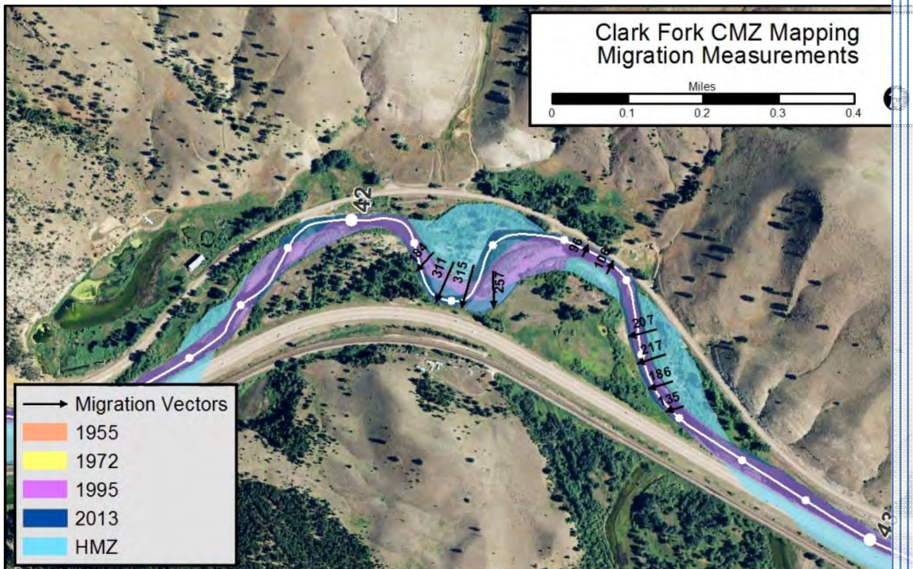

Final Report

January 8, 2016

Clark Fork River
Channel Migration Zone Mapping
Drummond to Milltown

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Executive Summary

This report presents the results of a Channel Migration Zone (CMZ) mapping effort on the Clark Fork River between Drummond and Milltown, Montana. The results indicate that although the river is locally dynamic and able to migrate across its floodplain, it is largely confined and altered by land uses in the valley bottom.

The Channel Migration Zone includes the 2013 channel boundaries, the mapped footprint of channel locations since 1955 (Historic Migration Zone), an erosion buffer to accommodate future channel migration (Erosion Hazard Area), and floodplain areas that have meander cores prone to cutoff or relic side channels that may be prone to reactivation (Avulsion Hazard Zone). The total area comprising the Historic Migration Zone and Erosion Hazard Area is 3,720 acres. This footprint reflects the post-1955 CMZ. About 1,120 acres or 30 percent of this area has been restricted by transportation encroachments and bank armor.

Transportation infrastructure has imparted the largest impact to the CMZ in the project reach, with these impacts starting well before 1955. Construction of the Northern Pacific Railroad in 1883 included channel straightening and relocation. In several areas this original rail line bisects the historic floodplain of the river, and it continues to encroach into the stream corridor. In 1908 and 1909, the Milwaukee Line was similarly constructed. This line has been abandoned, although in places it serves as an access road. About 10 years after the Milwaukee Line was built, US Highway 10 was built through the canyon. This was eventually replaced by Interstate 90 sometime around the late 1960s, although the old highway is still present in most areas and serves as a frontage road. The collective footprint of these transportation corridors has restricted 23 percent of the CMZ from river access. The early relocations displaced the river over almost 1,000 acres to its current course, and some of those historic channel corridor areas are not within the post-1955 CMZ.

Bank armor has been constructed to prevent erosion into transportation corridor as well as other land uses in the project reach. Bank inventory data indicate that as of 2013 there were about 21.4 miles of bank armor in the reach which has arrested bank movement on 21 percent of the bankline. The largest non-transportation related armor is protecting agricultural lands. The bank armor not associated with transportation elements restricts an additional 7 percent of the CMZ from the river.

Although the Channel Migration Zone has been highly impacted by human development, there are areas where the channel remains dynamic and geomorphically diverse. Additionally, there are areas where the abandoned rail line has become somewhat decrepit, and its removal would restore substantial acreage to the CMZ footprint.

1 Introduction

This report describes the development of a 100-year Channel Migration Zone (CMZ) map for the portion of the Clark Fork River that extends from just south of Drummond, Montana to its confluence with the Blackfoot River at Bonner, a distance of 53 river miles (Figure 1-1). The purpose of this write-up is to summarize the project methodology and provide some interpretation regarding river process, management challenges, and restoration opportunities. Although the mapping results are described in this report, the complete CMZ map is provided as a separate PDF document.

