medium	5.8
10.3		Bank Erosion	1970s-80s river avulsed into smaller eastern channel. Lots of migration since, ~190 ft. Migration is towards active ag operations.	High	High	5.16
9		Bank Erosion	Rapid erosion 180+ ft into fields. No woody veg.	High		
7.2		Bank Erosion	Failed jetties with increased bank erosion into irrigated fields.	High		
6.9		Bank Stabilization	Short section of bank stabilization/jetty. Below the bendway is actively migrating with ~100 ft of short-term migration.	High	Medium	5.26
6.8		Bank Erosion	Rapid (100+ft) bank erosion into fields.	High		
6.5		Bank Stabilization	Very unstable bendway with nearly 150' of short-term migration.	High	Medium	5.27
5.3		Bank Erosion	Very unstable bendway with nearly 180' of short-term migration. Threat of ag operations in the short term and degrading alignment under Byam Rd in the long term.	High	Medium	5.29
3.5		Bank Erosion	Rapid bendway development. 120+ ft recent erosion.	High		

4.1.1 RM 60.6 Left – Transportation (Hwy 72)

This site is located where the river parallels the Hwy 72 road grade (Figure 44). There is an area of isolated floodplain on the landward side of the highway. On the opposite bank the Clarks Fork and Silver Tip Ditch parallels the river. While there is little long-term erosion into the site, approximately 24 feet of flood-driven erosion was noted from the 2022 event. The fact that the road grade has narrowed the river corridor may put additional erosive forces on the left bank and threaten a key roadway. There is no obvious immediate stabilization need, but the site should be monitored.

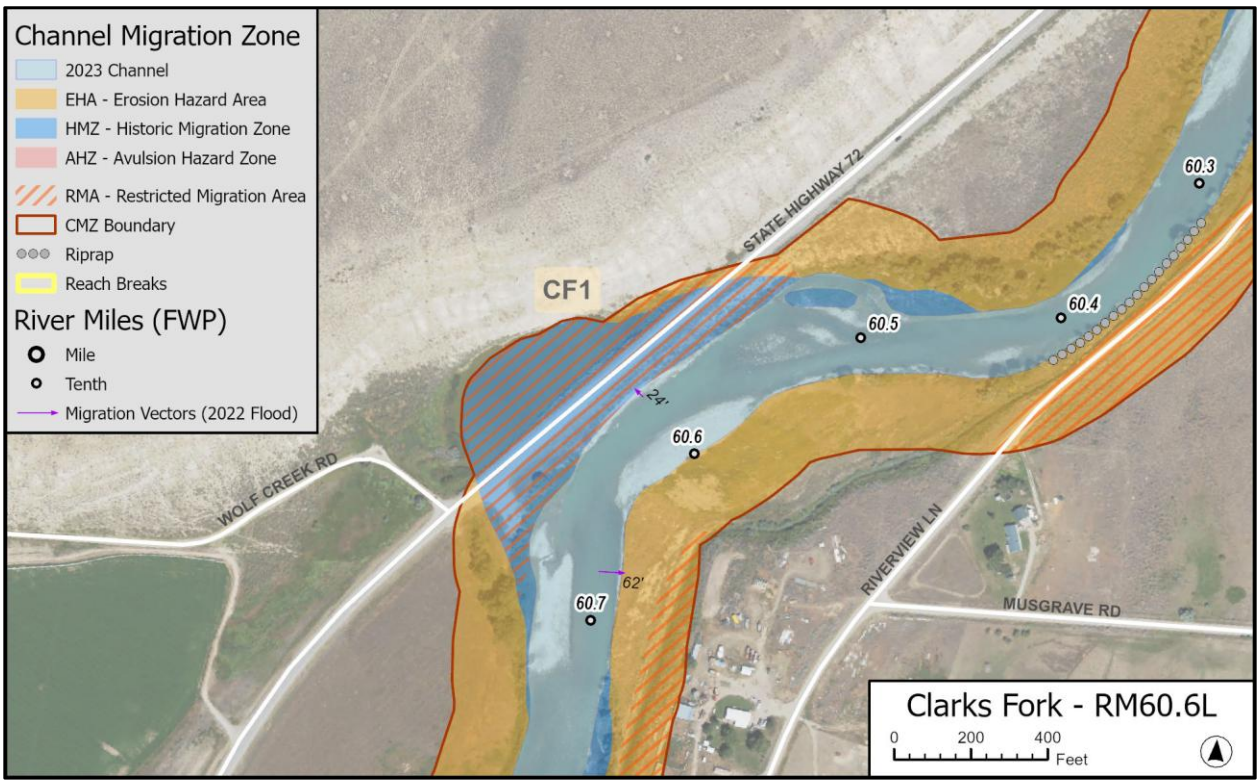


Figure 44. Flood driven erosion towards Hwy 72.

4.1.2 RM 59.6 Right – Transportation (Lovers Lane)

Downstream of Riverview Lane, Lovers Lane runs along the right bank for nearly a quarter of a mile (Figure 45). This bankline is heavily protected, though there is some notable flood-driven erosion (50+ feet) at the downstream end where the riprap ends. This site should be monitored to ensure that localized scour downstream of the bank protection does not threaten the roadway.

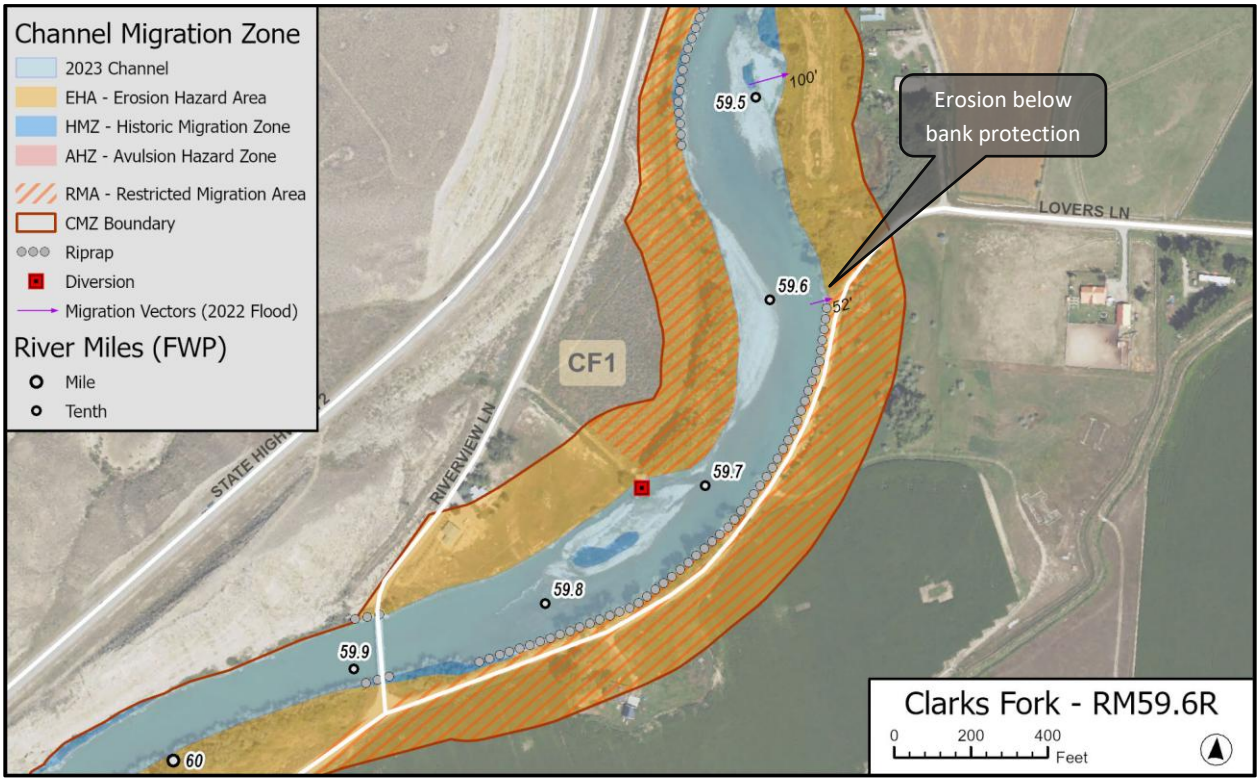


Figure 45. Lovers Lane encroachment.

4.1.3 RM 45.1 Right – Agricultural Operations

This site is located on the right bank about a half mile above the Hwy 310 bridge. A large scour pocket has developed since the early 1980s, with nearly 200 feet of erosion towards a small tree farm and ranch buildings (Figure 46). An island is developing and creating a more permanent secondary channel along the right bank. While the lateral migration appears to have slowed down and more recent erosion appears to be concentrated at the lower end of the bendway, future impacts to the downstream landowner may require some stabilization measures.

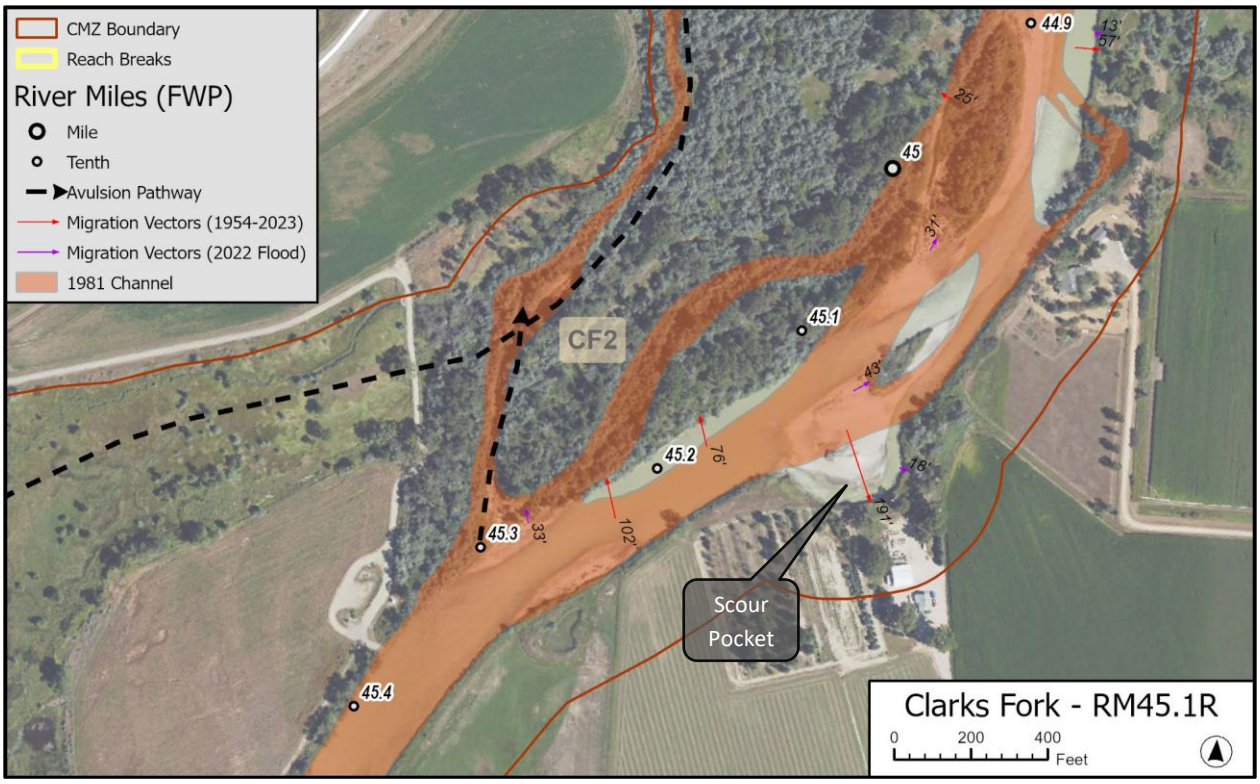


Figure 46. Large scour adjacent to tree farm.

4.1.4 RM 43.5 Right – Irrigation (Orchard Canal)

The Orchard Canal diversion is located at the lower end of an avulsed bendway (Figure 47). There are two primary structures in place to maintain flows into the avulsed eastern channel – a permanent diversion dam in the newer channel and a seasonally maintained gravel levee just upstream. An additional diversion dam on the eastern channel is located at the actual diversion. This site presents multiple challenges for natural resources, primarily fish migration, as well as for maintaining critical infrastructure. Warren Kellogg (Kellogg, 2019) goes into detail about the structures, management challenges and potential solutions. While this site has changed little since the avulsion and diversion efforts, it is located in an active section of the river that will continue to change through time. The historic bendway avulsion that is at the core of this management challenge illustrates the challenges of protecting and maintaining critical infrastructure in a dynamic river system.

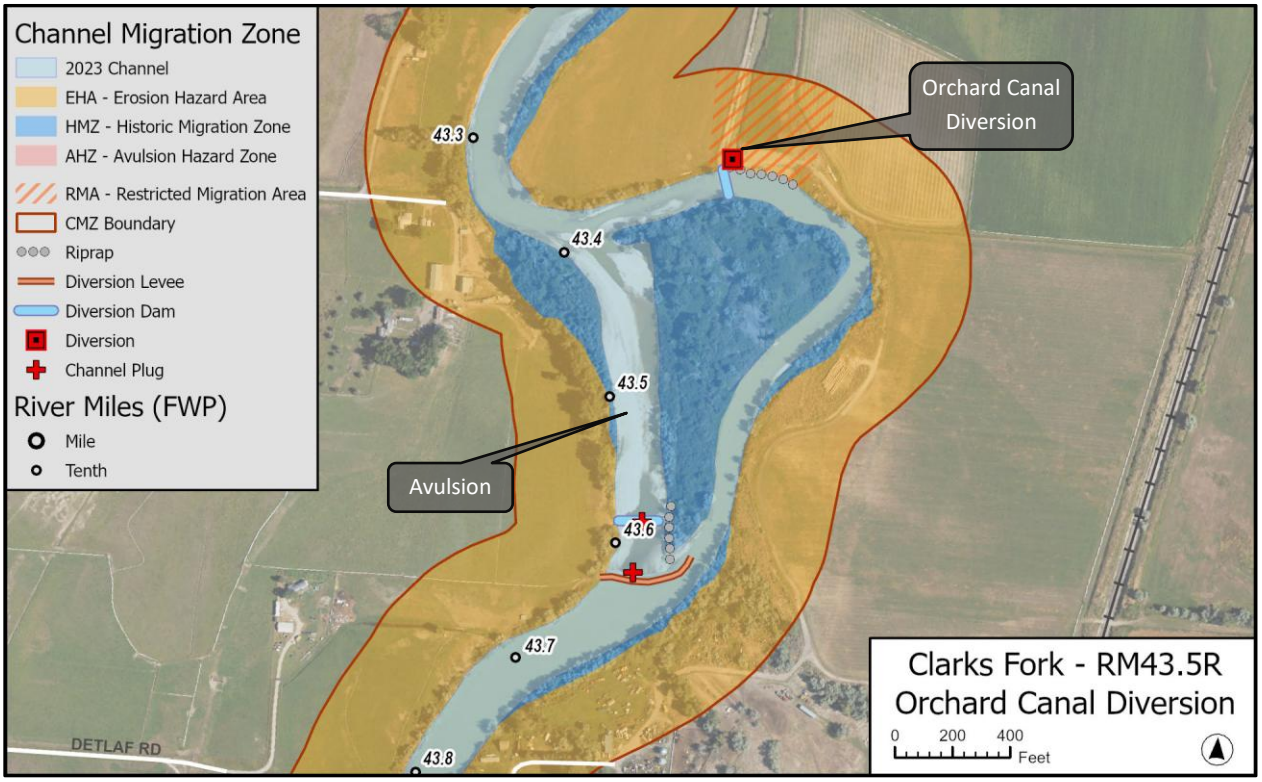


Figure 47. Orchard Canal diversion.

4.1.5 RM 35.7 Right & 35.5 Left – Agricultural Operations

There are multiple channel migration and flooding concerns at this location. This is the primary site on the Clarks Fork where overbank flows were focused enough to scour the floodplain surface (Figure 48). It is on the inside of a right hand bendway where a subtle historic swale is located. Ranch corrals and infrastructure were impacted by the floodwaters (Figure 26). There was some flood related erosion on the right bank at the head of the channel. Just downstream on the outside of the bendway, around 170 feet of erosion happened since 1954, with nearly one third of it being flood related. While no major infrastructure is immediately at risk due to erosion of this outside bendway, there are potential avulsion pathways across the floodplain that could be activated if erosion continues and another large flood occurs. Additionally, there is some risk of continued erosion at the head of the swale that could impact ranch infrastructure.

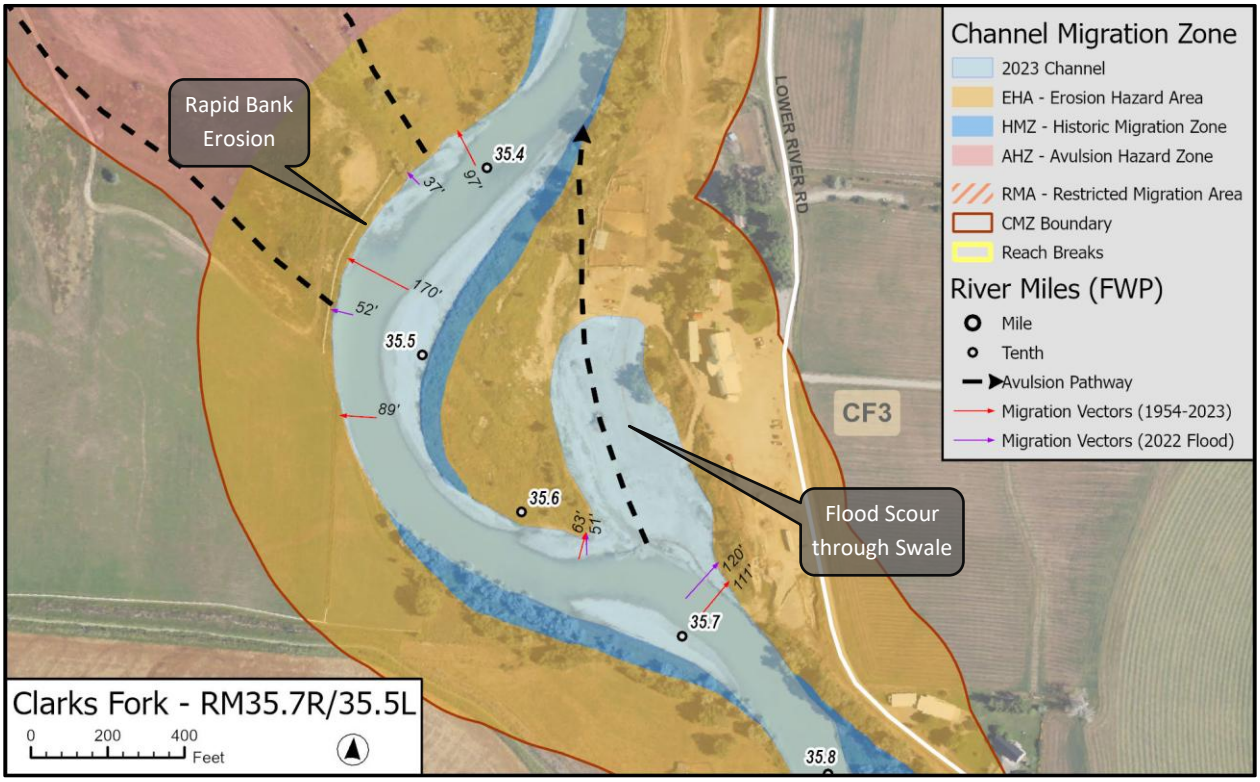


Figure 48. Overland floodwater flow through corrals.

4.1.6 RM 32.7 Left – Transportation (Railroad)

At this site, the Clarks Fork follows the railroad grade for over 800 feet. The bankline is currently heavily riprapped, but there is significant erosion towards the unprotected sections of rail grade at the lower end. Nearly 50 feet of lateral movement can be attributed to the 2022 flood (Figure 49). Though, there does not appear to be any immediate risk to the railroad grade, this site should be monitored.