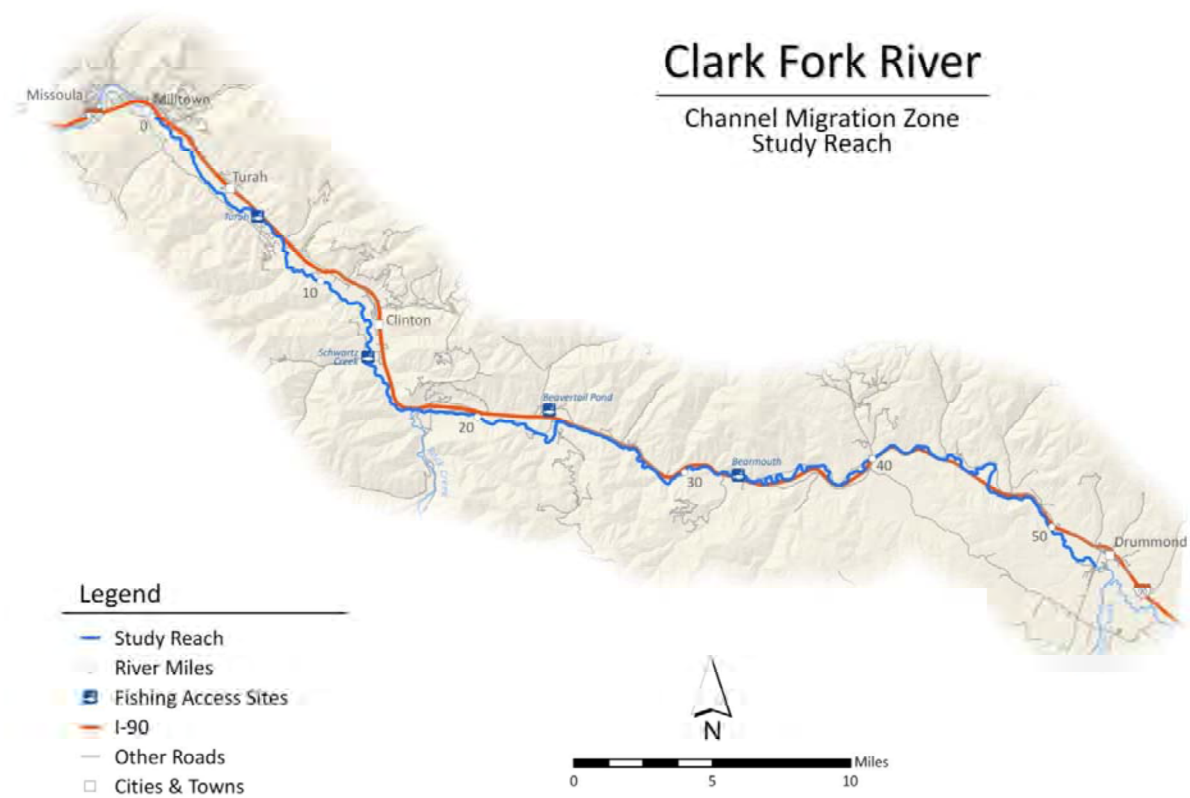

Figure 1-1. General project location.

Channel Migration Zone mapping is based on the understanding that rivers are dynamic and move laterally across their floodplains through time. As such, over a given time period, rivers occupy a corridor area whose width is dependent on rates of channel shift. The processes associated with channel movement include progressive channel *migration* and more abrupt channel *avulsion*. These processes and related hazards can be highlighted and presented by using CMZ mapping techniques. For this effort, a 100-year timeframe has been adopted in developing the CMZ boundaries.

The CMZ product provided here depicts a migration corridor boundary for the Clark Fork River, which, based on rates of historic channel movement, would allow for typical reach-averaged rates of migration over a 100 year time frame. That is not to suggest that certain areas may exceed the CMZ boundary sooner; it is likely that areas of extreme erosion will exceed the mapping boundary provided here. It does, however, provide a corridor that, if allowed to migrate naturally, will provide for and support processes that allow the channel to trend towards geomorphic stability and ecological diversity for decades.

1.1 The 100-Year CMZ Timeframe

For this study, a 100-year timeframe was selected to analyze the potential lateral migration of the Clark Fork River, which is typical for CMZ studies (WSDE, 2010). Suggested reasons for the adoption of this timeframe include the following:

1) 100-year floodplains are mapped to identify flood hazards due to inundation.
2) The availability of supporting archival material used in the analysis commonly dates back around 100 years.
3) A century is sufficient time for growth of mature trees that could potentially affect channel process (King County, 2004).

Ultimately, however, the 100-year timeframe reflects more of a policy decision than a scientific one; this window has proven to be a useful and generally acceptable management framework for landowners and resource managers.

1.2 Human Impacts and CMZ Mapping

One of the objectives of this mapping effort is to consider the impacts of human development on the Channel Migration Zone of the Clark Fork River. Within this reach, however, human impacts extend well before the availability of data to assess those impacts. Aerial imagery used to map river location and quantify rates of bank movement extends from 1950 to 2013. In 1950, however, the river corridor had already been impacted by two rail lines (Pacific Northern and Milwaukee Lines) as well as Highway 10.

As a result, it is critical to acknowledge that ***the analyses presented in this report reflect an impacted condition***, ***such that the CMZ is not reflective of a pristine river valley condition***. The transportation corridor impacts through the project reach began in the 1880's. As a result, all mapping and migration rate measurements reflect river location and processes subsequent to those impacts. Thus, the CMZ presented here should be considered a conservative estimate of the natural Clark Fork River corridor footprint. Attempts have been made to assess the pre-1880 corridor condition, but due to a lack of data, these results are approximate.

In order to help determine the impacts of transportation development prior to 1950, General Land Office Survey (GLO) maps were obtained and integrated into the GIS. These maps provided a coarse indication of channel location; however mapping extents and timeframes were inconsistent. In some cases, the Pacific Northern line was already present during the GLO survey. In many cases, the river mapping was too generalized to be useful.

The Northern Pacific Railway Historical Association is a non-profit educational organization that formed in 1981. The organization maintains a web site that has numerous historical documents regarding the Northern Pacific (www.nprha.org). Attempts were made to contact the organization to locate any original right-of-way maps for the rail line that might have shown where the river was relocated for the railroad. These attempts were unsuccessful. Similarly, archivists at the Maureen and Mike Mansfield

Library Archives and Special Collections at the University of Montana were contacted to try and access historic maps. Archivists in Special Collections researched their materials and found no historic mapping through the project reach. The National Archives in Washington DC may have useful mapping, but that information is not easily accessible and thus was not available. Similarly, the Minnesota Historical Society (www.mnhs.org) has extensive resources that could produce useful information with targeted research.

1.3 Other Relevant Studies

The following section briefly describes other CMZ-related studies recently performed in the region.

1.3.1 Clark Fork Overview: Warm Springs to Garrison

In 2013, CDM Smith and Applied Geomorphology completed a report entitled *Clark Fork River Operable Unit Milltown Reservoir/Clark Fork River Superfund Site, Powell, Deer Lodge, and Granite Counties: Geomorphology and Hydrology of Reach A* (CDM Smith and AGI, 2013). This report provides a general overview of the hydrology and geomorphology of the Clark Fork River from Warm Springs to Garrison. The project was undertaken in support of ongoing remediation efforts in what is known as Reach A of the superfund operable unit. The analyses include the creation of preliminary CMZ maps for Reach A to help identify anticipated tailings removal extents. Other geomorphic information includes assessments of slope/sinuosity, bank erosion, floodplain turnover, floodplain access, and riffle density. The hydrologic analyses describe peak flow and flow duration analyses on the mainstem and tributaries.

1.3.2 Bitterroot to Huson

From approximately one mile upstream of the confluence of the Bitterroot River downstream to Huson, the Clark Fork River was mapped for Missoula County in 2009. This study resulted in approximately 13 miles of full CMZ mapping, including banklines (1955, 1972, and 2005), segmented migration vectors, and the development of a 100-year CMZ. This product is being used by Missoula County to assist with permit review for projects close to the river.

1.3.3 Milltown to Bitterroot Confluence

In 2014, the core CMZ data sets used for CMZ development (banklines and migration vectors) were developed for the section of the Clark Fork River from the former Milltown dam site to the confluence with the Bitterroot River. A full CMZ mapping effort was not undertaken for this reach.