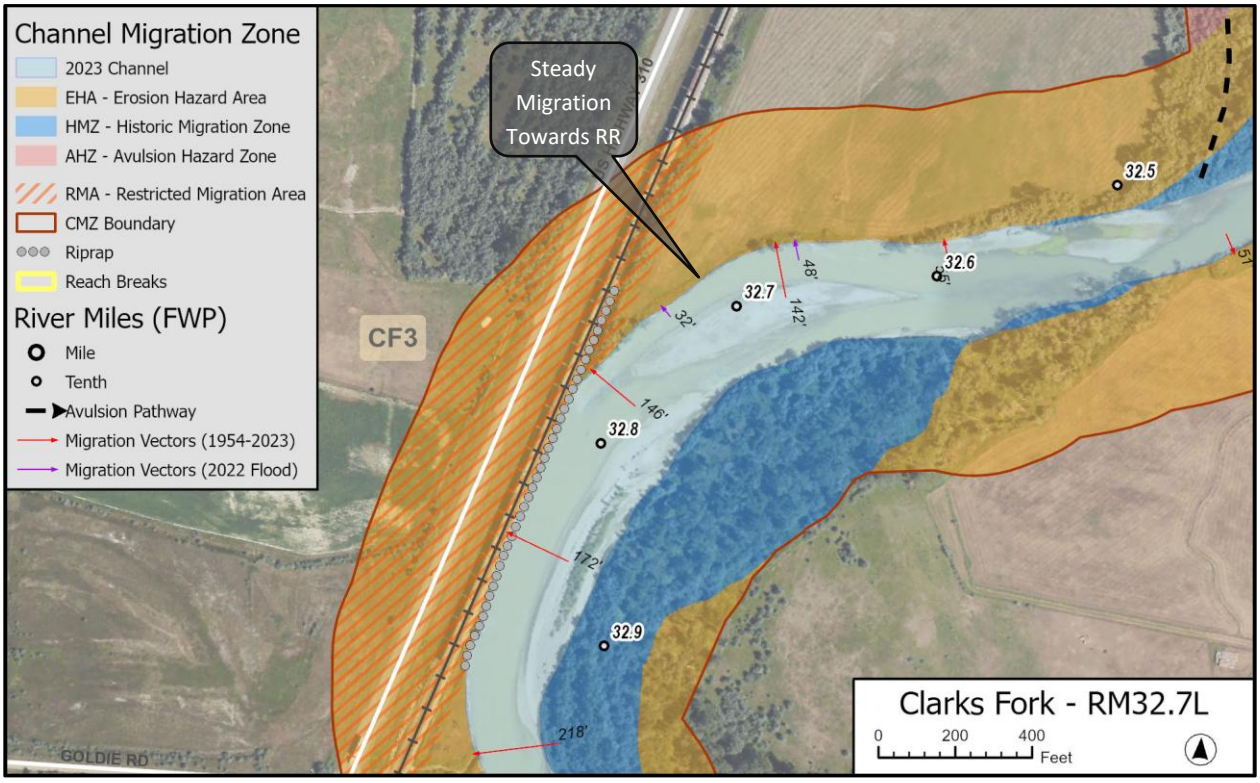


Figure 49. Erosion towards railroad grade.

4.1.7 RM 32.0 Left – Residential Development, Fromberg

The bendways leading to the Fromberg, MT bridge present multiple challenges (Figure 50). Firstly, the left bank of right hand bendway upstream of the bridge was experiencing steady, long-term erosion since 1954. This lateral movement was threatening several structures at the upper end of the bendway and encroaching on the Fromberg City wells located at the bottom of the bendway. The 2022 flood overtopped the bank, damaging the wells and required emergency repairs. Flood waters also impacted numerous houses and trailers, many of which were complete losses. This bendway now has an approximately 1,000 foot long bank stabilization project. Further upstream at RM32.0L the river has migrated over 350 feet since 1954, one of the largest measurements within the project area. While this movement has been concentrated into mature riparian forest, it is starting to flank a short section of bank protection at the lower end of the bendway and is threatening several structures. The inside of the bendway shows a rapidly growing point bar that is further driving migration into this bankline. Given the infrastructure in the area on both sides of the river, options for stabilizing or taking pressure off this bankline are limited.

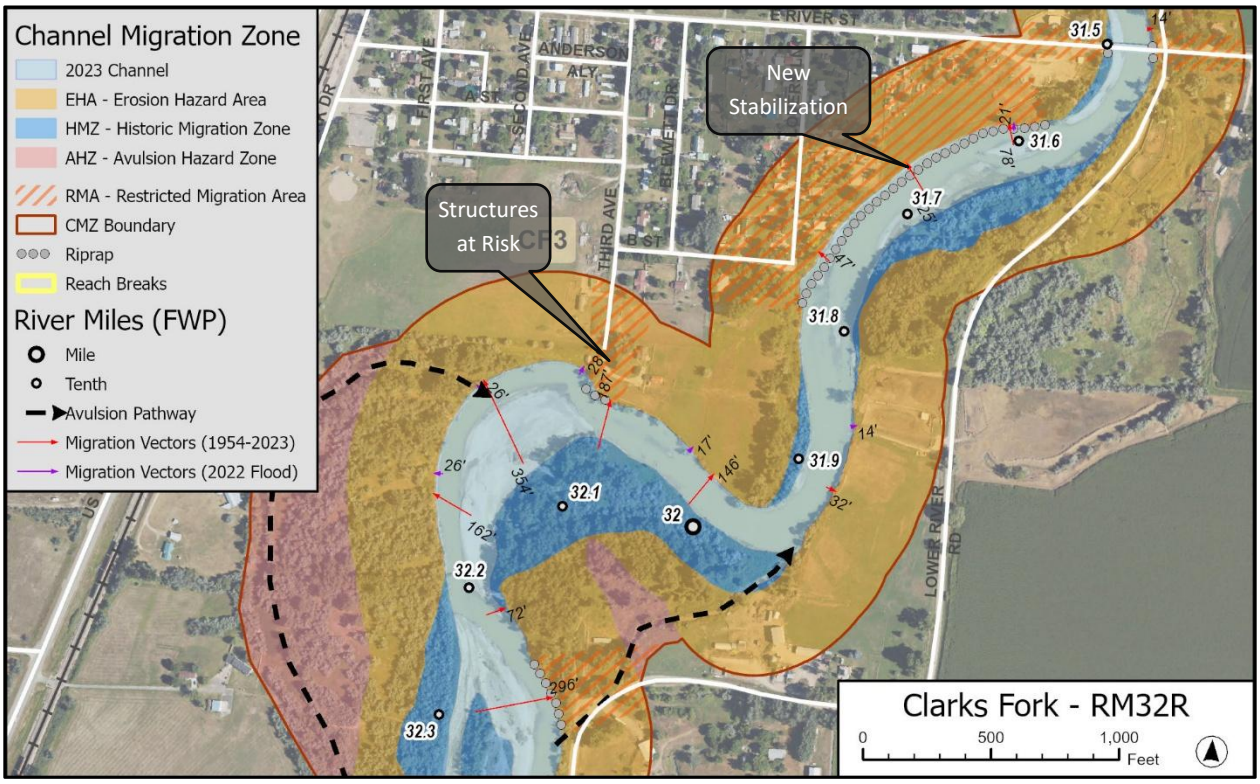


Figure 50. Fromberg channel migration issues.

4.1.8 RM 30.7 Left – Transportation (Railroad)

The lower end of this bendway at RM30.7L has some more recent erosion towards the BNSF rail line (Figure 51). There is still some mature vegetation on the bankline before the erosion hits the open field adjacent to the rail line, so the site isn't of immediate concern. The site should be monitored for future erosion.

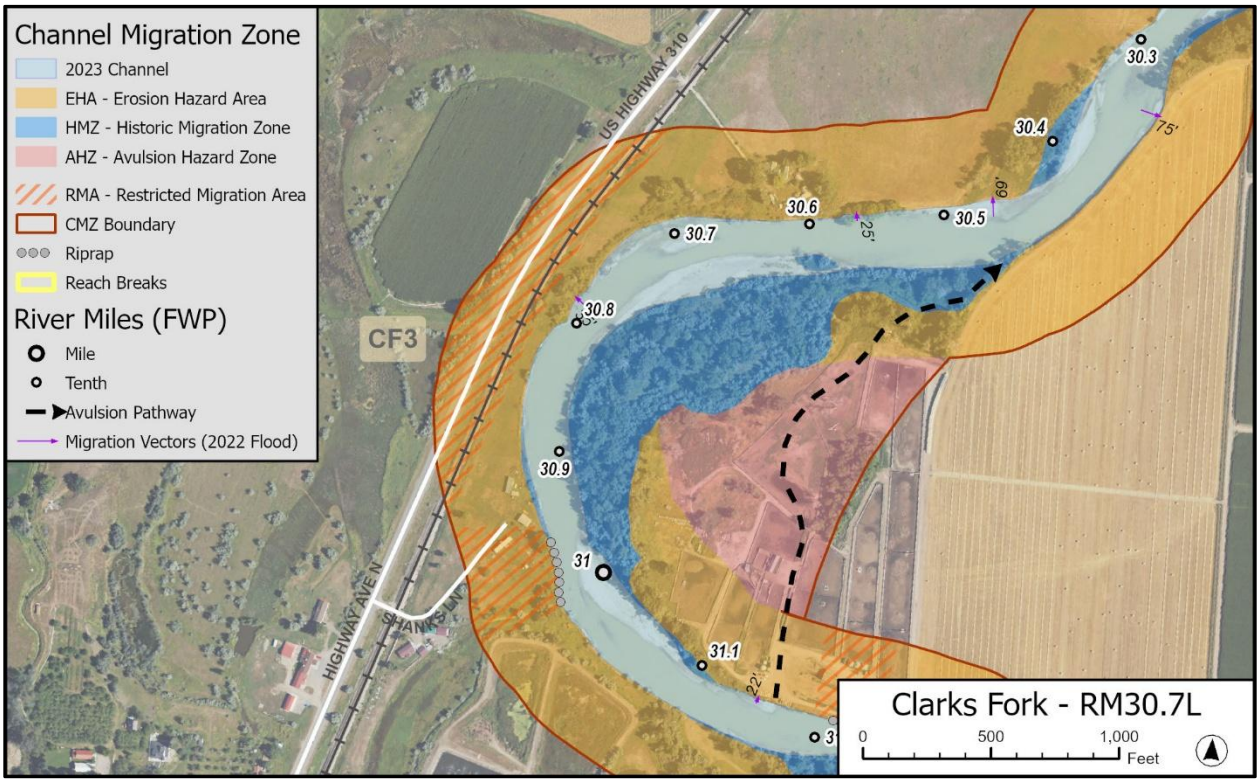


Figure 51. Erosion towards rail grade.

4.1.9 RM 30.2 Left – Agricultural Operations

While this is a relatively stable section of the river with very little positional shift since 1954, the 2022 flood appears to have driven erosion on the left bank and towards numerous ranch buildings (Figure 52). Up to 60 feet of shift has occurred. This is also just upstream of the CF3/CF4 reach break, where downstream channel migration is much higher.

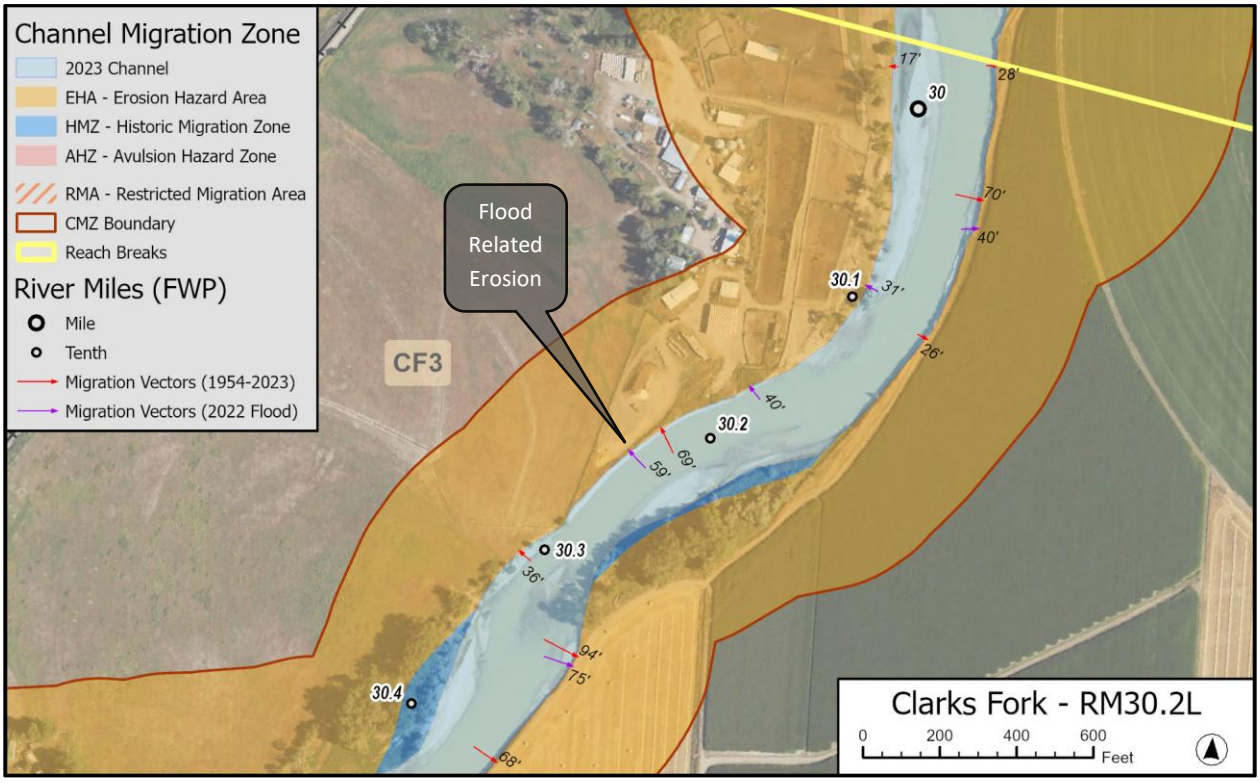


Figure 52. Recent erosion towards ranch buildings.

4.1.10 RM 27.3 Right – Agricultural Operations

This site is located in series of tight bendways with high migration rates and multiple avulsion pathways. This site has seen over 600 feet of lateral movement into irrigated agricultural fields since 1954 and has been armored to stem future erosion (Figure 53). The lower end of the armored bank experienced nearly 50 feet of flood-related erosion. It is unclear if this was due to armor failure, or whether the erosion occurred where the armor ends. Regardless, as erosion continues, this could be the site of a future avulsion across the neck of the meander bendway. The same can be said for the next bendway upstream, though that site has much denser woody riparian vegetation to slow down future channel migration. Note that this section of river is extremely active and has seen multiple avulsions during the period of record used for this study. Addition armor in this area is not recommended, as the channel is already confined between the railroad and the armor at RM 27.4R. Further constriction of the channel width will likely create new management challenges in the future.

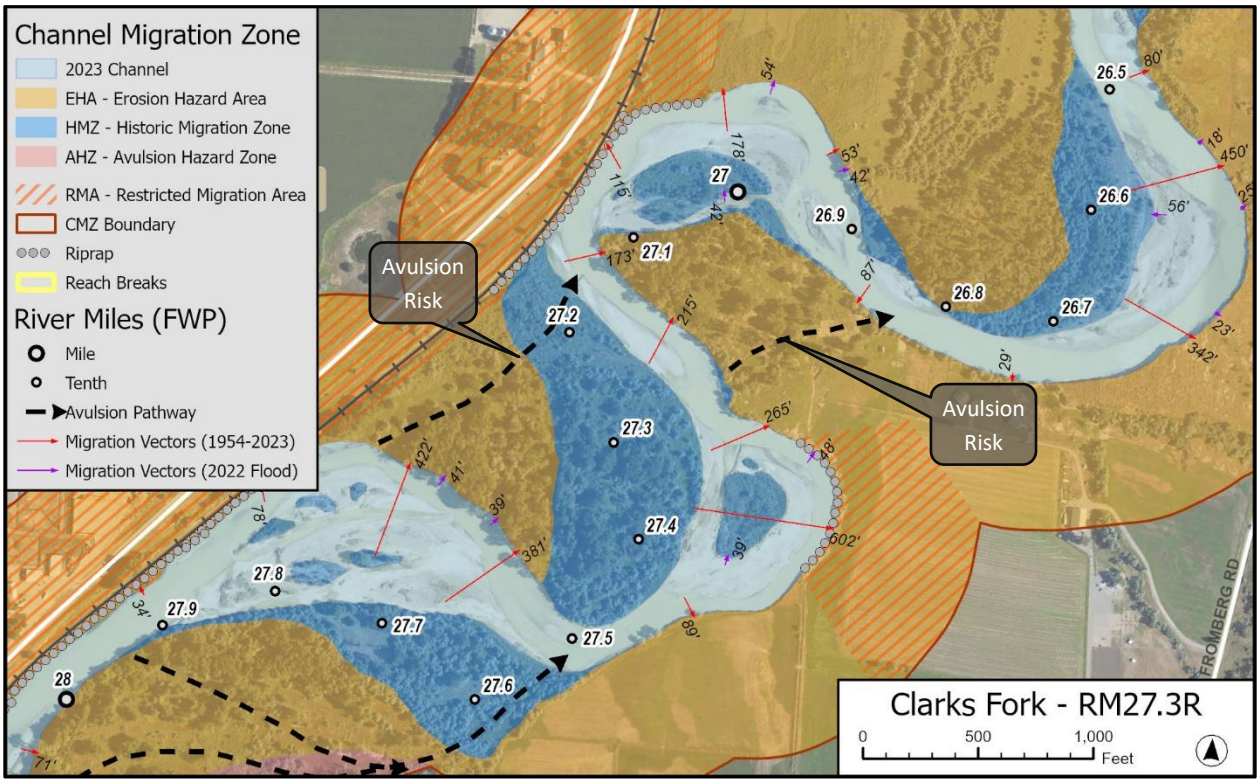


Figure 53. High erosion rates and avulsion risk.

4.1.11 RM 27.3 Right – Agricultural Operations

This bendway showed no significant signs of erosion resulting from the 2022 flood, suggesting that it is likely armored (Figure 53). Channel migration since 1954 is nearly 300 feet, so this has historically been a very active bendway. There is no significant infrastructure in the area if the river were to continue to move.

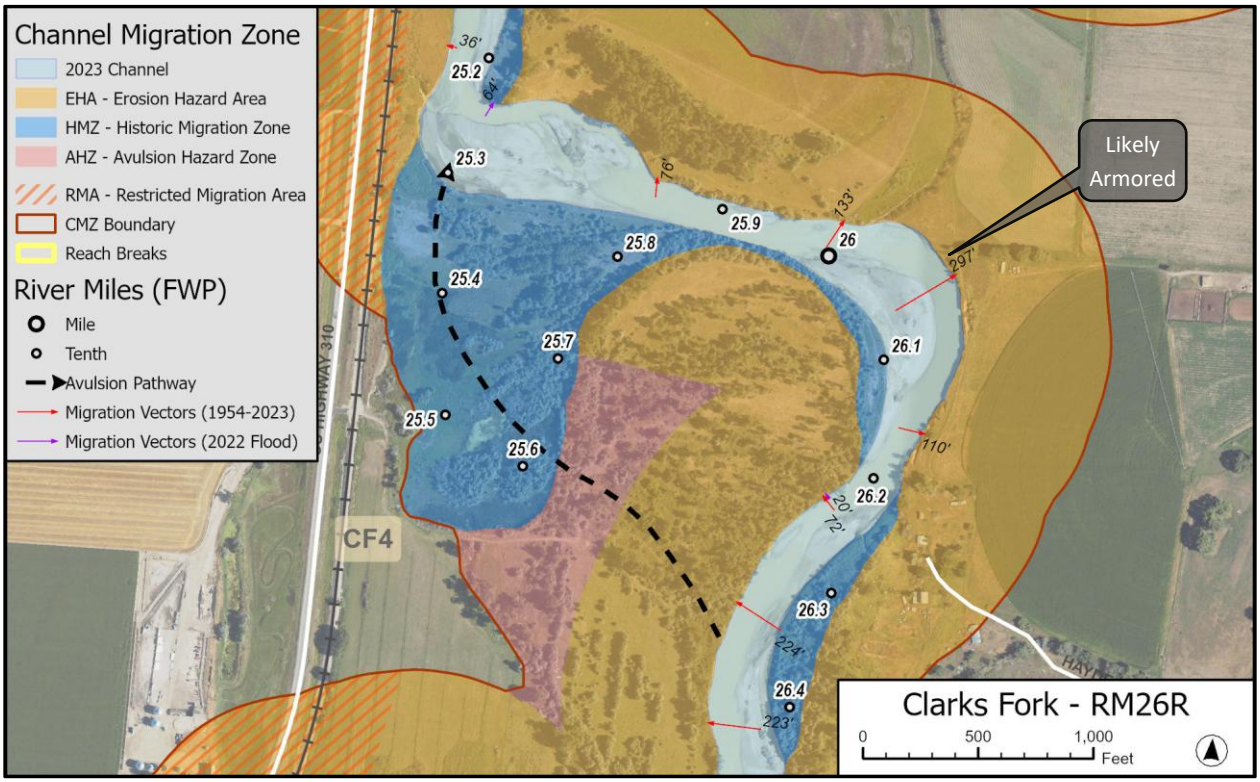


Figure 54. Historically active bendway shows little recent erosion.

4.1.12 RM 27.7 to 22.6 – Agricultural Operations

This dynamic section of river is adjusting to numerous avulsions, both natural and resulting from development of the railway at the turn of the 20th century (Kellogg, 2019). These avulsions significantly shortened the channel, resulting in in a steeper gradient. As a result, the river is actively trying to gain length through channel migration. Figure 55 shows the 1954 and 2023 channels. Migration distances are consistently high throughout the area, nearing 500 feet at RM22.9 through valley bottom alluvium and 243 feet at RM22.8 into a high terrace and bedrock shales. A series of bendway weirs at RM23.1R have effectively limited erosion, but immediately below the bank protection is one of the fastest moving banklines on the river. This will likely be the site of a future avulsion across the narrow bendway core. An avulsion at this location should eliminate any concerns of continued migration towards the Orchard Canal and the Edgar Fromberg Road.

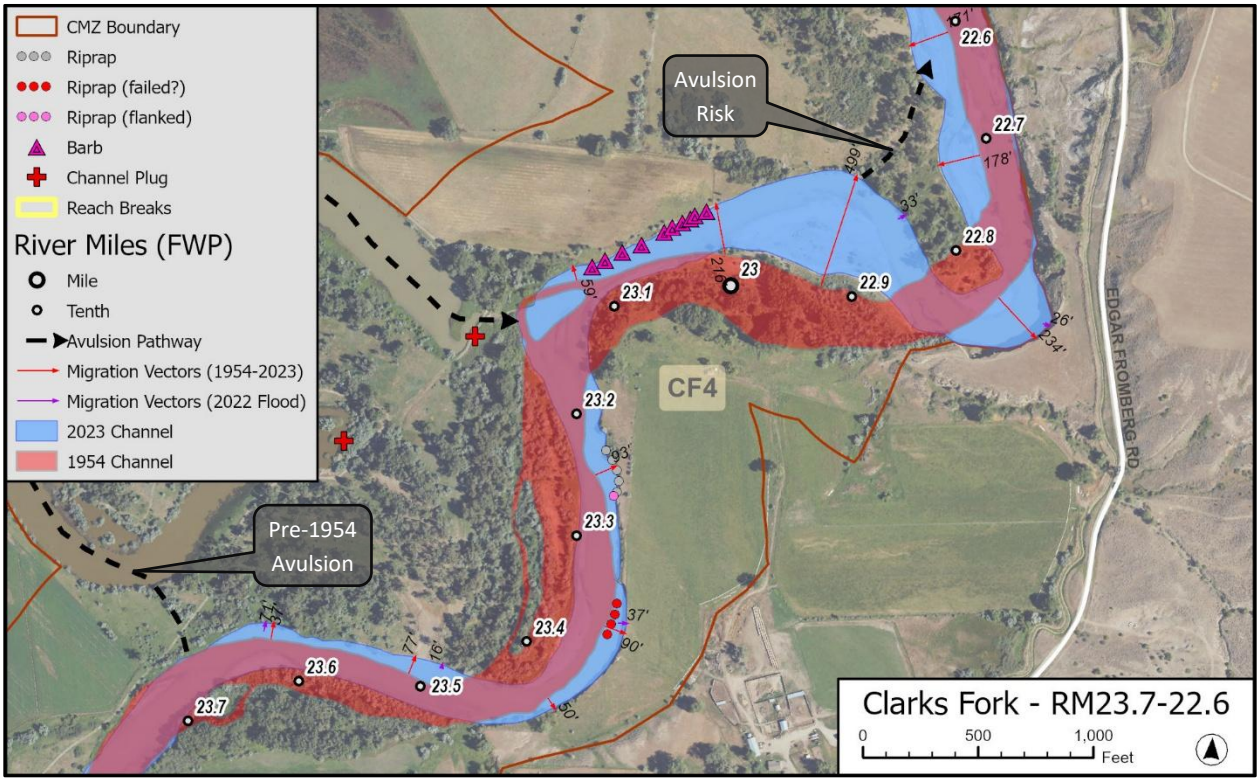


Figure 55. Large avulsions resulted in channel shortening.

4.1.13 RM 18.1– Irrigation/Agricultural Operations (White Horse Canal)

This section of river has seen extensive changes since 1954. A major avulsion at RM17.7 cut over half a mile of channel (Figure 56). Numerous bendway weirs were installed near RM17.1 to prevent erosion into irrigated fields. Maintenance of the White Horse Canal diversion is an ongoing process. The small southern side channel that bypasses the diversion has seen over 200 feet of bendway migration in places. Below the diversion, there has been recent erosion of the left bank into the agricultural fields. Due to the dynamic nature of the channel, one can expect continued maintenance challenges at the diversion and the surrounding area in the future. Note that there is a Highway Department wetland mitigation site at RM16.9 R and any channel management in this area should strive to maintain that natural resource.

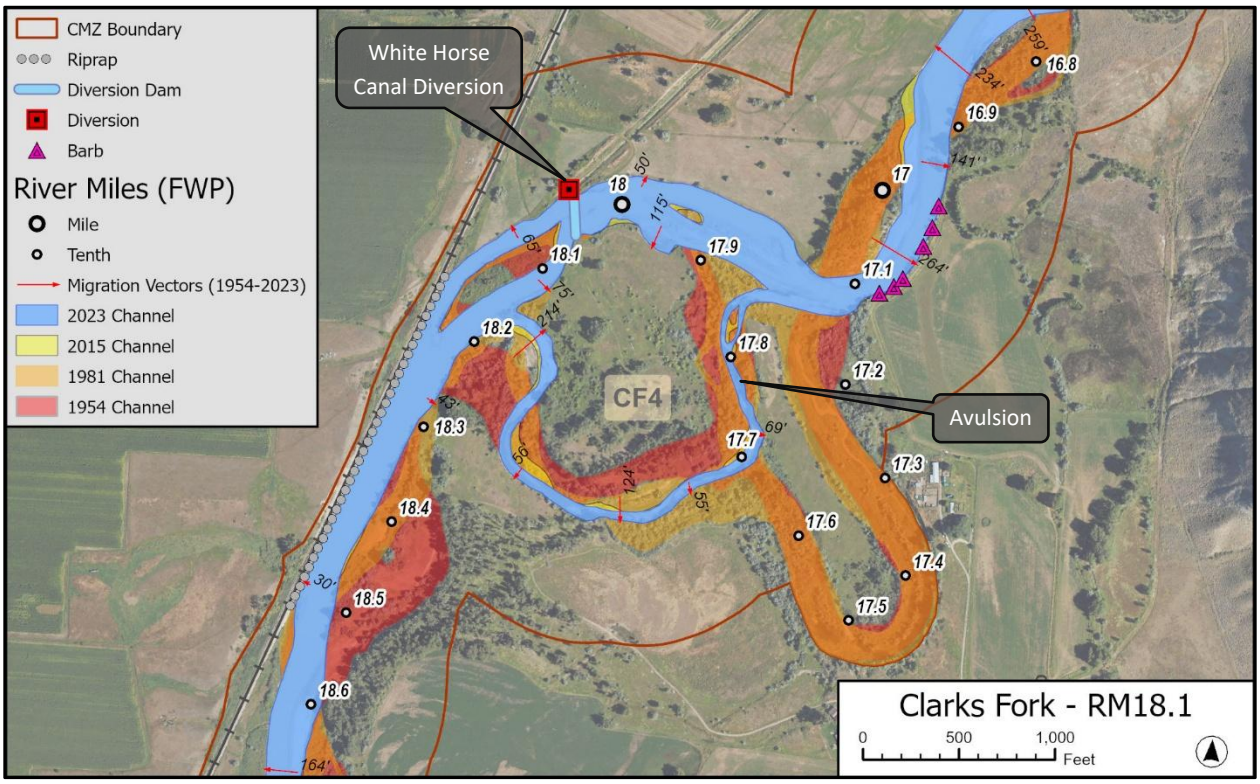


Figure 56. White Horse Canal diversion.

4.1.14 RM 16.4 Left – Agricultural Operations

This site is located approximately 0.7 miles upstream of the Rock Creek confluence. The left bank at RM16.4 has seen nearly 625 feet of erosion since 1954, with over 100 feet associated with the 2022 flood. The right bank of the river is largely anchored by bedrock bluffs, which is driving the bendway to steadily translate downstream (Figure 57). It is currently located around 750 feet from the 1954 and 1981 Rock Creek Channel. Erosion is likely higher than normal due to the lack of any mature riparian vegetation. If this trend continues, or if another large flood event occurs the results in an avulsion, one can expect the bendway to continue to move downstream, eventually intersecting the historic Rock Creek Channel.

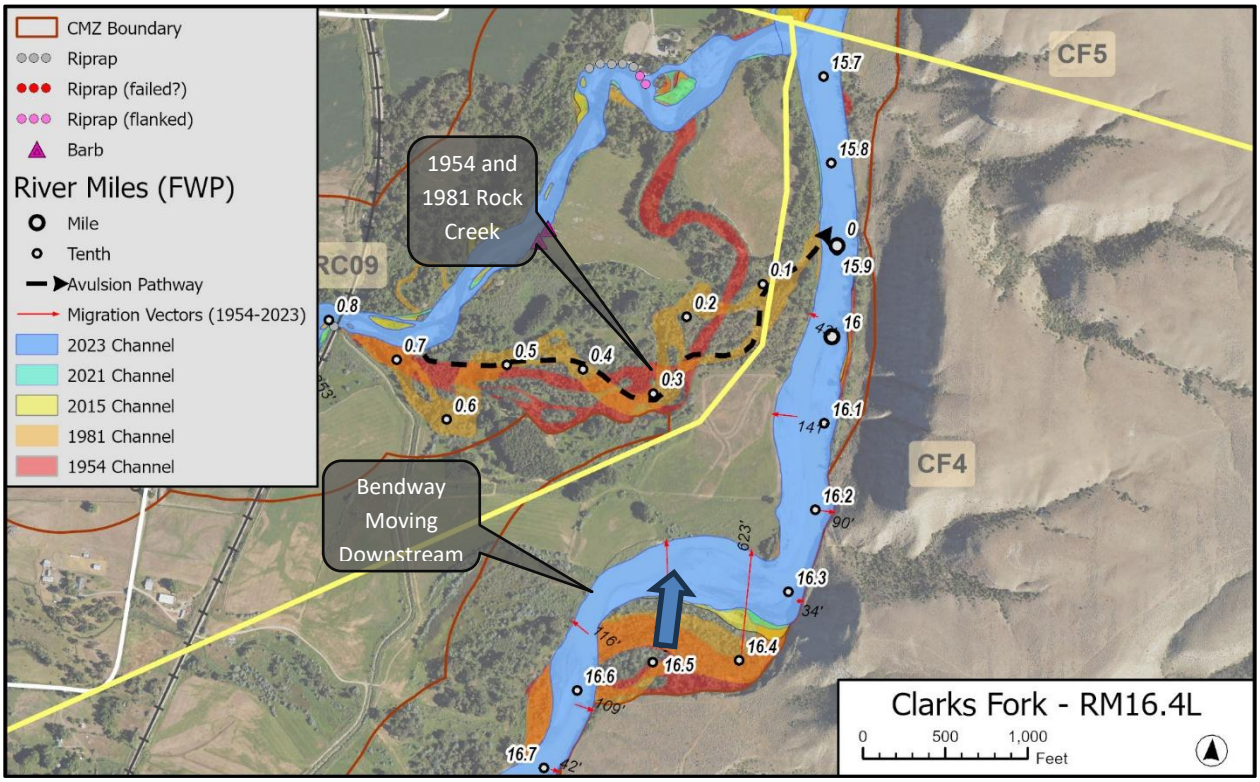


Figure 57. Rapid progression of bendway downstream.

4.1.15 RM 12.9 – Transportation

The Kellogg report (2019) notes significant undermining of the west abutment of the Cottonwood Road bridge (Figure 58). While the bridge is well-aligned with the river, this is an important bridge and should be monitored. Since the Kellogg report, some large rock has been placed to protect the abutment.

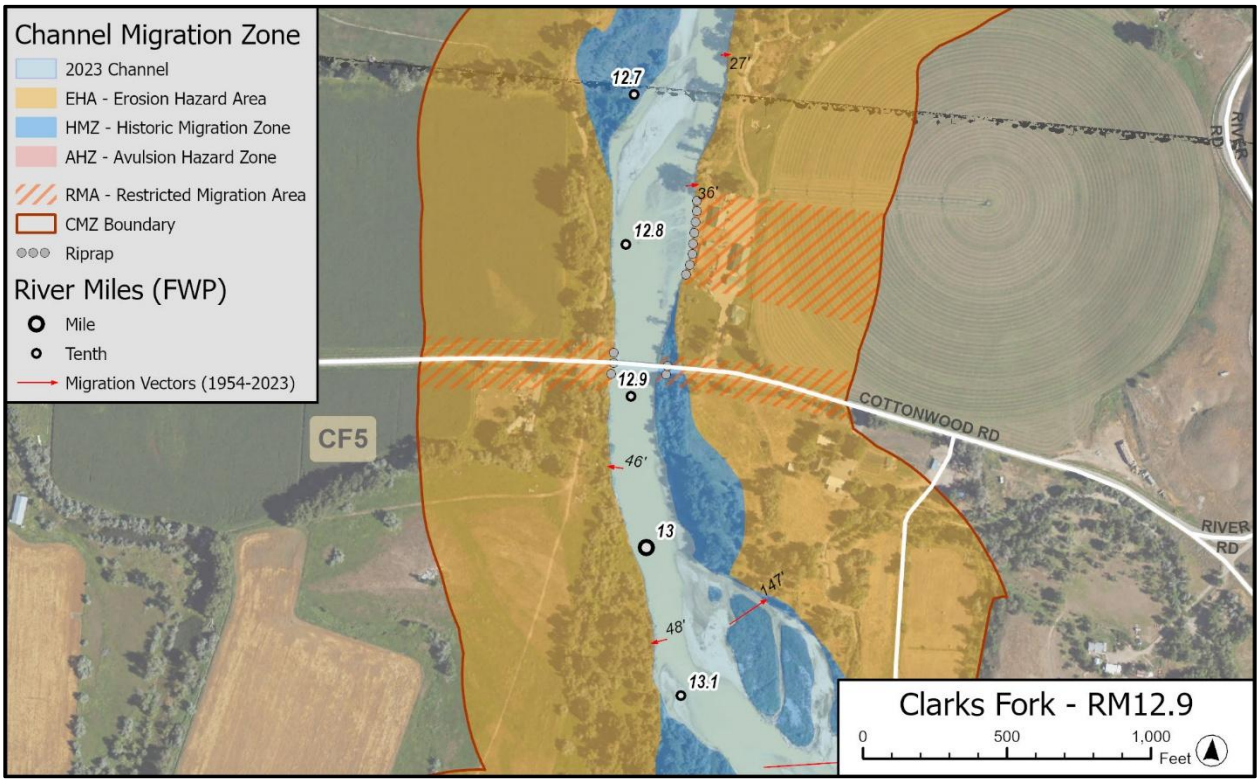


Figure 58. Cottonwood Road bridge.

4.1.16 RM 10.3 – Irrigation/Agricultural Operations

This is an extremely complex and dynamic section of river. High channel migration rates are present, along with multiple avulsions since 1954 (Figure 59). While the main channel is currently located along the eastern bluff after an avulsion between 1954 and 1981. The right hand bendway at RM10.4 developed rapidly between 1981 and 2023, then avulsed through the bendway core after 2015. While there is no infrastructure at risk, one can expect this region to continue to change in the future. As such, development should be limited to outside the CMZ boundary to avoid future conflicts.

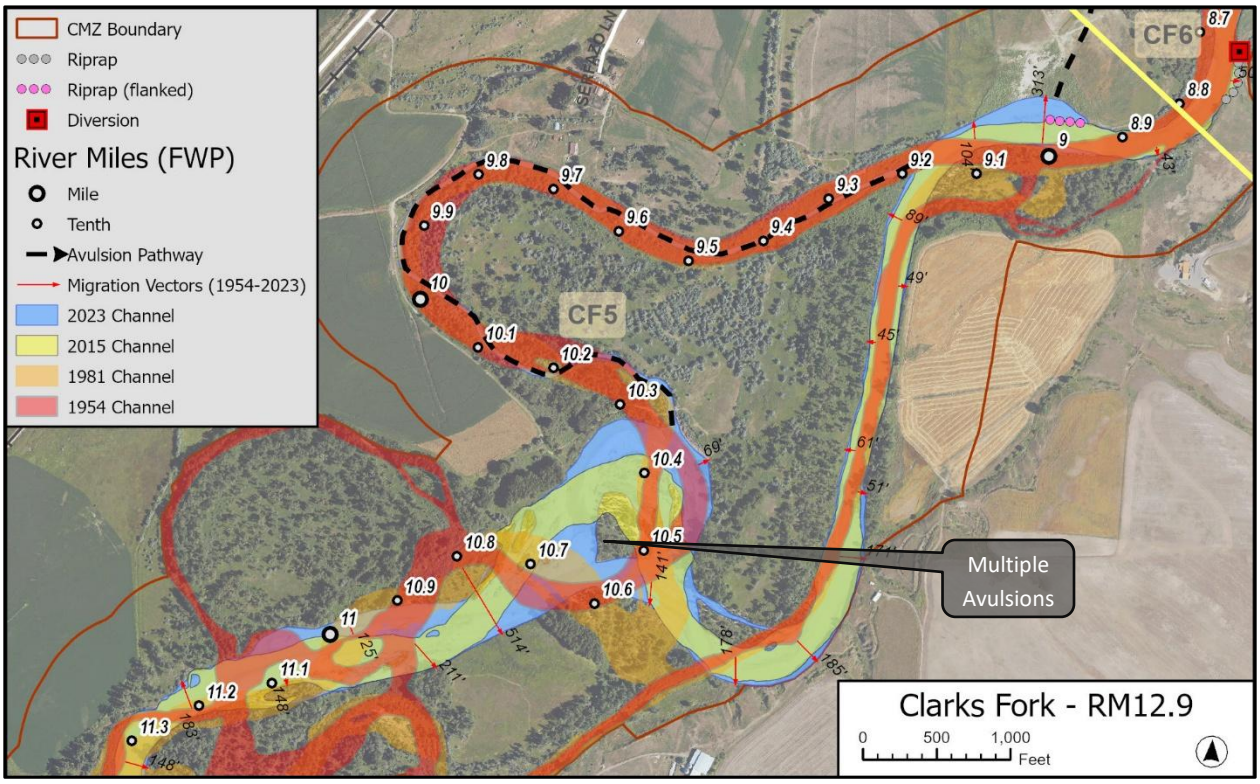


Figure 59. Channel complexity.