1.3.4 CMZ Mapping of the Plains Reach of the Clark Fork River

This study consisted of CMZ mapping of an 8-mile reach of the Clark Fork River near Plains Montana. The study was performed by RESPEC and the general techniques applied were similar to those presented here. The results were specifically applied to determine short-term erosion rates (1995-2013) and to use that information to define bank stabilization and revegetation strategies.

1.4 Acknowledgements

Field data summarized in this report were collected by several people who assisted with the mapping of these features by boat. These people that assisted Dan Brewer of the U.S. Fish and Wildlife Service in the field data collection include the following:

- Brad Liermann - Fisheries Biologist, Montana Fish Wildlife and Parks
- Casey Hackathorn - Upper Clark Fork Project Manager, Trout Unlimited
- Joe Weigand - Missoula District Biologist, Montana Department of Transportation
- Mike McGrath - Fish and Wildlife Biologist, U.S. Fish and Wildlife Service
- Mark Novak - Fish and Wildlife Biologist, U.S. Fish and Wildlife Service.

We would like to extend our gratitude to these assistants for their time and competence in field data collection and delivery. It is our hope that these data will provide a solid baseline inventory that can be periodically updated to track projects, identify restoration opportunities, and help to understand the cumulative impacts of bank armoring on the Clark Fork River.

2 Transportation Development in the Clark Fork River Corridor

Between Drummond and Milltown, the Clark Fork River corridor has experienced over 100 years of progressive encroachment due to the construction of a complex transportation corridor in the valley bottom. Two rail lines were constructed through the stream corridor in the late 1800s and early 1900s, with construction of what is now the Frontage Road in the 1920s. In the 1960s, Interstate 90 was built in the valley bottom, further expanding the transportation footprint (Figure 2-1). Each of these impacts has encroached into the natural Channel Migration Zone (CMZ) of the river. In numerous places, the construction included relocating and straightening the river. Because the railroad impacts were so early, it is impossible with available data to accurately assess the condition of the river prior to transportation corridor development, and to define the CMZ boundaries that would have reflected river process at that time. As a result, the CMZ provided herein is a reflection of measured rates of lateral movement since the mid-1950s, and intends to capture the encroachment of the infrastructure into the CMZ based on those rates.

Figure 2-1. Main transportation corridor elements including (from left)—Milwaukee Line, BNSF Line, abandoned rail line, I-90, and Frontage Road on right.

A brief summary of the transportation infrastructure elements that most affect the Clark Fork River CMZ is provided below.

2.1 The Northern Pacific Railroad

In July of 1864, President Abraham Lincoln signed the charter authorizing construction of the Northern Pacific railroad from Lake Superior to Puget Sound. Construction started in 1870 and progressed rapidly (Figure 2-2 and Figure 2-3). The first Northern Pacific passenger train entered Missoula from the west on July 6, 1883 (Fort Missoula Museum). Later that year, the railroad was completed at Gold Creek and former president Ulysses S. Grant attended the ceremony and drove in the “golden spike” to commemorate the occasion. During World War 1, the railroad became part of the federal government transportation network. On March 2, 1970 the Northern Pacific was merged with the Chicago, Burlington & Quincy, Great Northern, and Spokane, Portland and Seattle and their subsidiaries to become the Burlington Northern. This line is currently active and closely follows the river corridor.

General Land Office (GLO) survey maps from 1883 show the rail line constructed at that time (Figure 2-2). In many places, however, it has been relocated since its original construction, leaving remnant, discontinuous berms throughout the project reach.

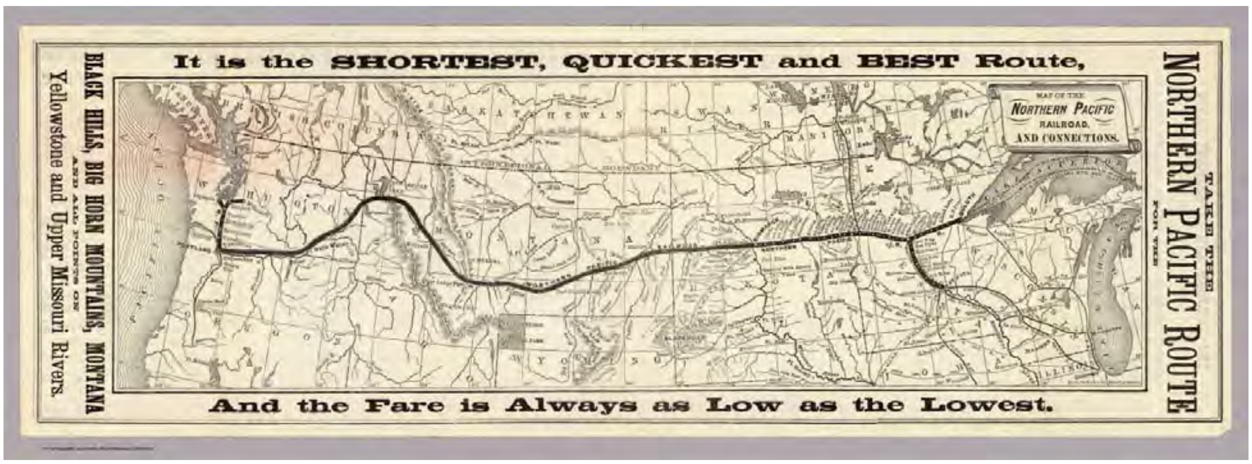

Figure 2-2. Northern Pacific Railroad Route Map (Northern Pacific Railway Historical Association).

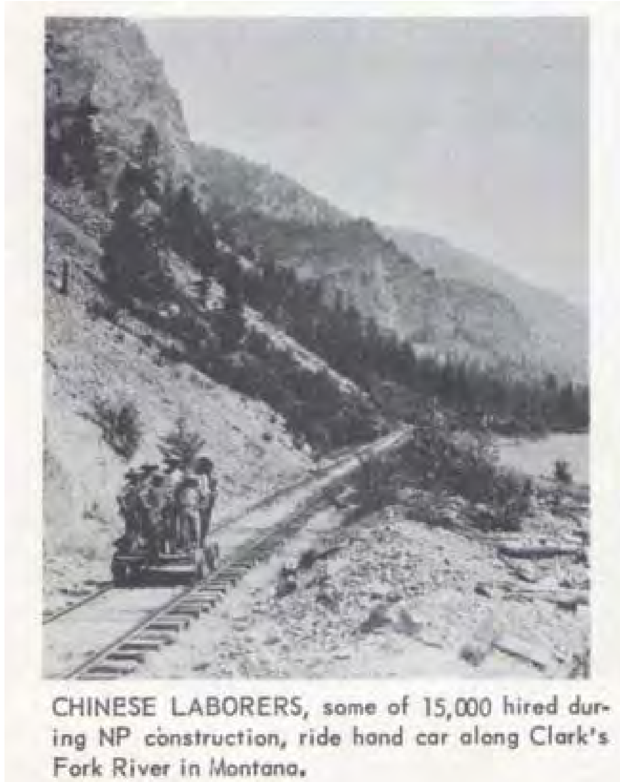

Figure 2-3. Early construction photo of railroad construction in the Clark Fork River corridor (Northern Pacific Railway Historical Association).