4.1.17 RM 9.0 Left – Irrigation/Agricultural Operations

The left bank at RM 9.0 has seen over 160 feet of post-flood lateral movement to the north. There is evidence of overland flows from floodwaters, suggesting a low bank and propensity for continued erosion (Figure 60). There is at least 300 feet of failed bank protection. One quarter of a mile downstream is a diversion structure on the right bank. If this bendway were to avulse, several residences and outbuildings could be at risk and the diversion bypassed. More recent Google Earth imagery from 2026 shows that this erosion has continued.

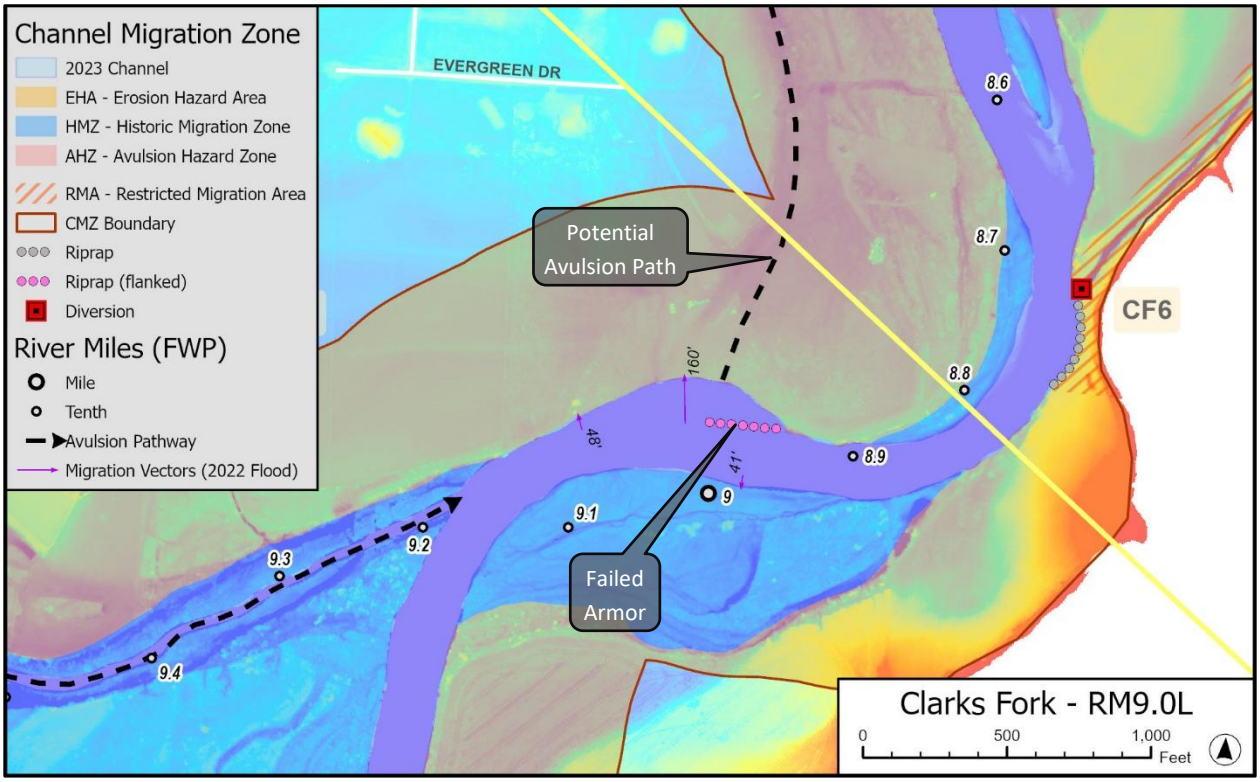


Figure 60. Failed armor and overland flow from the 2022 flood.

4.1.18 RM 7.2 through 6.4 – Agricultural Operations

This section of river has multiple migrating banklines and sections of failed bank armor. Flood-related erosion distances approaching 150 feet are present (Figure 61). A 300 foot section of bank armor at RM6.5L protects a residence and multiple outbuildings, but shows signs of being flanked on both the upstream and downstream ends.

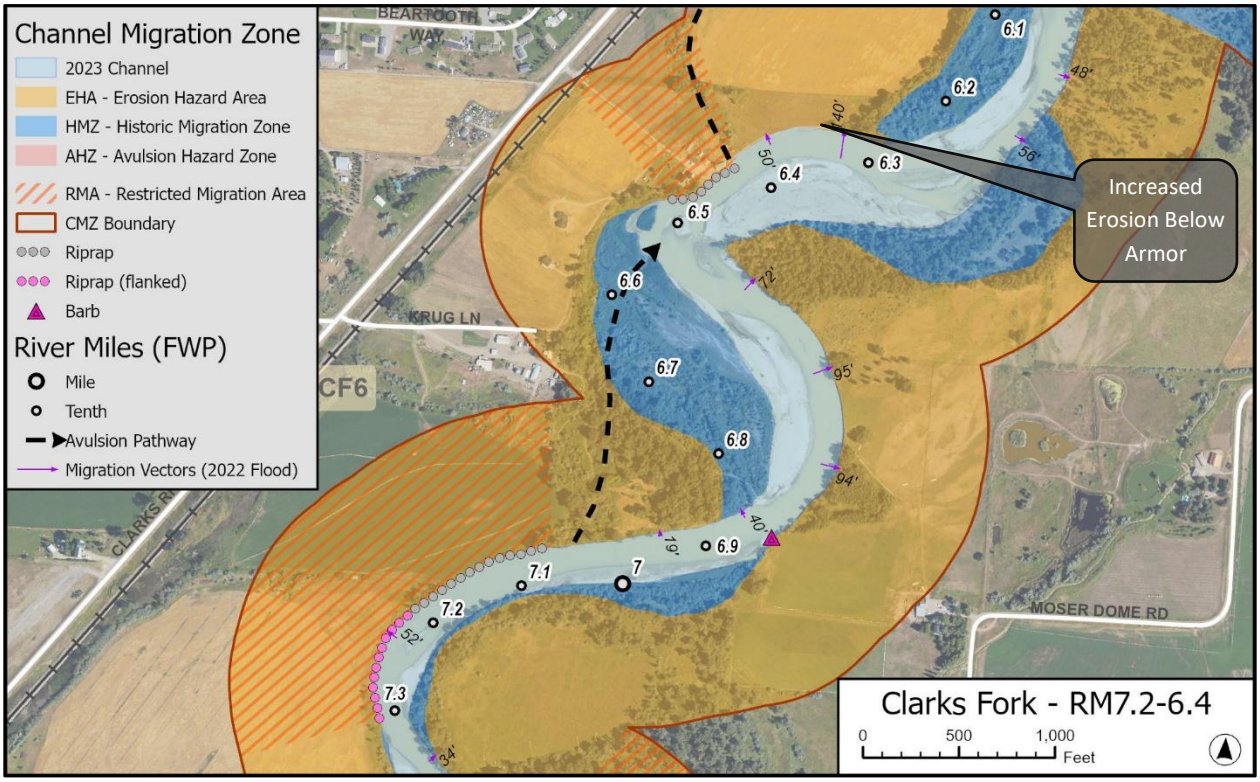


Figure 61. Agricultural field erosion.

4.1.19 RM 5.3 – Agricultural Operations

The left bank at RM5.3 has seen at least 160 feet of post-flood bank erosion towards ranch buildings (Figure 62). Some historic bendway weirs have been lost due to the erosion and the remaining jetties show signs of degradation. Across the river on the right bank, there is a section of failed armor and erosion has widened the river, leaving several buildings perched on the bankline. The alignment to the Byam Road bridge just downstream is somewhat skewed and may degrade more if erosion were to continue.

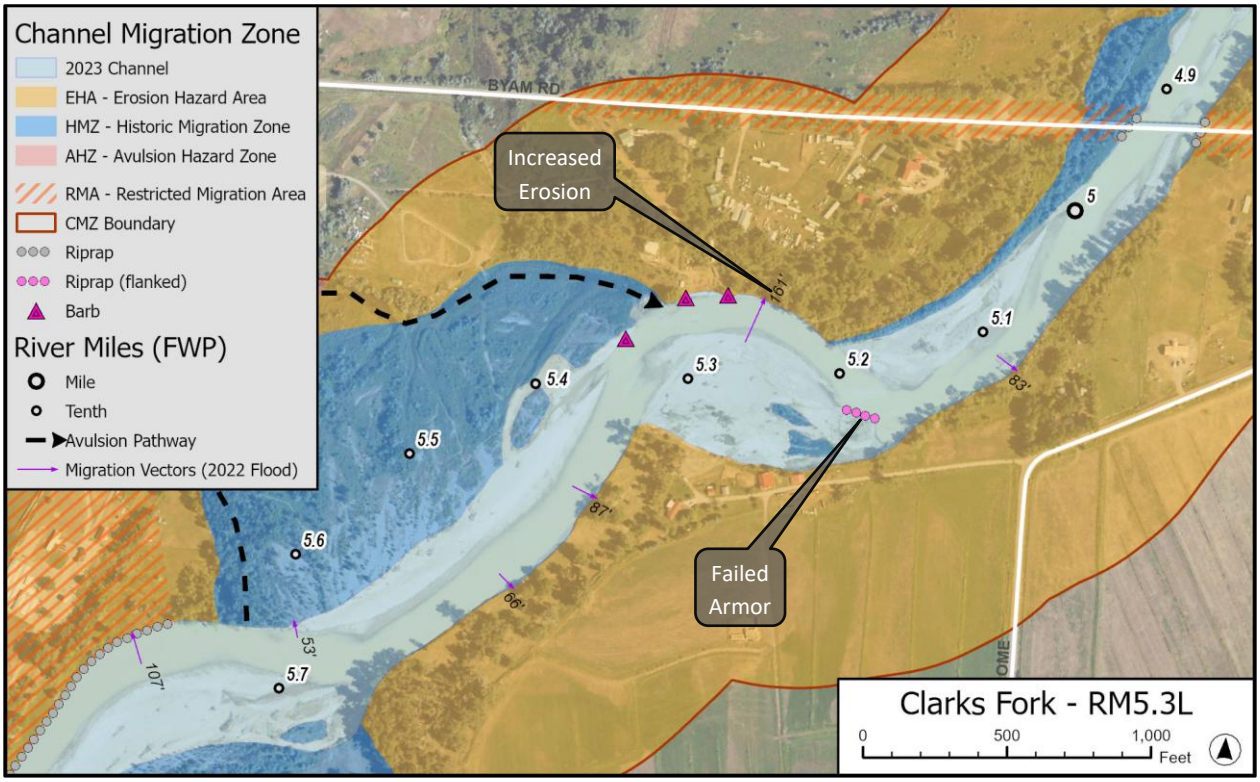


Figure 62. Byam road erosion and failed armor.

4.1.20 RM 3.5 – Agricultural Operations

While the left bank at RM5.3 has migrated steadily since 1954, this appears to have accelerated due to the flood. Over 130 feet of lateral movement has occurred between 2021 and 2023 (Figure 63). Ownership from here down to the confluence with the Yellowstone River is BLM and is maintained for public access. This includes the Sundance Lodge Recreation Area on the Lewis and Clark and Nez Perce National Historic Trails. There is no significant infrastructure at risk. Public ownership makes this an ideal location to allow natural processes to happen.

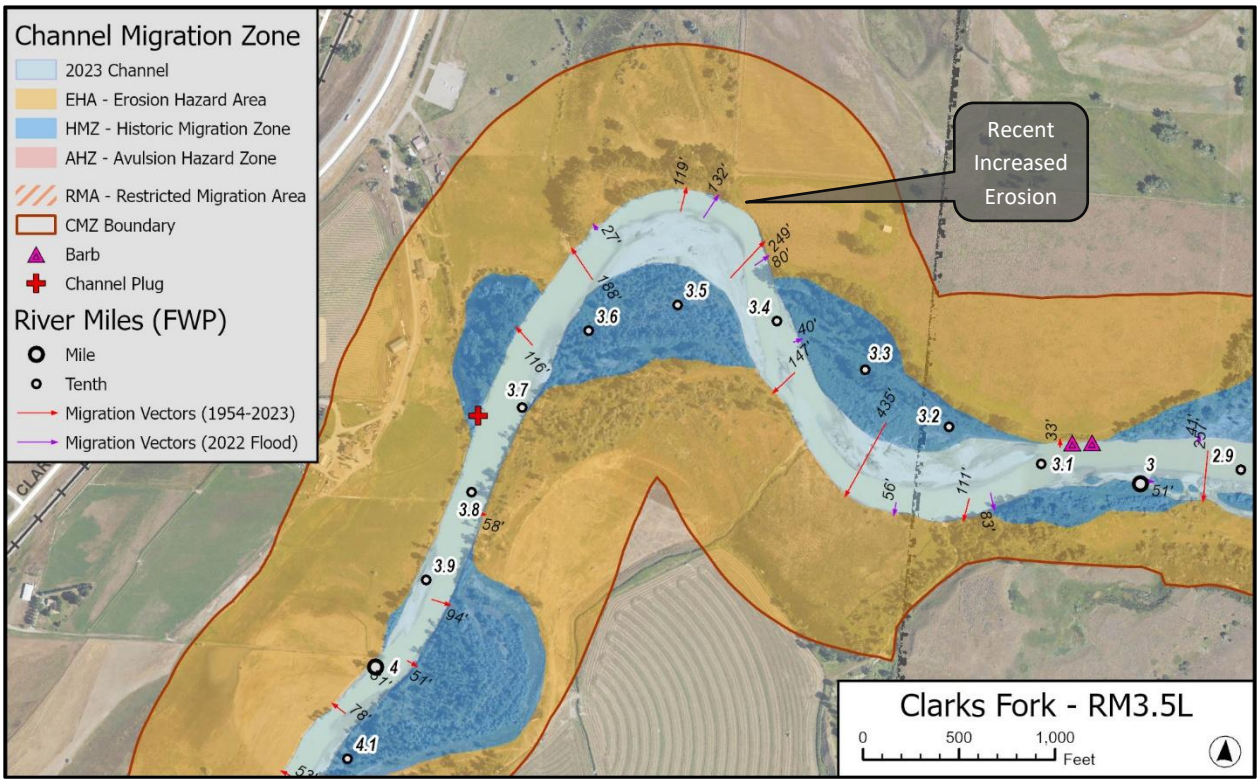


Figure 63. Flood driven erosion into fields.

4.2 Rock Creek Concerns

Table 6 lists sites along the Rock Creek that were identified with High-Priority CMZ issues based on historic channel migration and likely future channel migration.

Table 6. CMZ concerns on Rock Creek.

RM	Name	Type	Notes	Priority
40.9	Red Lodge	Transportation, Development	Channel constriction entering Red Lodge and under Hwy 308 bridge.	High
27.4L	Moose Tracks Subdivision	Development	Loss of bridges and development in the floodplain and active river corridor.	High
24.9L		Development	Left bank erosion on a tight bendway has potential to flank the existing bank protection and threated a driveway.	High
9.0	Joliet	Critical Infrastructure, Bank Erosion	Bendway adjacent to the water treatment ponds has migrated 350 ft. The bendway will likely translate downstream and be captured by existing swale.	High
0.8	Gibson Rd/Railroad	Transportation	Channel doglegs into railroad bridge. Could continue to degrade and flank existing bank protections.	High

4.2.1 RM 40.9 – Red Lodge

As Rock Creek enters Red Lodge, the floodplain corridor narrows to less than half the width of the corridor upstream. The corridor is further restricted by the Hwy 308 bridge. The corridor through Red Lodge is heavily armored, though there have been areas with significant localized erosion both pre- and post-2022 flood (Figure 64). Due to the extensive armoring, the risk here is more of flooding than of channel migration. It appears that most sites that were impacted by the 2022 flood have been restored, so future lateral channel movement is of limited concern.

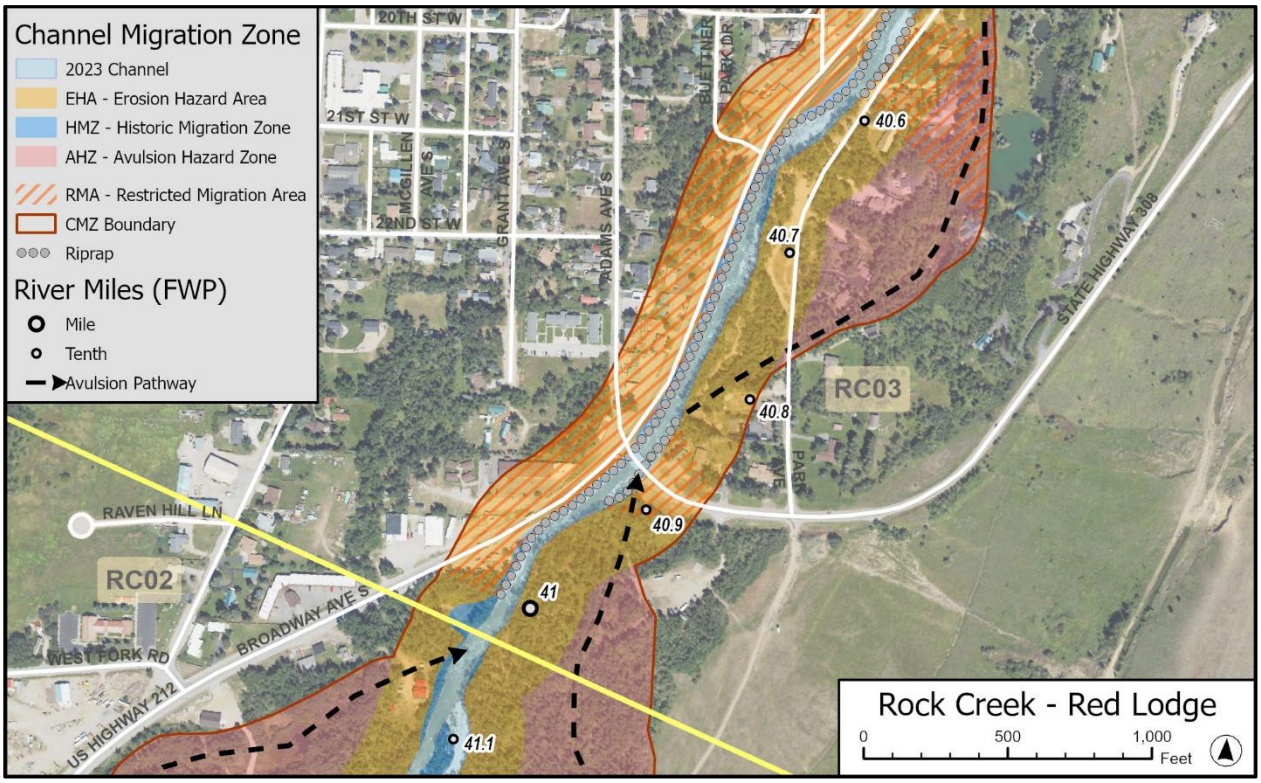


Figure 64. Channel constriction and extensive armoring in Red Lodge.

There was significant channel migration into the right bank just below the Kainu Ave bridge (lost during the June 2022 flood). This erosion was into historical tailings deposits. Post-flood remediation efforts have since filled the erosion scar and stabilized the bankline near its pre-flood location (Figure 65).



Figure 65. Google Earth imagery showing 2021 (pre-flood, 2022 (post-flood) and 2026 of the tailings site below Kainu Ave in Red Lodge, MT.

4.2.2 RM 27.4 Left – Residential Development (Moose Tracks)

The parcels on the west side of the Moose Tracks Subdivision present some of the only residential development within the active river corridor. Numerous homes are located within the Erosion Hazard Zone and may face challenges as the river continues to move. One site of immediate concern is the parcel at RM27.4L where a scour pocket has developed below some existing bank protection (Figure 64). This scour is into an open field that lacks any substantial woody riparian vegetation to slow down bank erosion.

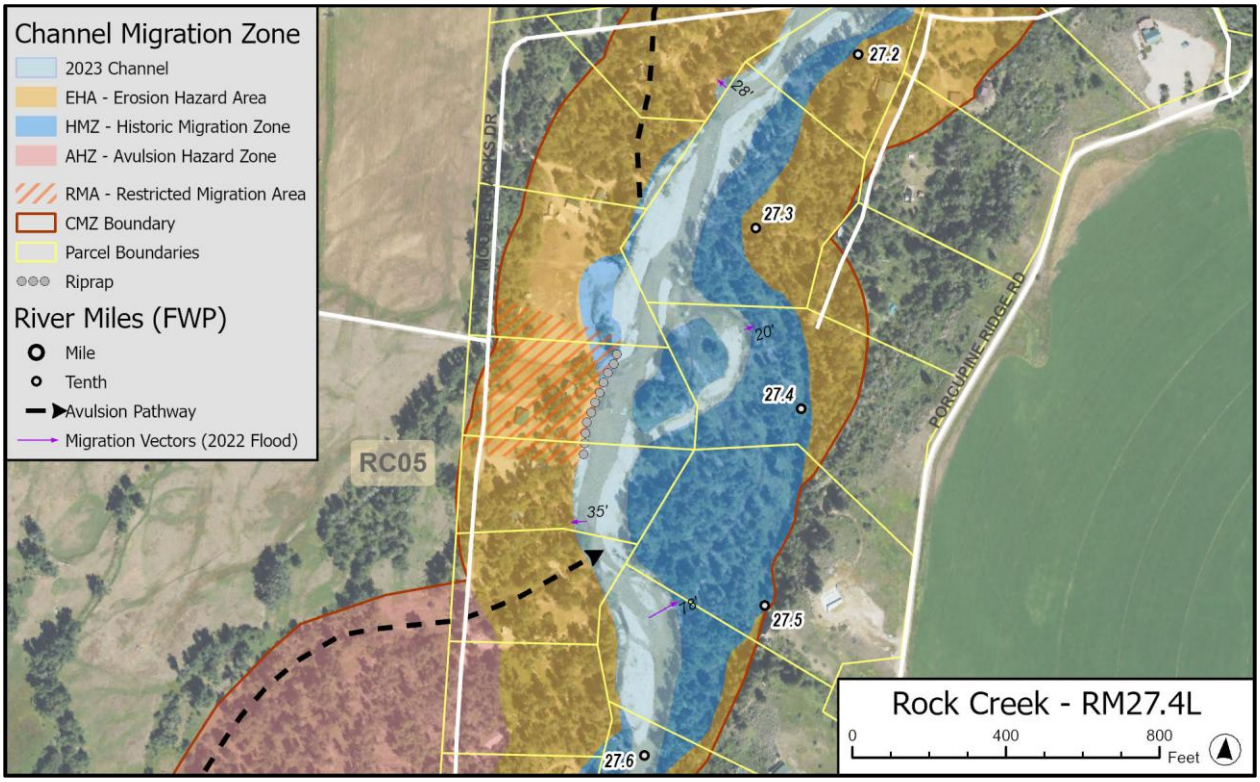


Figure 66. Residential development in the CMZ, Moose Tracks Subdivision.

4.2.3 RM 24.9 Left – Residential Development

At RM 24.9, Rock Creek flows along the western edge of the floodplain corridor before making a sharp right turn (Figure 66). This tight bendway has some existing bank protection to prevent continued erosion and possibly threatening a driveway. Flood-driven migration in this area was upwards of 50 feet where the banks were not armored. The upstream end of the bank protection shows nearly 25 feet of movement and threatens to flank the structure.

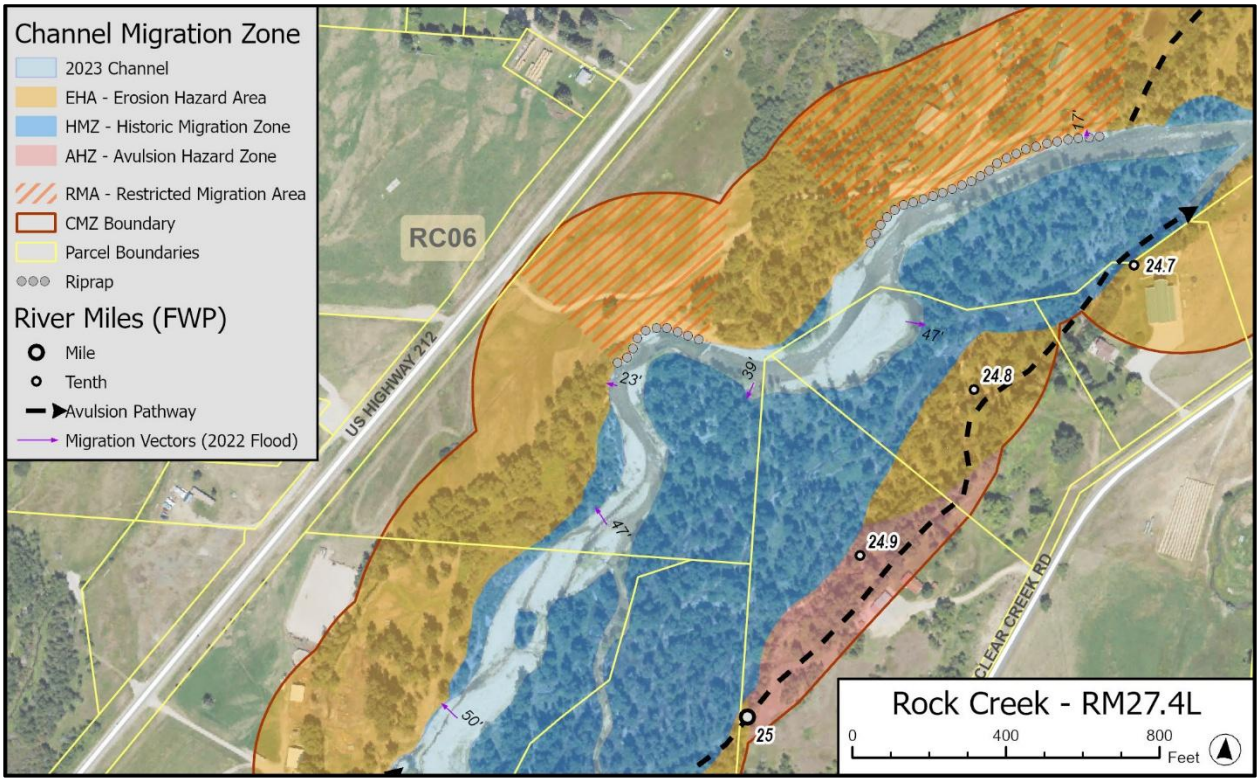


Figure 67. Bank migration to the edge of the Rock Creek cottonwood corridor.

4.2.4 RM 9.0 – Joliet

Rock Creek through Joliet presents several challenges (Figure 68). The right bank is bounded by an irrigation canal, Granite Road and bedrock geology, effectively limiting floodplain access to only the area north of the river. Extensive bank protection exists for areas of where the river directly abuts the road and canal. There is one area of apparently failed bank armor at RM8.7R. The primary concern here is at RM9.0L where Rock Creek makes a right hand bend. Current erosion is towards the wastewater treatment facility, currently located at the edge of the CMZ ~500 feet away from the current bankline. This is a fairly mature bendway and is currently moving down valley faster than it is towards the treatment facility. There is a historic swale that has been identified as a likely avulsion path on the downstream leg of the bendway. As the river continues to move, there is a strong chance that it will either cut off across the inside of the bendway, effectively moving further from the treatment facility, or be captured by the swale, again bypassing the facility.

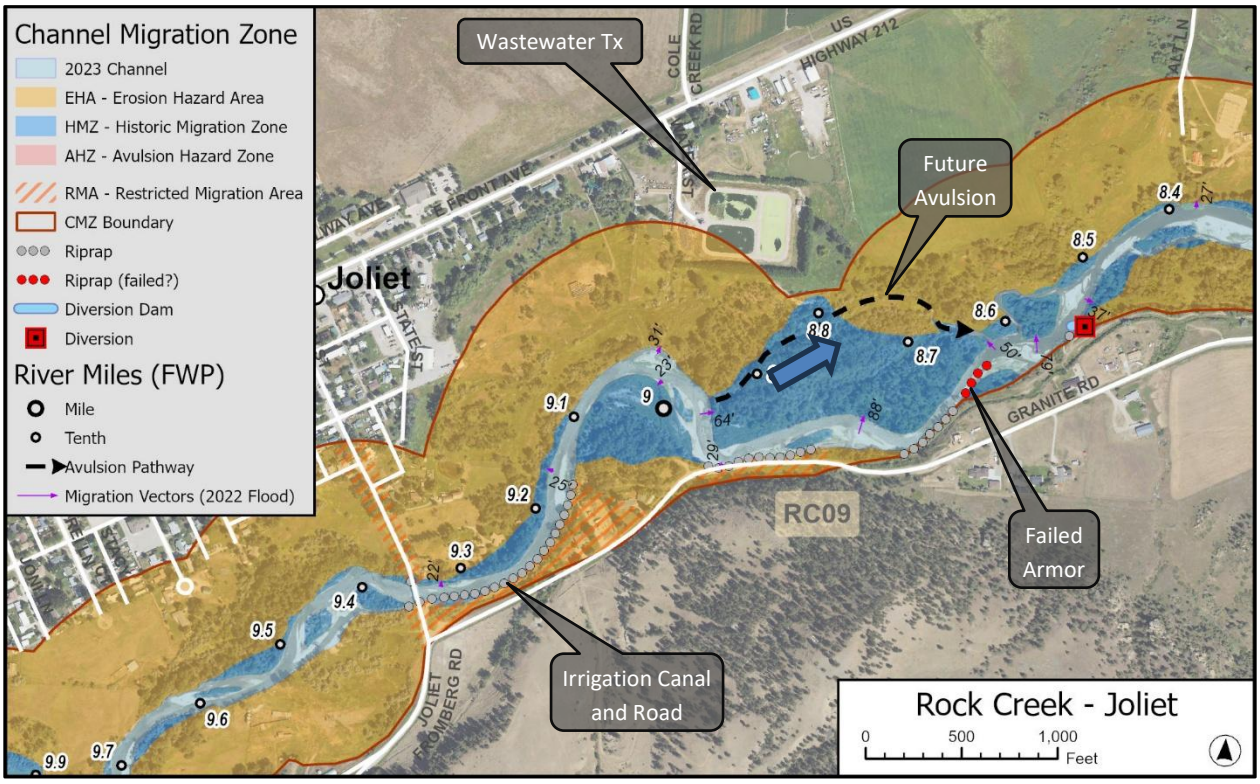


Figure 68. Transportation, irrigation and public works issues in Joliet.

4.2.5 RM 0.8 – Transportation

Below Gibson Road at RM0.8, Rock Creek has migrated approximately 250 feet south and runs along the railroad grade (Figure 69). It then makes a 90 degree "dogleg" to the right to pass under the railroad bridge. It is currently armored where the river encounters the railroad grade, though this will likely continue to work its way upstream, requiring additional bank protection. There is a narrow strip of mature riparian vegetation on the south bank that will provide some stability, but if this is breeched, erosion will likely accelerate in the open field. If addition repairs are made to this site, one should consider approaches that provide better bridge alignment by tapering the corridor to pass under the bridge.

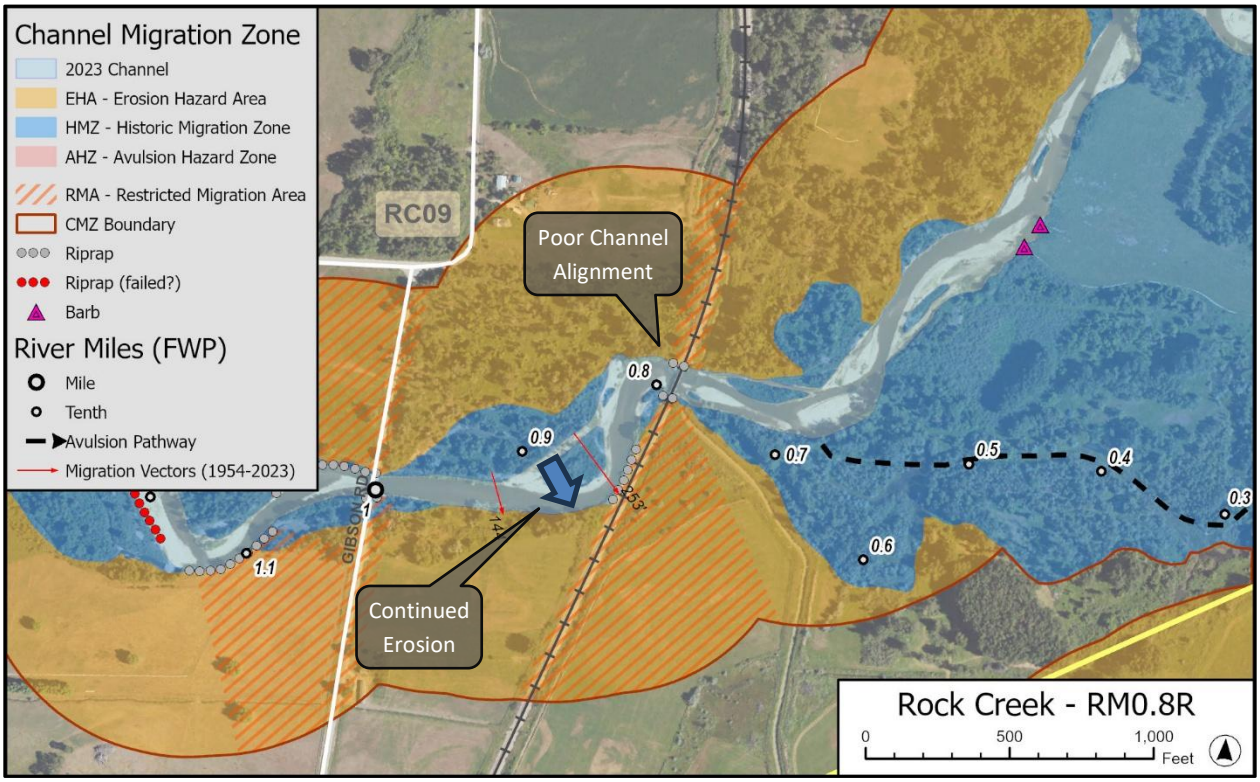


Figure 69. Bank erosion leading to poor alignment under rail bridge, below Gibson Road.

5 Public Outreach and Review

The draft CMZ map for this project was reviewed by multiple people representing local government offices, elected officials, natural resource experts, as well as local landowners and residents before it was finalized and published in this report. The draft map and report did not go through a formal 30-day public review period as this was not necessary given that the map is non-regulatory, however, extensive efforts were made to properly notice all public meetings through social media, flyers, newspaper announcements and word of mouth.

Public outreach activities included 3 public meetings and an open meeting to the Clarks Fork Yellowstone Partnership (Figure 70).

- May 19, 2026 – Joliet, MT – Clarks Fork Yellowstone Partnership annual meeting, ~25 attendees
- August 20, 2026 – Red Lodge, MT, Roosevelt Center Conference Room, 22 attendees
- August 20, 2026 – Joliet, MT, Joliet Community Center, 13 attendees
- August 21, 2026 – Bridger, MT, Senior Center, 11 attendees



Figure 70. Red Lodge Meeting on August 20, 2026.

6 CMZ Management Concepts

This section is included to introduce several key management concepts when working within a Channel Migration Zone that we have developed from experience of mapping over 1,500 miles of river corridor in Montana and the western United States.

The management of the river as a "corridor" is an important first application of CMZ mapping. While river corridor management often focuses on protecting investments in the corridor, the same concepts for protecting those investments also protect and enhance the natural resources within the corridor by providing a broad enough corridor to allow for critical environmental processes to take place. As such, minimizing economic and natural resource losses due to land loss, infrastructure failure, or bank armor loss should consider the following:

- Minimize development encroachment into the CMZ boundaries to maintain system resilience and ecological function. This is most important for the Historic Migration Zone and Erosion Hazard Area. The Avulsion Hazard areas may be at either high or relatively low risk of channel reoccupation, and development in these areas should be based on site-specific conditions.
- Carefully taper the CMZ to bridge openings using bank armor approaches that gradually narrow the stream corridor to the bridge opening.
- Consolidate infrastructure where possible. For example, diversion headgates tend to function well below bridges, which taper the CMZ to the width of the bridge opening.
- Promote woody riparian growth in the corridor, to increase the resiliency of the floodplain during long floods that have the potential to scour floodplain channels and drive cutoffs.
- Place infrastructure such as shallow pipelines or utility towers beyond the margins of the Erosion Hazard Area to reduce the need for near-term bank armoring.
- As possible, minimize bank armoring projects that run at a high angle to the axis of the CMZ. Any channel segments that trend across the CMZ will have increased erosive pressure on the down-valley side, as the armor is disrupting normal down-valley translation of bends. As such, these projects typically fail or require a higher level of maintenance than projects that trend on the edge of the CMZ in a direction parallel to the stream corridor axis.

Whereas CMZ mapping is commonly used to identify development risks, it is also important to recognize the role that channel migration plays in maintaining geomorphic stability and optimizing the ecological function of these rivers. The Clarks Fork Yellowstone River and Rock Creek have been impacted by development pressures related to transportation, irrigation water delivery, industrial floodplain development and residential expansion, and there has been substantial human encroachment into the CMZ footprint. As a result, there are progressively fewer sections of river that show largely unimpeded channel movement and resulting complex channel forms, both spatially and temporally. The Rock Creek corridor downstream from Red Lodge is typically over one thousand feet wide and supports a broad riparian forest of diverse age classes. The continual turnover of floodplain forest supports long term riparian health as the woody vegetation is constantly regenerating. In contrast, much of the Clarks Fork is armored to protect irrigation infrastructure and agricultural fields. As a result, the river lacks much of the complexity needed to support these riparian functions.

It is also important to recognize that the geomorphic response to the 2022 flood is likely not over. The disturbance from such an event can have positive impacts to stream function and habitat, but channel adjustments are prone to continue for years as gravel delivered during the flood moves its way through the

lower end of each drainage. In some situations, the best approach may be to allow, rather than attempt to limit those adjustments wherever possible, so that resources aren't wasted on a continually adjusting channel. At this point, "choosing one's battles" is an important concept, and allowing channels to migrate and adjust where room and infrastructure allow is recommended.

6.1 CMZ Management and Maintenance Considerations

The nature of human encroachment into the natural CMZ of a river can sometimes be directly correlated to infrastructure maintenance costs. For example, the Nooksack River in Washington State flows from the northern Cascades westward to Bellingham Bay near Bellingham, Washington. As the river leaves the mountains and crosses the coastal plain near Everson, Washington, it rapidly loses gradient and deposits high volumes of coarse sediment as a result. As this is a productive farming area, armored levees have been constructed along much of the length of this dynamic river, and they require frequent and costly maintenance. As part of a larger geomorphic study of the river completed for Whatcom County, AGI and others (2019) evaluated the maintenance requirements on the levees as a function of river corridor width. The evaluation was prompted by a perceived correlation between corridor width and cost of maintenance, in that corridor areas that were more confined by levees experienced more erosive damage. Figure 71 show the results of that analysis. First, several levees were segmented in terms how much they impinge into the river corridor. Some areas reflect corridor narrowing in long levee segments and others represent "hooks", where the lowermost end of a levee turns directly into the stream corridor. The width values range from 590 to 2,450 feet and the levees were sorted by width from narrowest (left on graphic) to widest (right on graphic). Second, those levee segments were evaluated for maintenance intensity, which is the length of maintenance that has been recorded per foot of levee segment. In plotting both the width value and maintenance intensity value for each levee segment, and sorting those by corridor width, an inverse relationship between the two can be seen, in that confining levee segments require substantially more maintenance than less confining structures. The primary drivers for this are twofold: first, where the corridor is narrower, the river spends more time flowing directly on the levee resulting in more damage, and second, the hydraulics at narrowing points and hooks can be especially damaging to the levees. These results are relevant to Rock Creek, especially from Red Lodge upstream to the Forest Service Boundary and on the Clarks Fork below Fromberg where the river is actively trying to gain length due to numerous human-caused and natural avulsions.