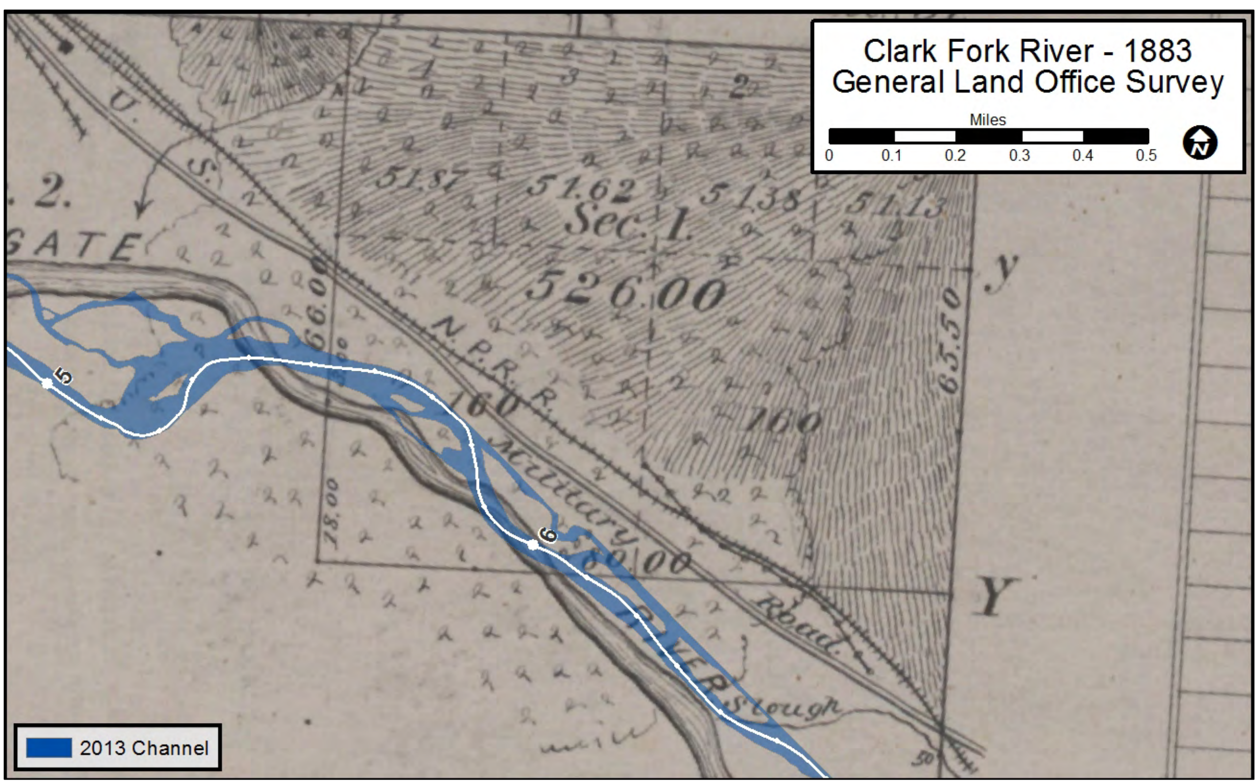

Figure 2-4. General Land Office (GLO) map from 1883 showing constructed Northern Pacific Railroad Line about six miles upstream of Bonner (blue polygon is 2013 channel course).

2.2 The Milwaukee Railroad

The Chicago, Milwaukee, St. Paul and Pacific Railroad—otherwise known as the Milwaukee Road, began operating between Milwaukee and Waukesha, Wisconsin in 1850. Between 1906 and 1909, the railroad extended through Montana to Seattle/Tacoma on the west coast. In Montana, the Deer Lodge to Alberton section was built between 1908 and 1909 (Rails to Trails Conservancy, 2004).

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

Figure 2-5. Route of the Chicago, Milwaukee & St Paul Railway through Montana (Rails to Trails Conservancy, 2004).

2.3 US Highway 10

US Highway 10 is an east-west highway that extended from Detroit to Seattle. Much of this highway was obliterated when I-90 was constructed on top of its right of way. Within the project reach, however, imagery indicates that the highway has been maintained as the Frontage Road. This system was constructed in the mid-1920s tends to follow the north valley wall through the project reach.

Figure 2-6. View downstream showing the Frontage Road following north valley wall of Clark Fork River corridor.

2.4 Interstate 90

Interstate 90 replaced US Highway 10 between Livingston and the Idaho border. The Interstate Highway System was born when President Dwight Eisenhower signed the Federal Aid Highway Act of 1956. The system has been called "the greatest public works project in history." Within the project reach, it is difficult to find the exact date of I-90 construction, however it is assumed to have been built around the late 1960s.

3 Methods

The methodology applied to the CMZ delineation generally follows the techniques outlined in Rapp and Abbe (2003) as well as Washington Department of Natural Resources (2004). The Channel Migration Zone (CMZ) developed for the Clark Fork River is defined as a composite area made up of the existing channel, the historic channel since 1955 (Historic Migration Zone, or HMZ), and an Erosion Buffer that encompasses areas prone to channel erosion over the next 100 years. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as "Avulsion Hazard Zones" (AHZ).

The primary methods employed in developing the maps include air photo acquisition and incorporation into a GIS environment, centerline digitization, migration rate measurements, and data analysis. The mapping information and measured rates of channel shift are then utilized to define historic channel locations and to apply an erosion buffer to allow for future erosion.

3.1 Aerial Photography

Table 1 lists imagery used for this project from the USGS and archives of current GIS data sets. Examples of the imagery used in the analysis are shown in Figure 3-1 through Figure 3-4.