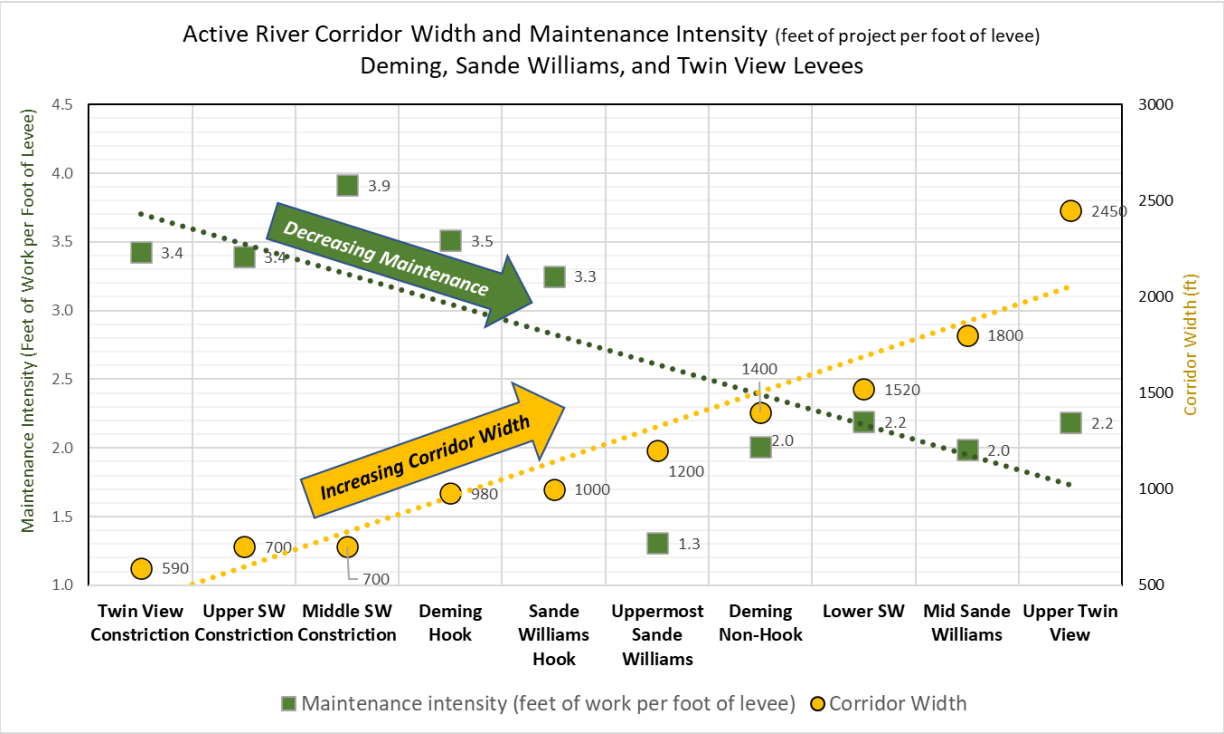


Figure 71. Nooksack River levee segments sorted by corridor width showing reduced maintenance intensity in wider sections.

6.2 Roads and Bridges

The CMZ mapping area includes transportation features that encroach into the CMZ footprint. The main issues with bridges are twofold: 1) alignment of the river to the bridge crossing; and 2) consolidation of multiple stream channels at a bridge crossing. Bridges are typically designed at a right angle to stream flow, so that the bridge is perpendicular to flow paths. As the channels migrate laterally, this alignment can decay. It is not uncommon for poor alignments to cause problems at bridges through accelerated scour which can damage bridge piers and embankments. To that end, it is important to consider stream corridor alignment and tolerance for change in both bridge design and management. In general, managing channel alignments at bridges should be considered with CMZ concepts taken into account rather than treated as a late-stage emergency when streams dogleg through bridges, causing scour or deposition problems. The maps can help identify optimal bridge locations, appropriate bridge spans, and define anticipated future alignment issues so support cost-effective risk mitigation.

6.3 Development Pressures

In developing CMZ maps across Montana, it is always striking to see how many structures are at risk of damage due to bank erosion. In CMZ related public outreach meetings that we have held across the state for other projects, we have heard numerous testimonies in which landowners have described their anxiety over river movement and financial stresses of property protection. Bank armoring typically costs on the order of $90-$120 per linear foot of bank, so protection of structures on these rivers can easily cost over $100,000. Yet structures are still constructed close to actively migrating channels. We sincerely hope that this analysis will help

landowners make cost-effective decisions in locating homes or irrigation structures. On the Big Hole River, for example, one landowner moved his house site 100 feet back from the top of a terrace edge based on the mapping; subsequent erosion of that terrace has proven that decision to be a major cost saving move.



Figure 72. Residential development within EHA of Clark Fork River during the 2018 flood near Frenchtown (May 10, 2018).

6.4 Long-Term Resiliency

Rivers morphologically respond to changes in inputs, primarily the quantity and caliber of sediment and the quantity and pattern of water delivery from upstream. One challenge in CMZ mapping is that the analysis is based on the historic record of channel form and rates of channel movement, meaning its accuracy in part relies on a presumption that historic inputs will not substantially change in the future. In Section 1.9 we discussed these limitations with a retrospective approach. In a larger sense, however, the CMZ developed in this project reflects numerous floods and decades of channel movement, such that it will allow for substantial flexibility in the system to respond to future impacts such as floods and fires. This concept is commonly referred to as "resiliency". There is a strong movement in river management to maintain and improve system resiliency, so that either anticipated or unanticipated changes in inputs can be self-managed by the system itself, while ecological functions are maintained. This concept is especially important in the face of climate change.

Streambank protection along these rivers can easily cost over $100,00 to construct, followed by years of maintenance and replacement costs. Bank armor does not eliminate risk. Thus, the best approach to protecting homes, utilities and infrastructure from river-related impacts is to locate structures out of harm's way.

These concepts and potential approaches are discussed in the following sections.

6.4.1 Opportunities for Improving Resiliency to Future Floods

Site visits throughout the Clarks Fork River and Rock Creek drainages within the study area offered an opportunity to observe some of the flood-related damages that remain evident three years following the floods, as well as many repairs that have been completed since 2022. Immediate flood-related damage along Rock Creek primarily occurred within the town of Red Lodge, where overbank flows inundated the city and caused severe damage to residential and commercial buildings and multiple bridge crossings. Several additional public and private bridges washed out both upstream and downstream of Red Lodge, and bank erosion resulted in loss of agricultural lands and threats to highway infrastructure along U.S. Highway 212. Much of the critical infrastructure has been repaired, although not all bridges have been replaced and bank erosion continues to threaten the highway in some locations. Along the Clarks Fork River, the flood resulted in extensive highway and county road damage and bridge failures, and agricultural land loss due to bank erosion. Many river banks have been rebuilt, stabilized, or riprapped to address threats to road infrastructure, and critical bridge infrastructure has largely been addressed over the past three years.

Observations of the Clarks Fork River and Rock Creek channels, as well as their associated floodplains and riparian corridors in less developed areas indicated these features handled the 2022 floods remarkably well considering the extreme magnitude of this particular flood. Records from two USGS gages on the Clarks Fork and one gage on Rock Creek indicate 2022 was the flood of record, with the Clarks Fork experiencing a greater than 500-year event (0.2% probability) and Rock Creek experiencing a greater than 200-year event (0.5% probability). The ability of heavily flooded areas to resist more substantial geomorphic adjustments such as channel avulsions, channel re-alignments, and severe vertical and lateral bank erosion can be associated with the relatively uninterrupted connectivity between these two channels and their floodplains. This connectivity allowed for overbank flows to spread across a broad floodplain, thereby dissipating energy rather than being confined to a narrow corridor constricted by levees and other flood controlling features, which often results in accelerated riverbank erosion and bed scour.

While rapid flood recovery efforts have largely addressed critical infrastructure needs and limited the potential for severe, near-term property losses, local communities have opportunities to reduce future flood damage by improving the area's resilience to high water events. The following sections summarize flood resilience measures that may be relevant to Carbon County's residents and are aimed at reducing the potential for flood-related damages.

6.4.2 Understanding Flooding Cycles

As described in Section 2.3, a flood equivalent to the 2022 event is considered extremely rare, and had not previously occurred throughout the >100-year period of record for two gages on the Clarks Fork River at Edgar, MT and near Belfry, MT, nor the >90-year period of record for the Rock Creek gage near Red Lodge, MT. Floods greater than a 10-year event (10% chance of occurring any given year) have occurred on the Clarks Fork River at Belfry five times since 1975, but only twice at Edgar. Floods greater than a 10-year event have occurred five times on Rock Creek since 1950. These data indicate larger overbank floods have been regularly occurring over the past several decades and are likely to continue occurring in the future.

6.4.3 Maintaining Riparian Buffers

Riparian areas are important sources of livestock grazing, as one acre of riparian meadow can potentially support 10 to 15 times the stocking rate of uplands (EPA, 2015). Thinning or removing woody vegetation from riparian areas to increase arable land for hay and crop production is also a common practice. Grazing and conversion from riparian to agricultural ground has become an increasing concern due to its negative effects on stream health and flood resilience. The degradation of riparian vegetation results in a loss of streambank stability, shading/temperature, woody debris recruitment to channels for fish habitat, overhanging bank habitat, and capture of sediment from adjacent hillslopes. In particular, the reduction of bank stability due to vegetation loss can have detrimental effects during floods due to the likelihood if increased lateral erosion rates and loss of property.

Protecting and restoring riparian areas is often a foundational strategy to improve stream health and flood resilience, as robust streambank vegetation and buffers between uplands and rivers help prevent physical habitat degradation, temperature spikes, and nutrient loading. Filter strips are a type of riparian buffer that can be placed on the downgradient edge of a field, pasture, or animal confinement area. The strip helps absorb pollutant runoff from these facilities by filtering out particulate matter and absorbing nutrients while reducing erosion potential due to root masses along bank lines. Installing hardened water gaps and livestock crossings concentrates livestock access to specific locations, allowing for protection of riparian corridors from unimpeded grazing, hoof shear, and degradation.

With the exception of the reach through Red Lodge, riparian buffers remain largely intact along the entire length of Rock Creek. Short segments of the channel exhibit loss of riparian vegetation from clearing near residential homes and intense grazing. These areas are subject to accelerated erosion and often exhibit hard armor to prevent rapid lateral erosion. However, the vast majority of the Rock Creek channel exhibits dense riparian vegetation including cottonwood and willow galleries that resist erosive action during flood events.



Figure 73. Aerial photo of Rock Creek flowing through dense riparian corridor pre- and post-2022 flood. Note channel banklines remained relatively consistent despite extremely high flows due to intact riparian corridor and connectivity of channel and floodplain.

Riparian areas along the Clarks Fork River exhibit a greater degree thinning and vegetation removal due to the more developed agricultural operations along the river's length.

In many locations, the recent floods deposited fresh gravels and created new floodplain surfaces that have begun to vegetate with young cottonwoods and willows. Large scale disturbance events such as major flooding create an infrequent opportunity for woody species to colonize rapidly due to the sheer number of exposed gravel bars, which are prime locations for cottonwood establishment. These areas should be protected from

disturbance to the extent possible to encourage successful establishment of a new generation of woody species. If allowed to mature, this woody vegetation will aid in stabilizing the floodplain and resist bank erosion rates as the channel continues to migrate across its floodplain. Disturbing these fresh gravel deposits either by grazing, application of herbicides, or grading with heavy equipment may severely reduce the ability of woody species to colonize and aid in recovering long term stream and floodplain stability.



Figure 74. Segment of Clarks Fork River exhibiting reduced riparian vegetation buffer along outside (left) bend due to encroachment by agricultural production and inside (right) bend due to livestock feedlot.

6.4.4 Recommendations to Promote Healthy Riparian Corridors

In addition to the flood resiliency measures described above, the following specific practices are recommended to maintain the health and vigor of riparian areas, which in turn protect water quality, reduce erosion rates and limit land loss, and support sustainable aquatic habitats.

6.4.4.1 Riparian Management BMPs

Grazing Management Best Management Practices are intended to protect water quality and aquatic/riparian habitats by improving the health and vigor of desired plant communities, reducing erosion, and improving soil conditions. Livestock exclusions can help protect sensitive areas such as streambanks, wetlands, and riparian zones. Assistance in grazing and livestock management can be obtained through the NRCS Conservation Stewardship Program and NRCS Montana Focused Conservation. Some useful hyperlinks are provided below.

https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/#

https://www.nrcs.usda.gov/wps/portal/nrcs/mt/technical/cp/

https://www.nrcs.usda.gov/wps/portal/nrcs/mt/water/resources/nrcs144p2_057479/

Grazing management BMPs are intended promote uniform forage usage and uniform nutrient deposition. Grazing management can greatly improve plant growth while reducing soil erosion and pollutant runoff. Common approaches to grazing systems include rotation, rest-rotation, deferred rotation, short-duration grazing, and high intensity-low frequency grazing.

The Montana Rangeland Partnership has a program where ranchers work one-on-one with partnership technicians to create grazing plans that incorporate all grazing lands of the operation. More information can be found at: http://montanarangelandspartnership.org/

6.4.4.2 Corral/Pen Relocation

Moving part or all of an animal confinement structure away from streams and wetlands will reduce or prevent off-site transport of pollutants into those waterbodies.

6.4.4.3 Off-Stream Watering

Off-stream watering refers to a permanent or portable watering system for livestock or wildlife. These systems can be placed away from live waterbodies to reduce the impacts of cattle trampling and waste. There have been developments in plastics and pipes that have increased the options for watering livestock on pasture. Although electricity is often the most reliable and cheapest sources of energy to run pumps, other options include solar, wind-powered, 12-volt battery, or gas/diesel generators.

Livestock watering can provide the following benefits:

- Provides more flexibility in managing grazing systems, manure distribution and pasture utilization
- Provides a year-round supply of disease-free, freeze-proof water for livestock that is warmer in the winter and cooler in the summer
- When used in conjunction with protected heavy-use areas, they provide a solid, mud-free watering area
- Off-channel watering decreases soil erosion and helps maintain stable stream banks as well as reduces damage to irrigation ditches, preventing leakage and improving efficiency
- Improves water quality in streams while reducing incidents of injury and illness in livestock



6.4.5 Riparian Pastures

An issue faced by many landowners is the need to replace or repair fences that were installed across or along the stream corridors. The practice of installing fences to protect streams from grazing impacts is highly beneficial to water quality, bank stability, and protection of aquatic habitat; however, creating a livestock "exclosure" zone by installing fences tightly along river alignments has proven consequential when rivers rapidly migrate during flood events. An alternative to exclosure fencing that can mitigate against the effects of bank erosion on fences is the use of riparian pastures as part of a grazing management plan. Riparian pastures can be effective at protecting stream resources and water quality while not necessarily requiring fencing immediately along the creek. If managed properly, the additional benefits of riparian pastures include improved management flexibility, the ability to use livestock grazing to manage weeds and overgrown vegetation, improved access for wildlife to stream areas, and decreased costs of maintaining off-stream livestock watering facilities. Financial assistance for riparian pasture management may be available from the Montana Association of Conservation Districts' *Ranching for Rivers* program, which assists landowners develop riparian pastures to help reduce the long-term cost of lost fencing during flood events (https://montanaconservation.org/ranching-for-rivers/).

6.4.6 Prioritize Locations for Bank Stabilization

The desire to prevent further erosion and loss of land is understandable given the reliance of these areas for agricultural production. Bank erosion and lateral channel migration is a natural process by which streams maintain long term stability by being able to adjust their length and gradient to effectively transport water and sediment. Large scale stabilization and permanent bank armoring can disrupt a stream's natural processes of sediment transport and flood dissipation, and can transfer energy further downstream, thereby increasing erosion potential elsewhere. While sometimes challenging to accept, allowing a stream to migrate across its floodplain lends to the overall stability and function of the channel and its associated floodplain. This, in turn with the ability of riparian corridors to become vegetated following channel migration offers a stream and floodplain that is more resistant to damages from flooding.

While allowing streams to roam freely across their floodplains would maximize watershed health, many constraints exist within the Rock Creek and Clarks Fork drainages that demand protection from erosive forces (highways, roads, irrigation infrastructure, utilities, residences, and other infrastructure). Promoting stream corridors and floodplains that are resilient to flooding requires 1) building these types of infrastructure away from migratory stream corridors and outside of floodplains whenever possible, and 2) consideration of whether

bank stabilization and protection measures are warranted in settings where critical infrastructure is not jeopardized. While these topics can become controversial within the regulatory realm, they should be taken into consideration in order to balance pressure from development and resiliency to flooding.

6.4.7 Alternative Bank Stabilization Techniques

Both of the recommendations outlined in Section 6.4.3 (Riparian Buffers) and Section 6.4.5 (Riparian Pastures) promote practices that utilize vegetation as a natural means of reducing erosion, sediment delivery to the channel, and loss of productive lands while encouraging resiliency to future flooding. These practices, as well as the use of bio-engineered approaches to bank stabilization are highly encouraged as opposed to bank armoring with riprap, large angular rock, or other hard armor for the following reasons:

- Permanent bank armoring on a broad scale prevents a channel from lengthening, reducing slope, and the ability to dissipate energy. As a result, erosive energy is transferred further downstream and increases the likelihood of increased erosion elsewhere.
- Allowing for channel movement through bank erosion and sediment deposition promotes riparian forest regeneration by creating open bar areas available for woody riparian seedling colonization. Hardening banklines with armor disconnects the river from its floodplain, and severely limits riparian vegetation regeneration.
- Channel movements through bank erosion and sediment deposition promote instream habitat creation by recruiting woody debris and spawning gravels.
- Hard bank treatments can be expensive and more difficult to gain regulatory approvals, and often require ongoing repairs and maintenance.

It should be noted that bank erosion is a naturally occurring process in alluvial rivers and streams as they migrate across their floodplains (Figure 75). Lateral erosion is a symptom of rivers and streams that are lengthening to reduce gradient and better dissipate energy during high flows. In order to remain stable over the long term, rivers and streams behave in a state of “dynamic equilibrium”, meaning short reaches of the channel will lengthen or shorten to maintain an overall gradient that can effectively convey sediment. Erosion can be beneficial, in that it results in supplying channels a source of gravel, cobble, and wood that in turn develop complex habitats for fish and other aquatic organisms. Preventing a river from naturally migrating across its floodplain by artificially stabilizing banks reduces the long-term ability of that river to dissipate energy and access its floodplain. This, in turn, may result in increased energy and higher rates of erosion elsewhere within the drainage.