Table 1. Imagery used in CMZ development

Date	Source	Quality	Notes
1955	USGS	Good	Used from Milltown up to river mile 20
1956	USGS	Good	Used upstream from river mile 20
1972 - DOQ	USGS	Good	Available from Milltown to the Missoula County Line
1995 - DOQ	USGS	Good	Complete coverage
2011 NAIP	USDA	Excellent	Complete coverage
2013 NAIP	USDA	Excellent	Complete coverage

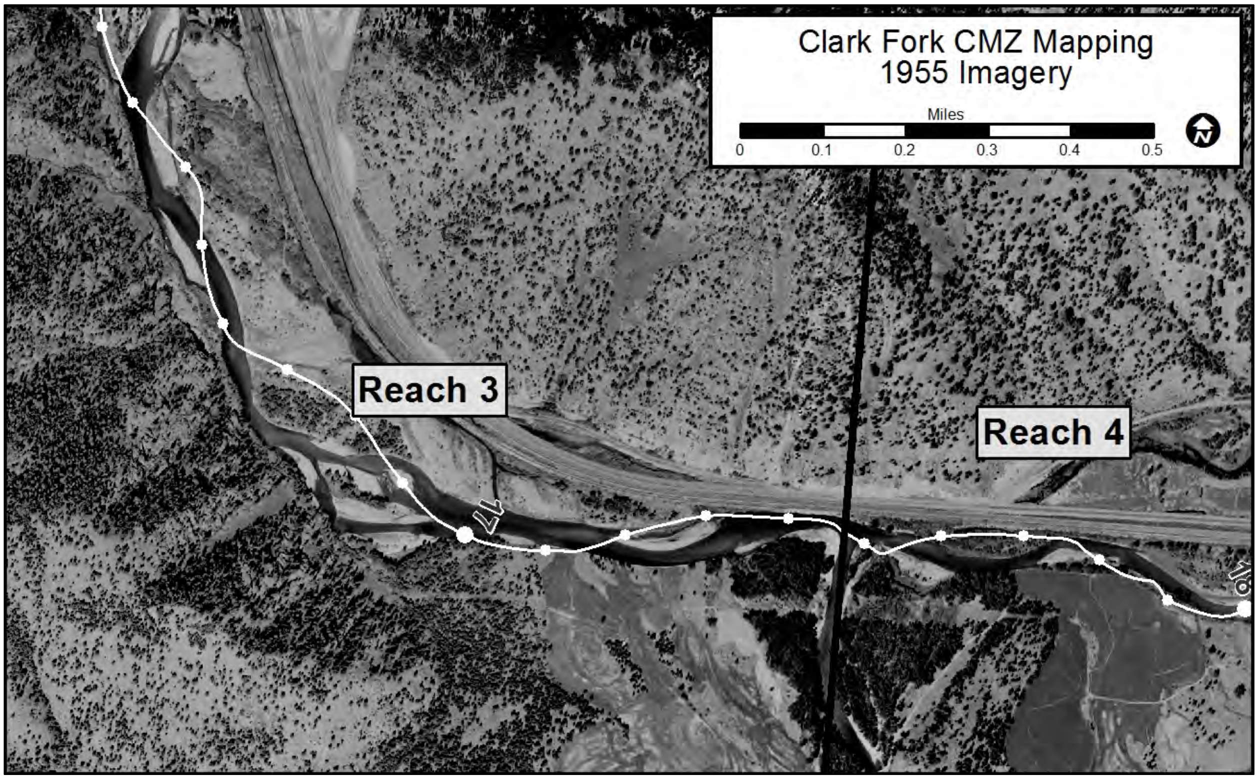

Figure 3-1. Example 1955 imagery, Clark Fork River CMZ development.

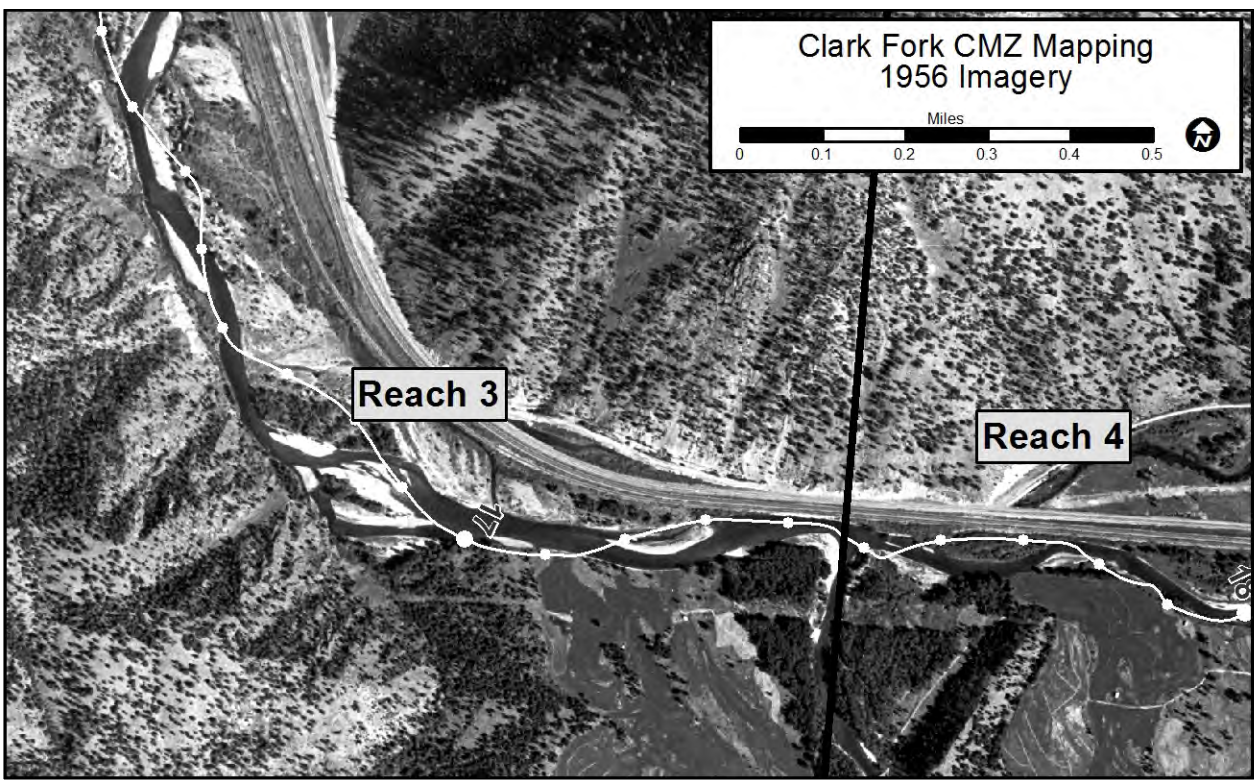

Figure 3-2. Example 1956 imagery, Clark Fork River CMZ development.