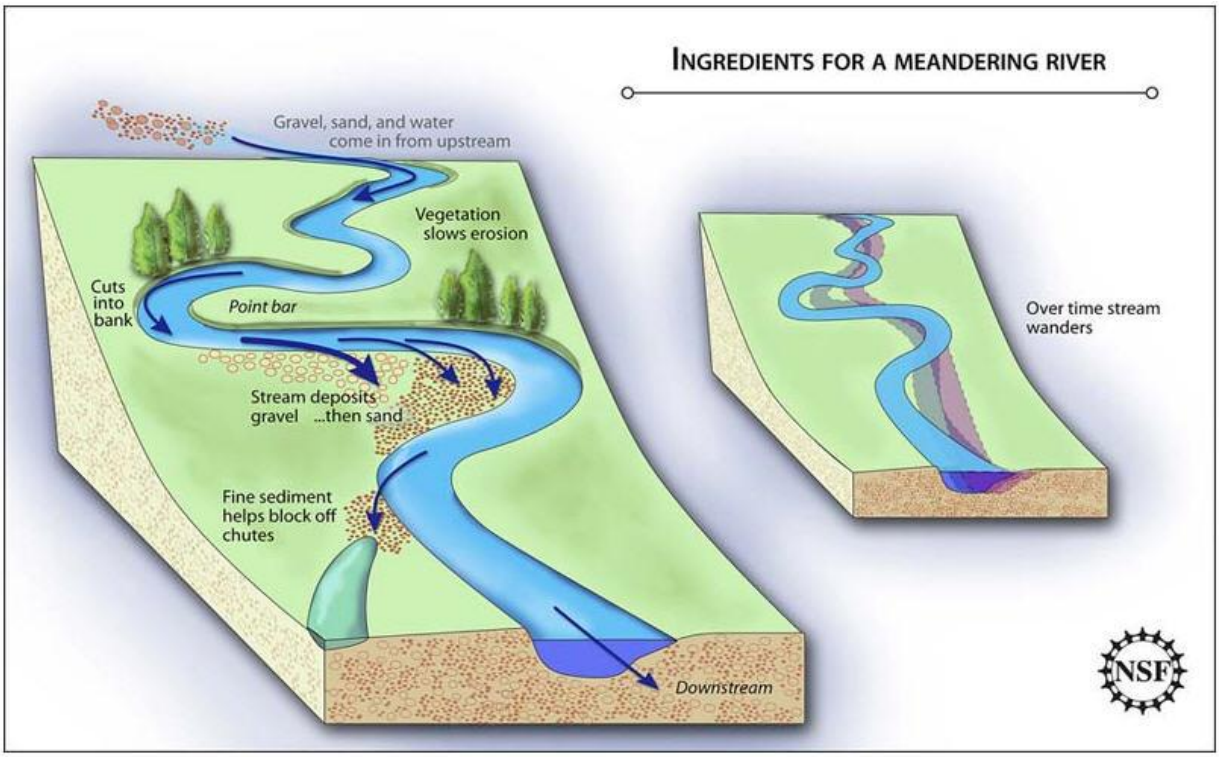


Figure 75. Schematic of natural erosion and deposition processes occurring along rivers.

Erosion can also be problematic, particularly when bank loss jeopardizes homes, barns, utility poles, bridges, roads, cropland, and other infrastructure. Addressing eroding banks in these areas can be accomplished using a variety of approaches depending on the erosion severity and required longevity of a stable bank configuration. Bank stabilization designs range from hardened banks (i.e. rock riprap), to softer techniques which utilize natural materials such as tree roots, willows, cobble, and sod mats. The following section describes a variety of bank stabilization techniques that may be applicable to landowners in Carbon County.

6.4.7.1 Bio-Engineered Approaches to Bank Stabilization

Bio-engineered banks utilize a combination of natural materials such as conifer fascines, root wads, willow cuttings, and sod mats to reduce erosion rates. When placed properly, these materials can be effective at reducing erosion without the need to install permanent armor. Examples of bioengineered bank stabilization techniques are provided in the illustrations below.

6.4.7.2 Construct Gravel Bench and Cap with Willow Transplants and Sod Mats

This technique is a simple, yet often effective technique of addressing bank erosion by constructing a gravel bench along the eroding bank, then transplanting mature woody shrubs and wetland sod mats along the gravel bench. This technique is illustrated in Figure 76, with project examples provided in Figure 77 and Figure 78.

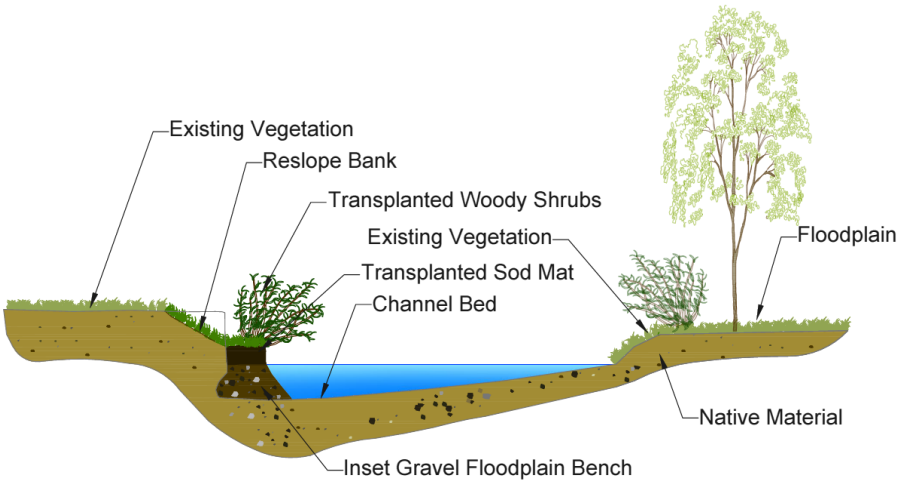


Figure 76. Bio-engineered bank stabilization technique using gravel bench and transplanted willows / sod mats.



Figure 77. Eroding bank prior to installation of gravel bench and willow / sod transplants.



Figure 78. Eroding bank being addressed with gravel bench and willow / sod mat transplants.

6.4.7.3 Layered Brush Mattresses

This technique involves installing brush mattresses to increase roughness and reduce erosion rates. Mature willows or other woody shrubs are transplanted along the bank and layered both horizontally and vertically to create a dense mattress of woody materials. Voids between the mattress layers are filled with native gravels to solidify the bank. This technique can also be built in combination with a toe wood treatment (described in next section).

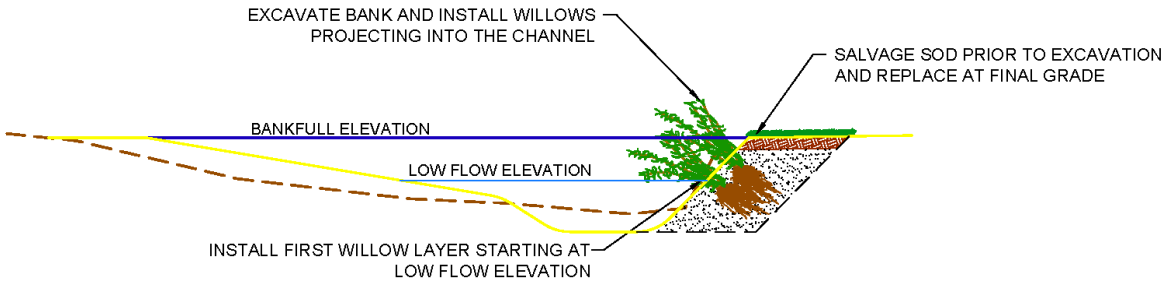




Figure 79. Photo of brush mattresses installed on an outside bend to reduce bank erosion.

6.4.7.4 Toe Wood and Conifer Fascines

Additional bank protection can be provided with native materials including toe wood and fascines. These materials can be positioned along banks to help deflect water or prevent banks from becoming undermined and soughing. Toe wood material such as root wads and tree trunks can be collected from live or recently fallen trees, often available on floodplains with recent deposits. Root wads are placed with the trunk of the tree anchored into the bank and root ball facing toward the river. Fascines are constructed by tightly wrapping tree or shrub stems together to create a log-type feature. Fascines can also be constructed of small juniper trees by wrapping the limbs against the trunk.

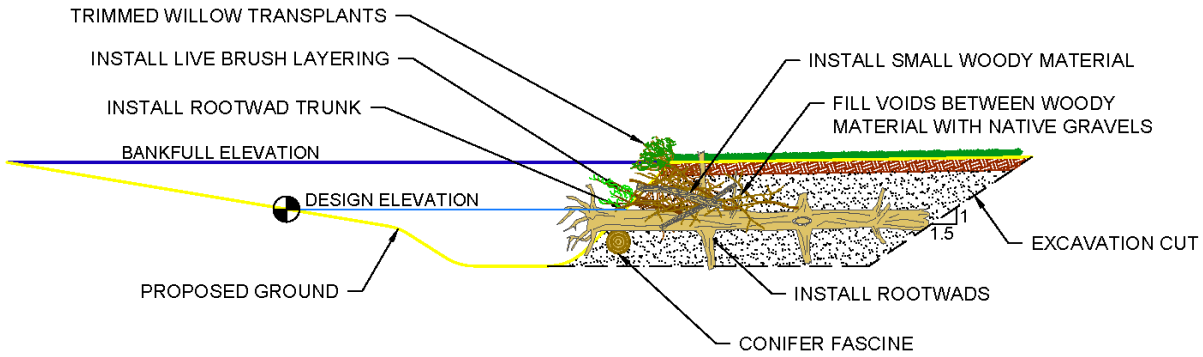




Figure 80. Bank stabilization project using combination of root wads and conifer fascines.



Figure 81. Second layer of conifer fascines placed on top of root wads.



Figure 82. Stabilized bank capped with coir fabric soil lift.

6.4.7.5 Coir Encapsulated Soil Lifts

This technique involves reconstructing the eroding bank with a gravel / cobble toe and building one or more coir fabric-encapsulated soil lifts (Figure 83). Willow stems are typically installed beneath the lifts, which eventually grow into larger shrubs. The fabric provides temporary stability for 3-5 years while vegetation establishes and protects the bank naturally. Mature willows or other shrubs can be installed along the bank as well to provide additional root mass.



Figure 83. Example of coir fabric-encapsulated soil lift placed to stabilize eroding terrace.



Figure 84. Bank constructed with multiple soil lifts and willow cuttings.

6.4.7.6 Use of Willow Cuttings in Bank Stabilization

The use of willow cuttings in bank stabilization treatments can be a cost-effective means of establishing woody vegetation. Often, woody cuttings are installed densely (i.e. 3 cuttings per linear foot) along bank stabilization treatments to account for mortality and competition. To maximize survival of woody cuttings in bank treatments, the following approaches are recommended:

- **Species**
  - Cuttings should consist of local species (typically willow) harvested from live, healthy plants. Alders are not recommended for cuttings due to low propagation rates.
  - Sources of cuttings should be within +/- 1,000 feet in elevation from the planting site.
- **Size / Dimensions**
  - Cuttings should range between 3 and 5 feet long.
  - Stem should range between 0.5 and 1.5 inches in diameter.
- **Collection Timeframe**
  - Cuttings should be collected during dormancy, which extends from leaf off (typically October/November) to bud swell (typically late March / early April).
  - Unless cuttings will be cold-stored, they should be collected no more than 14 days before installation.
- **Installation**
  - Cuttings should be soaked in water for up to 10 days prior to installation.
  - To discourage desiccation, cuttings should be installed with the base of the stem below the low water surface elevation
  - Stem tips should extend between 2” and 6” from soil to encourage root growth. Stem tips that extend further than 6” from bank should be trimmed.
  - Cuttings should be installed in good contact with fine-grained soils that offer a rooting medium. Cutting installed in coarse materials such as riprap or cobbles are likely to perish.
- **Maintenance**
  - New stem / leaf growth should be trimmed following first growing season to encourage root growth.



Figure 85. Installation of willow cuttings to bank stabilization project.

6.4.7.7 Combination of Bio-Engineering and Rock Toe

If additional bank protection measures are warranted to more permanently protect banks from lateral migration, a rock toe may be installed beneath native materials. The following techniques utilize a rock toe while utilizing softer materials for the upper bank.

6.4.7.8 Rock Toe with Vegetated Soil Lifts

This technique involves installing a layer of rock along the base (toe) of the eroding bank and constructing vegetated fabric lifts above the rock. The rock toe prevents the bank from scour and undercutting, while the vegetated lifts provide a more naturally functioning bank. The vegetated portion of the bank typically includes placing willow stems (rooted nursery stock or cuttings harvested locally), sod mats, and native seed within the coir-wrapped banks. The coir provides a temporary means of stabilizing the upper bank while the vegetation establishes over time, which typically takes 3-5 years. The coir fabric eventually biodegrades, leaving the vegetation to maintain bank integrity for the long term. This technique is illustrated in Figure 86 with a typical cross section view shown in Figure 87.



Figure 86. Example of rock toe with vegetated soil lifts installed on the Jefferson River.

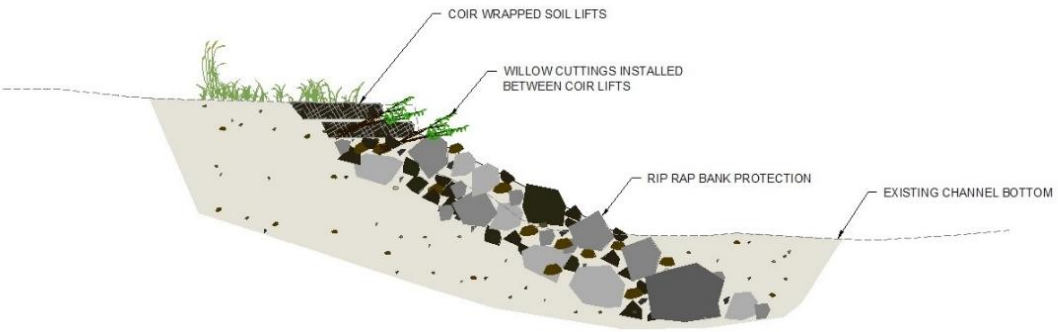


Figure 87. Typical cross section of rock toe and vegetated soil lifts

6.4.7.9 Combination of Rock / Wood Toe Treatment

This technique involves installation of both rock and root wads along the toe of the eroding bank (Figure 88 and Figure 89). The combination of these materials offers stability and habitat complexity during a variety of discharges. Root wads are typically cottonwood or coniferous trees that have been harvested from nearby sources and installed with the root ball extending outward from the bank. Trees and root wads may be installed at a variety of elevations to provide roughness and habitat at variable flows. The use of larger rock along the toe of the bank qualifies as permanent armor and may be subject to mitigation requirements. A modification to this approach would include eliminating the rock and installing continuous layers of woody debris and brush along the bank toe.



Figure 88. Example of rock / root wad bank stabilization.

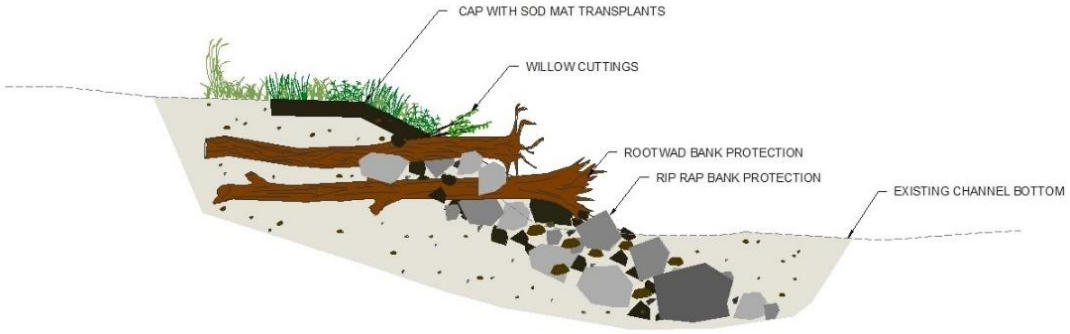


Figure 89. Typical cross section of rock and toe wood stabilization concept.

6.4.8 Hard Bank Protection Treatments

6.4.8.1 Rock Barb Structures as Flow Deflectors

This technique involves constructing one or a series of barbs to deflect water away from the eroding banks. Barbs are typically constructed with rock, anchored into the eroding bank, and angled upstream to reduce the energy of the river against the bank. Barbs may be placed in sequence and spaced appropriately to maintain stability along a meander. Example photos of a rock barb installed along the Jefferson River are shown in Figure 91; an aerial view of barbs on the San Miguel River in Colorado is shown in Figure 91. The actual number, location of and spacing between barbs requires a survey and determination of the geometry of the eroding bank. This technique is considered permanent bank stabilization and may be subject to mitigation as part of the permitting requirements.

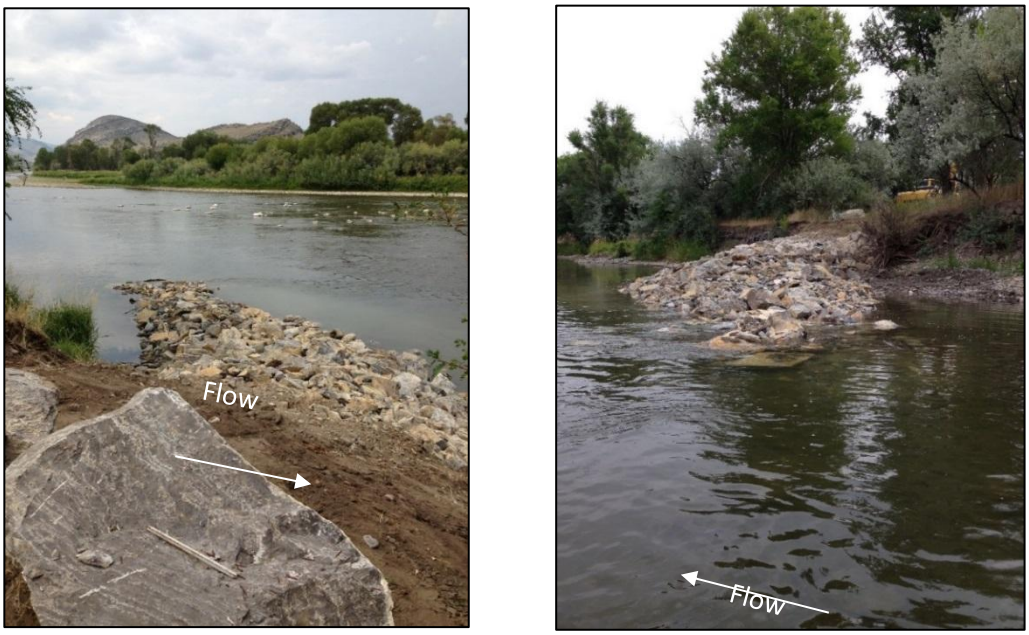


Figure 90. Rock barbs placed on Jefferson River.



Figure 91. Rock barbs placed on San Miguel River CO.

6.4.8.2 Vegetated Riprap

Riprap has been a commonly used approach to stabilize eroding banks, which involves installing rock along the bank and keying into the bed of the channel to prevent further scour and bank loss. The use of riprap is typically limited to locations that need to be permanently protected from channel migration, such as immediately upstream and downstream of bridge abutments, along highways, and adjacent to utility lines. The use of rock alone has fallen out of favor with many permitting agencies due to the associated loss of vegetation, cover, shade and aquatic habitats provided by naturally formed banks. Vegetation can be incorporated into a riprap bank design to allow for some re-establishment of woody vegetation, cover, and shade along the stabilized bank. An example of this technique is shown in Figure 92.



Figure 92. Example of vegetated riprap.

Benefits (pros)	Concerns (cons)	Costs
Gravel Bench with Sod Mats and Willow Transplants		
Inexpensive if nearby sod and willow materials are available	Less resistant to erosion than other bioengineering and hard bank treatments	$50 - $75 per linear foot
Does not require mitigation		
Uses native materials to reduce erosion rate		
Natural appearance		
Brush Mattress		
Inexpensive if nearby sod and willow materials are available	Less resistant to erosion than other bioengineering and hard bank treatments	$50 - $55 per linear foot
Does not require mitigation		
Uses native materials to reduce erosion rate		
Natural appearance		
Toe Wood with Conifer Fascines		
Uses native materials to reduce erosion rate	Toe wood does not appear as natural	$175 - $225 per linear foot*
Typically does not require mitigation	Costs can vary based on proximity to root wad sources	
More resistant to erosion than brush mattresses and sod mats		
Fabric Soil Lifts		
Provides temporary stability while vegetation establishes	Temporarily unattractive while fabric is in place	$80/foot for 1 layer* $120/foot for 2 layers* $150/foot for 3 layers* 1 layer = ~1' bank height
Natural looking bank following degradation of fabric	Less resistant to erosion than harder treatments	
Uses native materials to reduce erosion		
Does not require mitigation if no rock toe is installed		

*Cost/foot may be reduced if volunteer labor is used for willow harvesting and fabric lift installation.