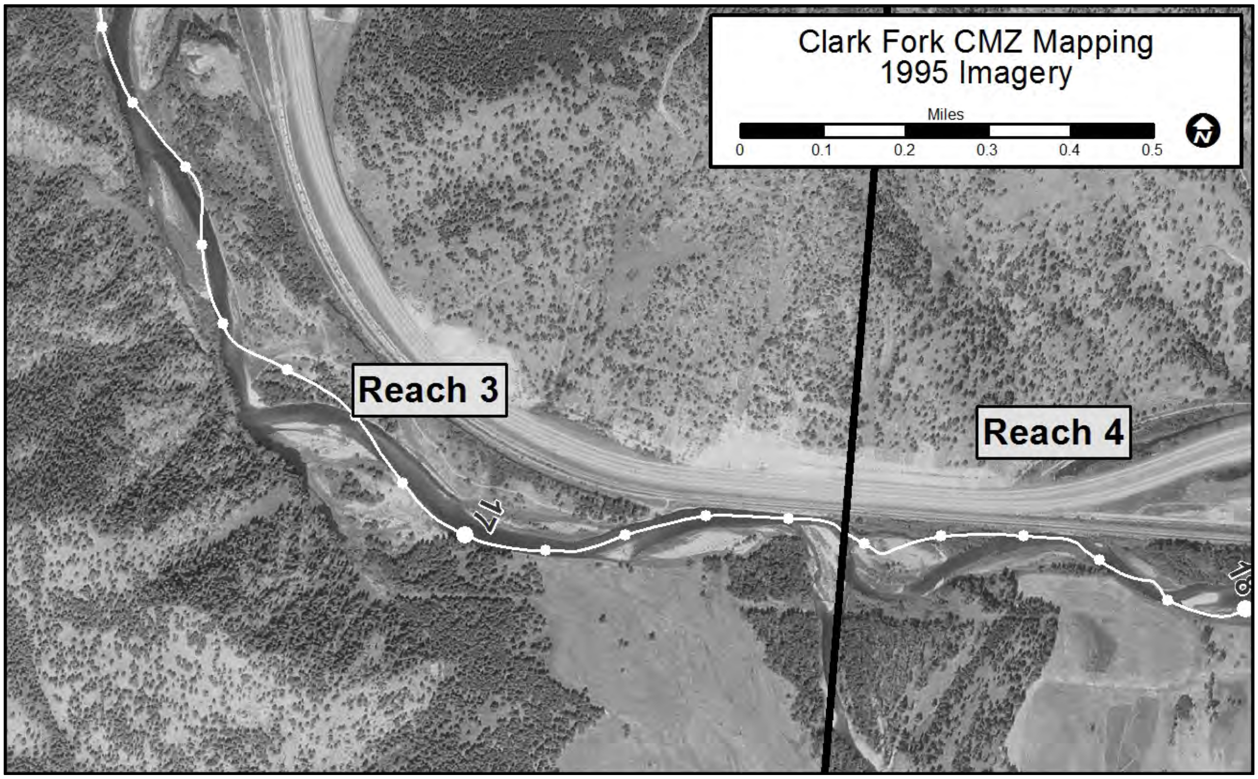

Figure 3-3. Example 1995 imagery, Clark Fork River CMZ development.

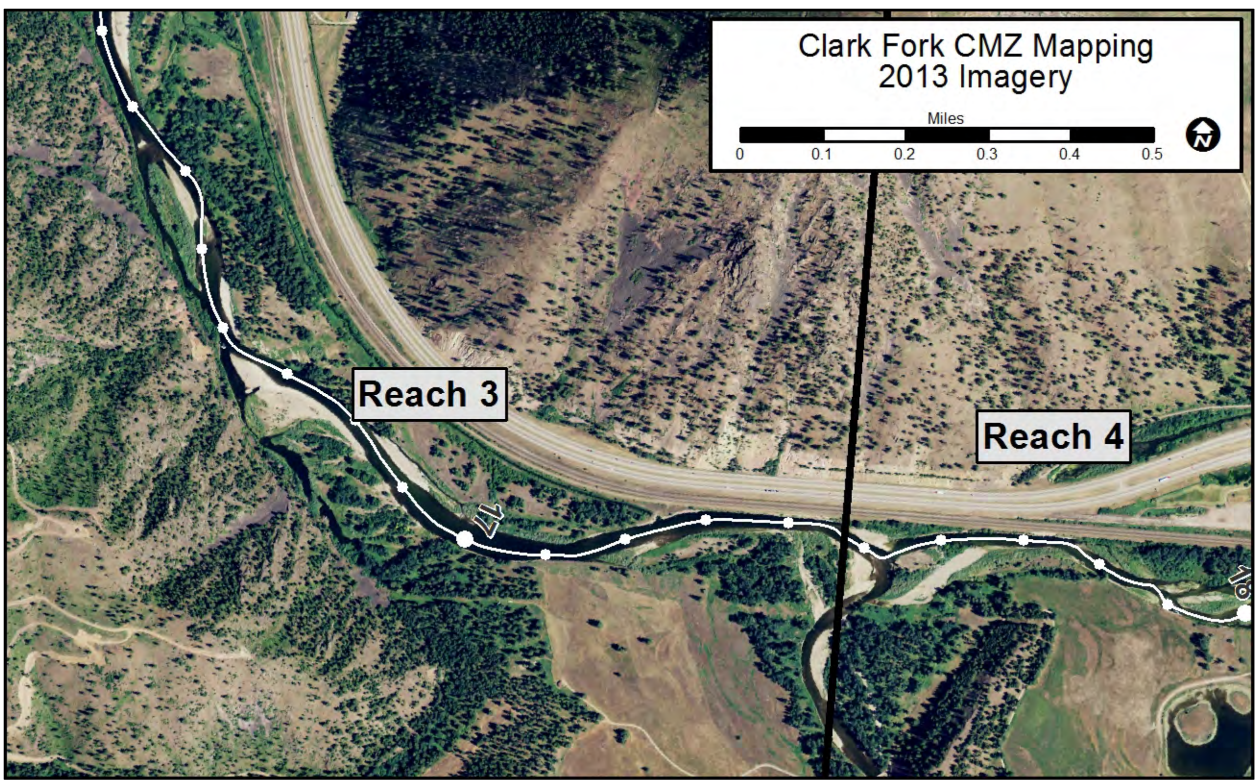

Figure 3-4. Example 2015 imagery, Clark Fork CMZ development.

3.2 Bankline Digitizing

Banklines approximating a bankfull flow condition were digitized at a scale of 1:3,000. Bankfull is defined as the stage above which water leaves the channel and flows onto the floodplain. There are several ways to identify bankfull channel margins, including using field indicators or analyzing flood return intervals at a given cross section. Although these approaches can provide a relatively precise depiction of bankfull conditions, CMZ development requires identification of bankfull on air photos and thus has lower resolution. In using imagery, we typically rely on the extent of the lower limit of perennial, woody vegetation to define the active channel bankline (Mount & Louis, 2005). The bankfull extent reflects those portions of channels that are at least seasonally inundated and thereby do not support woody vegetation. In addition, terrace margins and bedrock valley walls are used as boundaries. Fortunately, shrubs, trees, terraces and bedrock generally show distinctive signatures on both older black-and-white as well as newer color photography. These signatures, coupled with an understanding of riparian processes, allow for consistent bankline mapping through time and across different types of imagery.

3.3 Mapping the Historic Migration Zone

The Historic Migration Zone (HMZ) is based on a composite area defined by the channel locations in 1955/56, 1972 (Missoula County only), 1995, and 2013 (Figure 3-5). The resulting area reflects the approximate zone of channel occupation over the 58-year timeframe defined by the imagery. The method for delineating the HMZ is to overlay the digitized polygons for the channel for each time series, and then to union those polygons into a single HMZ polygon. All islands within the HMZ are included within the merged HMZ polygon.

It is important to recognize that the HMZ defined in this stretch of the Clark Fork River does not include areas where the river was relocated when the rail line was constructed in the late 1800s. Without information to map those areas, it is impossible to clearly define the river footprint at that time.

See section 5.2 for a discussion of historic channel relocations not captured in the CMZ.

3.4 Migration Rate Measurements

Within the GIS, the digitized banklines were evaluated in terms of discernible channel shift since 1955. Where migration was identifiable, vectors were drawn in the GIS to record that change (Figure 3-6). At each site of bankline migration, measurements were collected at approximately 150 foot intervals, and the vectors were attributed by length and reach. These measurements were then summarized by reach to determine appropriate reach-specific buffer widths to accommodate future shifts in channel location.

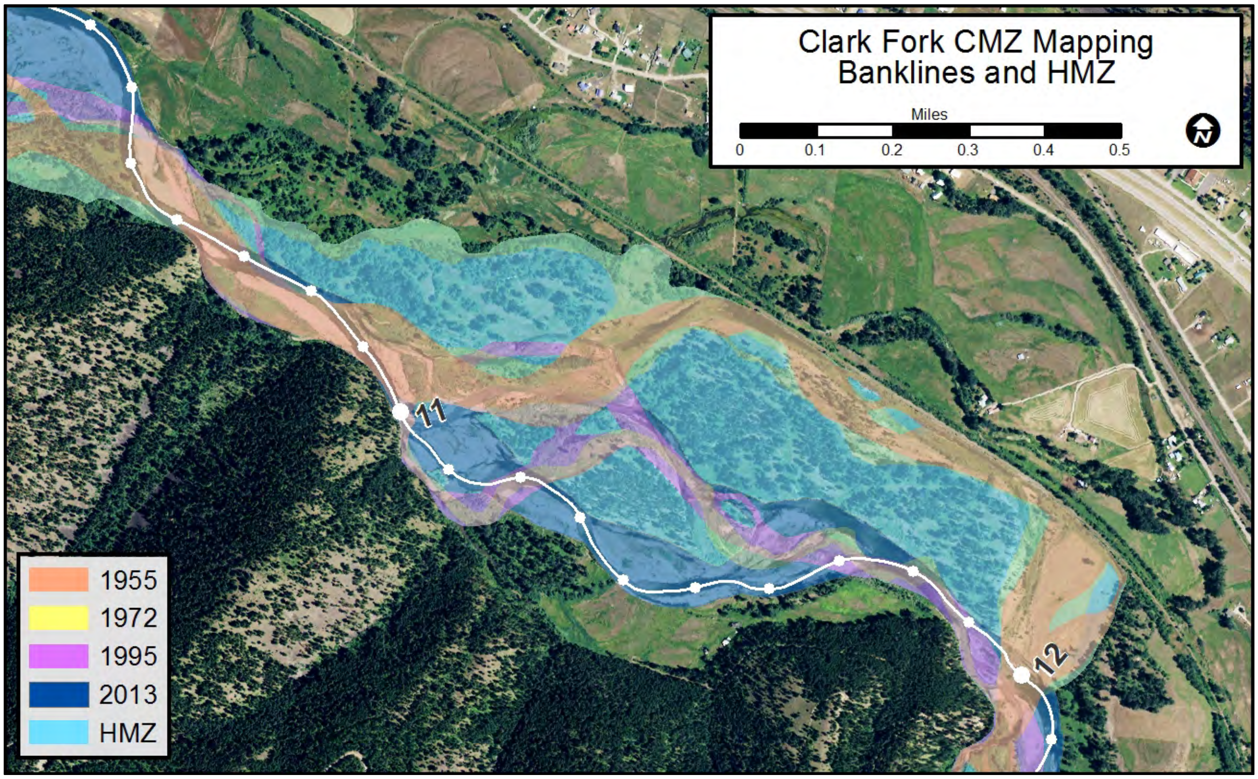

Figure 3-5. Example of mapped channel courses and composite Historic Migration Zone (HMZ).