Benefits (pros)	Concerns (cons)	Costs
Rock Barbs as Flow Deflectors		
Effective at stabilizing erosion along arcing river bends	Unattractive	$175/foot for treatment $60 per foot for mitigation if >300 feet
Can create deep pool habitat for fish	Not effective in straight river segments	
Less costly than rock toe treatments	May become ineffective if river adjusts its alignment upstream	
Rock Toe with Vegetated Soil Lifts		
Effective at straight river segments where flow vectors vary during floods	Requires continuous layer of rock along entire bank	$300 per foot for treatment* $60 per foot for mitigation if >300 feet*
More natural appearing and attractive than rock barbs or root wads	May become ineffective if river adjusts its alignment upstream and gets "behind" the treatment.	
	High cost	
Rock Toe with Root Wads		
Effective at stabilizing erosion along meander bends and straighter segments	Unnatural appearance of root wads extending outward from bank	$375 per foot for double layer of root wads $60 per foot for mitigation if >300 feet
Provides aquatic habitat at a variety of flows	Can be challenging to obtain large trees with root balls	
	High cost	

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Appendix A: Locations of Concern for Channel Migration

The sites below details locations along Rock Creek and the Clarks Fork that show some risk for lateral channel migration or avulsion. Flood risk is not included in this assessment. Many were chosen because the issues at the site present a higher risk of damage to important infrastructure – irrigation diversions, transportation, ranch operations, bridges, etc. A location, Type of Concern and Notes are included for each site. Table 5 and Table 6 in the report provide additional details for those site deemed "High" priority for assessment and potential future projects. High priority indicates that historic and flood-related channel migration at the site is such that there is a noted elevated risk to infrastructure due to channel migration or avulsion. Medium priority indicates that there is some risk posed by future channel migration or avulsion. And a Low priority indicates that there may be challenges to the site, there is no immediate risk due to channel migration or avulsion. Many of the sites along the Clarks Fork were noted in Warren Kellogg's 2019 report, in which case the Priority noted in that report is included.

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	1.9	Bank Stabilization		Medium	Numerous sections of flanked bank protection resulting in increased erosion. No current threats to infrastructure, but continued loss of floodplain grazing is likely.	Medium	5.38	Kellogg
Clarks Fork	3.5	Bank Erosion		High	Rapid bendway development. 120+ ft recent erosion.			CMZ
Clarks Fork	4.4	Bank Stabilization		Medium	Most of the bendway is holding, but some short term erosion at lower end.	Medium	5.32	Kellogg
Clarks Fork	4.9	Bridge	Byam Road	Medium	Extremely dynamic environment with migration and likely ice influences. Investigate options to protect Byam Rd bridge and adjacent farms.	High	5.31	Kellogg
Clarks Fork	5.2	Bank Stabilization		Low	Little current risk at this site. A point bar is building in front of the farmstead. But increased right bank erosion downstream.	Low	5.3	Kellogg
Clarks Fork	5.3	Bank Erosion		High	Very unstable bendway with nearly 180' of short-term migration. Threat of ag operations in the short term and degrading alignment under Byam Rd in the long term.	Medium	5.29	Kellogg
Clarks Fork	6.5	Bank Stabilization		High	Very unstable bendway with nearly 150' of short-term migration.	Medium	5.27	Kellogg
Clarks Fork	6.8	Bank Erosion		High	Rapid (100+ ft) bank erosion into fields.			CMZ
Clarks Fork	6.9	Bank Stabilization		High	Short section of bank stabilization/jetty. Below the bendway is actively migrating with ~100 ft of short-term migration.	Medium	5.26	Kellogg
Clarks Fork	7.2	Bank Erosion		High	Failed jetties with increased bank erosion into irrigated fields.			CMZ

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	7.7	Bank Erosion		Medium	~50' of recent erosion. Potential to flank downstream bank protection.			CMZ
Clarks Fork	8	Development	Evergreen Subdivision	Medium	Small tracts within the CMZ.	Medium	5.2	Kellogg
Clarks Fork	9	Bank Erosion		High	Rapid erosion (180+ ft) into fields. No woody vegetation.			CMZ
Clarks Fork	10.3	Bank Erosion		High	1970s-80s river avulsed into the smaller eastern channel. Lots of channel migration since (~190 ft). Migration is towards active agricultural operations.	High	5.16	Kellogg
Clarks Fork	11.7	Bank Stabilization		Medium	This bankline is actively migrating. 60+ ft of recent erosion flanking riprap and moving towards an irrigated field.	Medium	5.14	Kellogg
Clarks Fork	12	Bank Erosion		Low	2018 failed bendway weirs. No recent migration. Rock staged in piles on bankline.	Medium	5.13	Kellogg
Clarks Fork	12.5	Irrigation	Danford Ditch	Low	Older irrigation diversion. Looks like it may have had some work done?	High	5.1	Kellogg
Clarks Fork	12.9	Bridge		High	West bridge abutment showed undermining in Kellog study.	Medium	5.8	Kellogg
Clarks Fork	13.9	Meander Reactivation		Low	Would be challenging to reactivate this oxbow.	High	5.5	Kellogg
Clarks Fork	14.3	Bank Erosion		Medium	30+ ft of recent erosion into irrigated field. Mid-channel island developing.			CMZ
Clarks Fork	14.7	Bank Stabilization		Medium	Stable, but some recent movement on the upstream end showing regaining channel length. Remove car bodies per Kellogg study.	Medium	5.3	Kellogg
Clarks Fork	15.1	Irrigation	Glenwood Ditch	Medium	Diversion evaluation, install headgate? Convert to pumps?	High	5.1	Kellogg
Clarks Fork	16.4	Bank Erosion		High	120+ ft of recent erosion into grazing fields. Rapid development of bendway. Continued erosion potential extremely high.			CMZ
Clarks Fork	17.9	Bank Erosion		Medium	Extensive recent migration into grazing fields. No riparian vegetation. Below diversion.			CMZ
Clarks Fork	18.1	Irrigation	White Horse Canal	High	Diversion study looking at headgate/diversion replacement and fish passage.	High	4.17	Kellogg
Clarks Fork	19	Misc.		Low	Trash Dump. Debris is likely still there. No recent channel movement.	High	4.15	Kellogg
Clarks Fork	19.7	Bank Erosion		Low	Point bar growth and bendway extension into mature forest and old channel location.			CMZ
Clarks Fork	20	Bank Erosion	BNSF Railroad	Medium	50+ ft of recent erosion below bank protection. Towards RR track.			CMZ

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	20.8	Bank Stabilization		Low	Bendway is stable.	High	4.8	Kellogg
Clarks Fork	21	Bank Stabilization		Low	Bendway remains stable. Some short-term migration at lower end of bendway.	Low	4.7	Kellogg
Clarks Fork	21.2	Bank Erosion		Medium	Recent erosion into bendway core. Likely future avulsion site.			CMZ
Clarks Fork	22.6	Bank Stabilization		High	Likely site of an upcoming bendway avulsion. Neck is very narrow now.	Medium	3.27	Kellogg
Clarks Fork	22.6	Bank Stabilization		Low	No recent migration	Low	3.28	Kellogg
Clarks Fork	23.3	Bank Erosion		Medium	Newer rock appears to be stable and held up during the flood.	Low	3.24	Kellogg
Clarks Fork	23.4	Bank Erosion		High	Flanked riprap into irrigated field.			CMZ
Clarks Fork	23.7	Bank Stabilization		Medium	Some of the metal debris noted by Kellogg (2019) may have failed during the flood. ~40 ft of short-term erosion.	Medium	3.23	Kellogg
Clarks Fork	23.8	Bank Stabilization		Low	May have some newer rock protecting the farm road.	Low	3.22	Kellogg
Clarks Fork	24.4	Bank Stabilization		Low	Little short- or long-term channel migration.	Medium	3.21	Kellogg
Clarks Fork	24.7	Bank Stabilization		Low	Jetties are quite stable.	Medium	3.2	Kellogg
Clarks Fork	25	Bank Stabilization		Low	Stable bankline.	Low	3.18	Kellogg
Clarks Fork	26	Bank Stabilization		High	Upstream bendway is a concern but does not show any short-term movement from the flood.	High	3.16	Kellogg
Clarks Fork	27	Bank Erosion		Medium	50+ ft recent erosion into field.			CMZ
Clarks Fork	27.3	Bank Erosion		High	Increased recent erosion below bank protection. Future avulsion.			CMZ
Clarks Fork	28	Bank Stabilization	BNSF Railroad	Low	Lower end is an avulsion risk, though it did not happen during the flood. Little flood-related migration of lower bendway.	Medium	3.12	Kellogg
Clarks Fork	29	Bank Erosion		Medium	Lots of increased erosion throughout this area.			CMZ
Clarks Fork	29.2	Bank Stabilization		Medium	May have had some recent repairs. Upstream end may have moved toward the road.	Medium	3.9	Kellogg

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	29.5	Bank Stabilization		Medium	Bendway is stable except for some new erosion at lower end as the bendway translates downstream.	Medium	3.8	Kellogg
Clarks Fork	30.1	Misc.	Corrals	Low	Assessment of feed lot/corrals adjacent to the river for NPS pollution.	High	3.7	Kellogg
Clarks Fork	30.2	Bank Erosion		High	60+ ft erosion into agricultural operations.			CMZ
Clarks Fork	30.3	Bank Erosion		Medium	75+ ft of erosion into pivot.			CMZ
Clarks Fork	30.5	Bank Stabilization		Medium	10-foot-high terrace, an old combine, other metal debris, and rock have been dumped off the bank to serve as a jetty. A farm road and irrigated field are located on the edge of the terrace. Very little erosion has occurred over the last 20 years	Medium	3.5	Kellogg
Clarks Fork	30.7	Bank Stabilization		High	Bankline appears to have some new migration at the upstream end towards the BNSF rail line. Section along ranch buildings is stable.	Low	3.4	Kellogg
Clarks Fork	31	Bank Stabilization		Low	Bendway appears to be stable with no short-term migration.	Low	3.3	Kellogg
Clarks Fork	31.7	Bank Erosion	Fromberg	Low	Bendway has a full bank treatment post-flood.	High	2.34	Kellogg
Clarks Fork	32	Bank Stabilization		High	Point bar is rapidly developing. Erosion into Kellog "gauge" continues and threatens building.	Medium	2.32	Kellogg
Clarks Fork	32.3	Bank Stabilization		Medium	No short-term migration. Site seems stable. Might have some newer rock on the lower end.	High	2.31	Kellogg
Clarks Fork	32.7	Bank Erosion		High	Accelerated erosion into ag field.			CMZ
Clarks Fork	32.8	Bank Stabilization	BNSF Railroad	Low	Existing bank protection appears to be stable. Some newer erosion downstream, but into ag field and not the RR tracks.	Medium	2.3	Kellogg
Clarks Fork	33	Bank Stabilization		Medium	Old dirty bank stabilization is relatively stable. But could be cleaned up and revised.	Medium	2.29	Kellogg
Clarks Fork	33.7	Bank Stabilization		Medium	30-60 ft of short-term migration indicates the existing riprap likely failed during the flood. Good riparian corridor.	Medium	2.27	Kellogg
Clarks Fork	33.9	Bank Stabilization		Low	Bankline is stable. Issue is with possible nutrients from the feedlot located inland.	High	2.25	Kellogg
Clarks Fork	34.6	Bank Stabilization	BNSF Railroad	Low	Bankline appears stable post-flood. Perhaps some new scouring at lower end.	Medium	2.24	Kellogg
Clarks Fork	34.9	Bank Erosion		Low	Little apparent short-term flood related erosion at the site.	Low	2.23	Kellogg

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	35.7	Bank Erosion		High	Over 100' of flood related erosion and overland flow through corrals. Scour of inside bendway.			CMZ
Clarks Fork	36.9	Bank Stabilization		Medium	Some continued degradation of the jetties, but little flood-related impacts.	Medium	2.14	Kellogg
Clarks Fork	37.3	Bank Stabilization		Medium	Scour at upper end of site between jetties. And below the jetties at the lower end of the site. Relatively stable with no noted short-term migration.	Medium	2.12	Kellogg
Clarks Fork	37.5	Bank Erosion		Medium	Some recent (~50') erosion towards irrigated fields.			CMZ
Clarks Fork	38.5	Bank Stabilization		Medium	Jetties still exist but may have had some flood damage. No channel migration at site, so they are effective.	Medium	2.1	Kellogg
Clarks Fork	39.6	Bank Stabilization		Low	Little to no channel migration except at the lower end of the bendway.	High	2.4	Kellogg
Clarks Fork	39.8	Bank Erosion		Medium	Recent migration ~90ft into ag field.			CMZ
Clarks Fork	40.2	Bank Erosion		Medium	No evidence of any remaining jetties from Kellog report. 80+ ft migration, mostly during and post flood. No woody veg.	High	2.2	Kellogg
Clarks Fork	41.7	Critical Infrastructure	Bridger Water Tx	Medium	Slow migration towards Tx facility just upstream of bridge.			CMZ
Clarks Fork	42.3	Bank Erosion	Rail Grade	Medium	Low in Kellog study, but bank is against rail grade now. ~50 ft migration. Lower end will likely continue to erode (Kellog site 1.13).	Low	1.12	Kellogg
Clarks Fork	42.3	Bank Stabilization		Medium	75 ft migration. Concrete rubble is likely in the channel and washed downstream.	Medium	1.13	Kellogg
Clarks Fork	43.5	Irrigation	Orchard Canal Diversion	High	Key irrigation diversion on an avulsed channel. Extensive efforts to keep water delivered to the diversion.	High	1.9	Kellogg
Clarks Fork	44.3	Bank Erosion		Low	Lots of old metal debris and car bodies. Little to no channel migration	High	1.6	Kellogg
Clarks Fork	45.1	Bank Erosion		High	Localized scour pocket, 191 ft migration.	Medium	1.2	Kellogg
Clarks Fork	48.4	Bank Erosion		Medium	Recent erosion towards small ditch and grazing fields.			CMZ
Clarks Fork	52.2	Irrigation		Medium	Large, full-river dam for irrigation diversion. Fish passage?			CMZ
Clarks Fork	54.5	Irrigation		Medium	Large, full-river dam for irrigation diversion. Fish passage?			CMZ

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Clarks Fork	56.7	Irrigation		Medium	Annual maintenance on in-channel gravel berms for feeding the canal.			CMZ
Clarks Fork	57.3	Irrigation		Medium	Annual maintenance on in-channel gravel berms for feeding the canal.			CMZ
Clarks Fork	58.7	Bank Erosion		Medium	Recent erosion of left bank towards small irrigation ditch			CMZ
Clarks Fork	59.6	Bank Erosion	Lovers Lane	High	Recent erosion towards road where bank protection ends.			CMZ
Clarks Fork	60.6	Bank Erosion	Hwy 72	High	Recent short-term erosion towards roadway.			CMZ
Clarks Fork	61	Irrigation		Medium	Challenging in-channel diversion to feed irrigation ditch on inside of bendway.			CMZ
Clarks Fork	64.7	Irrigation		Medium	Long-term erosion towards downstream side of syphon (left bank).			CMZ
Clarks Fork	67.8	Irrigation		Medium	Long side channel parallel to river right maintained for irrigation diversion.			CMZ
Clarks Fork	69	Irrigation		Medium	Large full-channel dam for irrigation diversion. Fish passage?			CMZ
Clarks Fork	69.4	Bridge	Chance Road	Medium	Scour pockets on right bank upstream of bridge.			CMZ
Clarks Fork	69.9	Irrigation		Medium	Large in-channel gravel diversion.			CMZ
Rock Creek	0.8	Bridge		High	Channel doglegs int RR bridge. Could continue to degrade and flank existing bank protections.			CMZ
Rock Creek	7.4	Irrigation		Medium	Current primary channel could be abandoned in favor of the secondary channel to the east.			CMZ
Rock Creek	7.9	Irrigation		Medium	In-channel berm to divert flows into secondary channel to feed the ditch.			CMZ
Rock Creek	9	Critical Infrastructure	Joliet Wastewater Tx	Medium	Bendway adjacent to the water treatment ponds has migrated 350 ft. The bendway will likely translate downstream and be captured by existing swale. Keep an eye on it.			CMZ
Rock Creek	11.3	Bank Erosion		Low	Failed bank protection along Hwy 212 has been repaired.			CMZ
Rock Creek	14.8	Bridge		Low	Agricultural bridge is a choke point on the river. Right bank upstream has a significant scour hole between rock riprap that could flank the bridge.			CMZ

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Rock Creek	17.6	Bank Erosion		Low	Left bank erosion (50+ ft recent) in the direction of a home. Still ~150 ft to go.			CMZ
Rock Creek	23.9	Bridge	Hwy 212	Medium	Right bank erosion (55+ ft recent) upstream of the bridge has potential to flank the bank protection on the right approach.			CMZ
Rock Creek	24.9	Bank Erosion		High	Left bank erosion on a tight bendway has potential to flank the existing bank protection and threatened a driveway.			CMZ
Rock Creek	25.4	Misc.		Low	Area was scoured clean by the flood. Appears to be recovering somewhat.			CMZ
Rock Creek	26.8	Bank Erosion		Medium	Erosion of the left bank into floodplain grazing field. May have some existing bank protection.			CMZ
Rock Creek	27.4	Development	Moose Tracks Subdivision	High	Loss of bridges and development in the floodplain and active river corridor.			CMZ
Rock Creek	29.8	Bank Erosion	Water Birch FAS	Low	Bank erosion has taken out the upper end of the FAS. Site of current FWP project.			CMZ
Rock Creek	31.5	Bank Erosion		Medium	Left bank erosion (85+ ft recent) into field. Will likely continue and may impact outbuildings.			CMZ
Rock Creek	31.7	Irrigation		Low	The diversion on left bank likely requires in channel diversions 0.3 mi upstream to keep water in the secondary channel.			CMZ
Rock Creek	32.6	Bridge	Fox East Bench Road	Medium	Awkward riprap on right bridge approach has an actively flowing avulsion risk channel behind it.			CMZ
Rock Creek	33.6	Avulsion Risk		Medium	A secondary channel on the left floodplain through open fields has strong likelihood of becoming the primary channel.			CMZ
Rock Creek	34.1	Development	Dream Catcher Lane	Low	Channel migration into left bank and a structure right on the bankline. Looks like some recent bank stabilization work.			CMZ
Rock Creek	35.7	Development		Medium	Secondary channel is up against the right floodplain margin. No buffer to a couple of homes.			CMZ
Rock Creek	36.9	Development	Kent Lane	Medium	Small lots and homes at the edge of the cottonwood corridor.			CMZ
Rock Creek	37.8	Bridge	Two Mile Bridge	Low	Left bridge approach is threatened. Degraded alignment. Work Complete.			CMZ
Rock Creek	38	Bank Erosion		Medium	Left bank erosion at edge of cottonwood gallery.			CMZ
Rock Creek	38	Development		Low	Homes in the floodplain and avulsion risk area.			CMZ
Rock Creek	38.6	Bank Erosion		Medium	Some recent erosion on left bank towards channel plug in an avulsion risk channel.			CMZ

River	RM	Type	Name	Priority	Notes	Kellogg Priority	Kellogg Site ID	Source
Rock Creek	39.4	Bank Erosion	Highschool Stadium	Low	50+ ft of erosion into left bank. Project work complete.			CMZ
Rock Creek	39.7	Bank Erosion		Low	Right bank erosion into tailings. Project Work Complete.			CMZ
Rock Creek	39.8	Bank Erosion	9th Street	Low	Left bank at 9th street. Project work complete.			CMZ
Rock Creek	40.9	Bridge	Red Lodge	High	Channel constriction entering Red Lodge and under Hwy 308 bridge.			CMZ
Rock Creek	41.3	Bank Erosion		Low	Bendway migrating and growing on right bank. Potential avulsion risk.			CMZ
Rock Creek	42.6	Bank Erosion		Medium	46' of recent erosion into floodplain swale/overflow channel.			CMZ
Rock Creek	43.8	Bank Erosion		Low	30+ ft flood erosion. Bank project complete.			CMZ

Appendix B: 11x17 CMZ Maps (in a Separate Document)