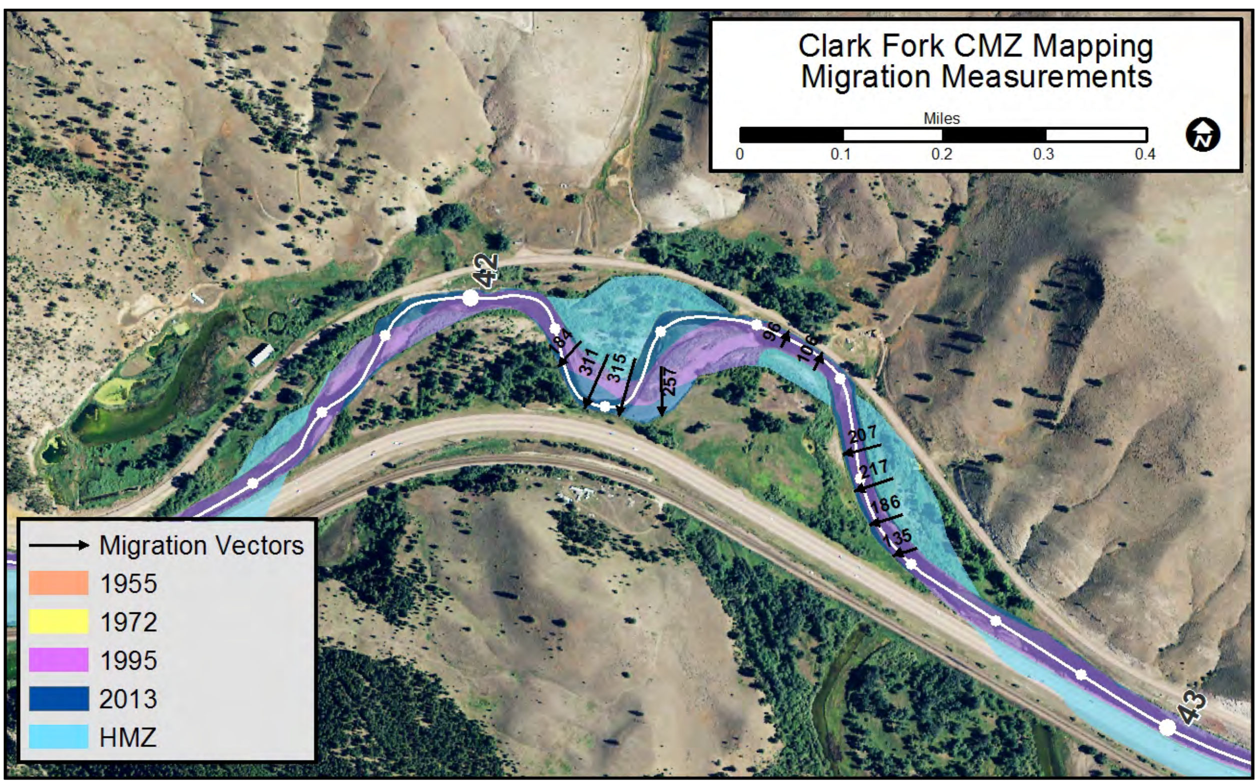

Figure 3-6. Example of migration measurements.

3.5 Avulsion-Prone Area Mapping

An avulsion is the sudden relocation of a channel into a new course. When water flows away from a primary channel, it will follow the most efficient course available. Sometimes, these overflows can channelize and create a whole new channel, potentially abandoning the original one. Two types of avulsion-prone areas were mapped in the project reach, including meander cores and distinct floodplain relic channels (Figure 3-7).

In general, the risk of channel reoccupation into a relic floodplain channel is low relative to compressed meander cutoff or perched channel relocation as floodplain avulsions tend to be rare events caused a combination of channel instability (aggradation), channel migration, high flows, debris jamming, or ice jamming. However, an effort was made to highlight areas where overflows may be channelized on the floodplain, and as such, may become reactivated during a flood. All of the avulsion prone areas between Drummond and Milltown are attributed as having a moderate risk of channel activation in the next century. There are no areas that show an imminent risk of avulsion.

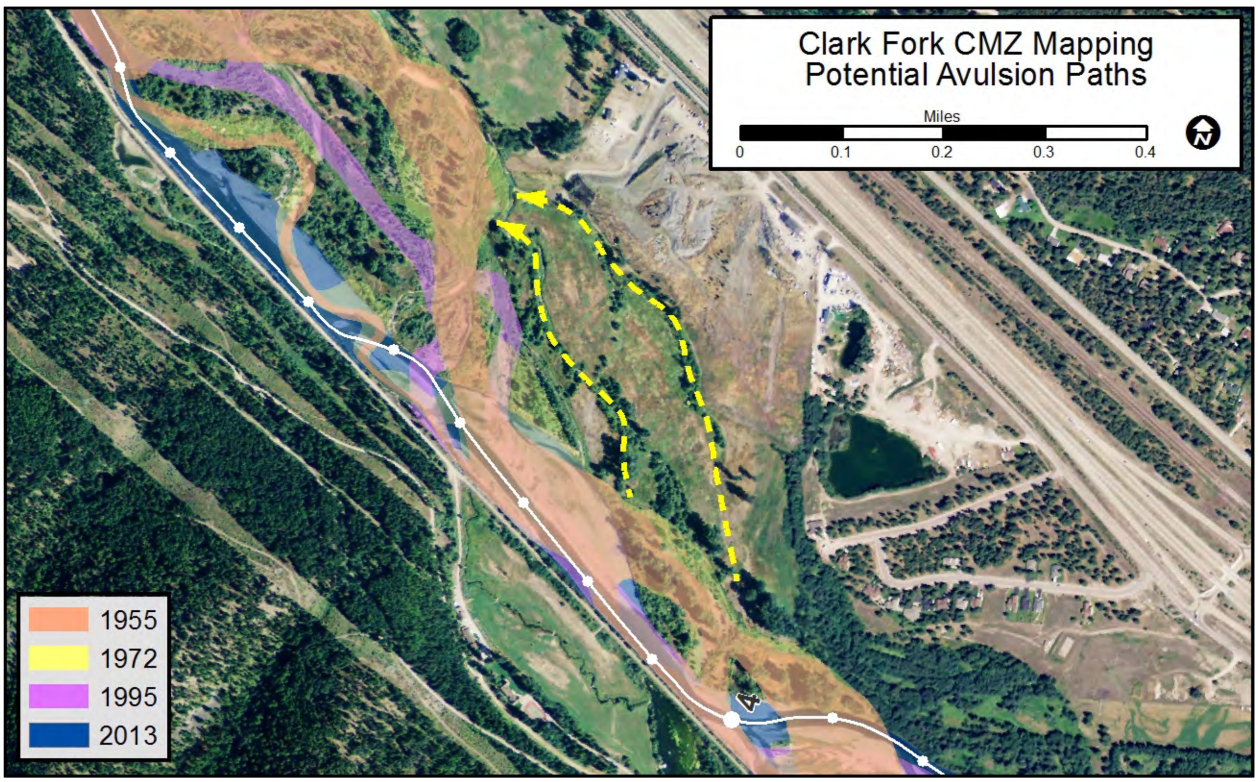

Figure 3-7. Example of floodplain channels that create a moderate risk avulsion hazard (risk of reactivation).

Figure 3-8 and Figure 3-9 show an avulsion that occurred between 1995 and 2011 a few miles upstream of the Milltown Dam site.

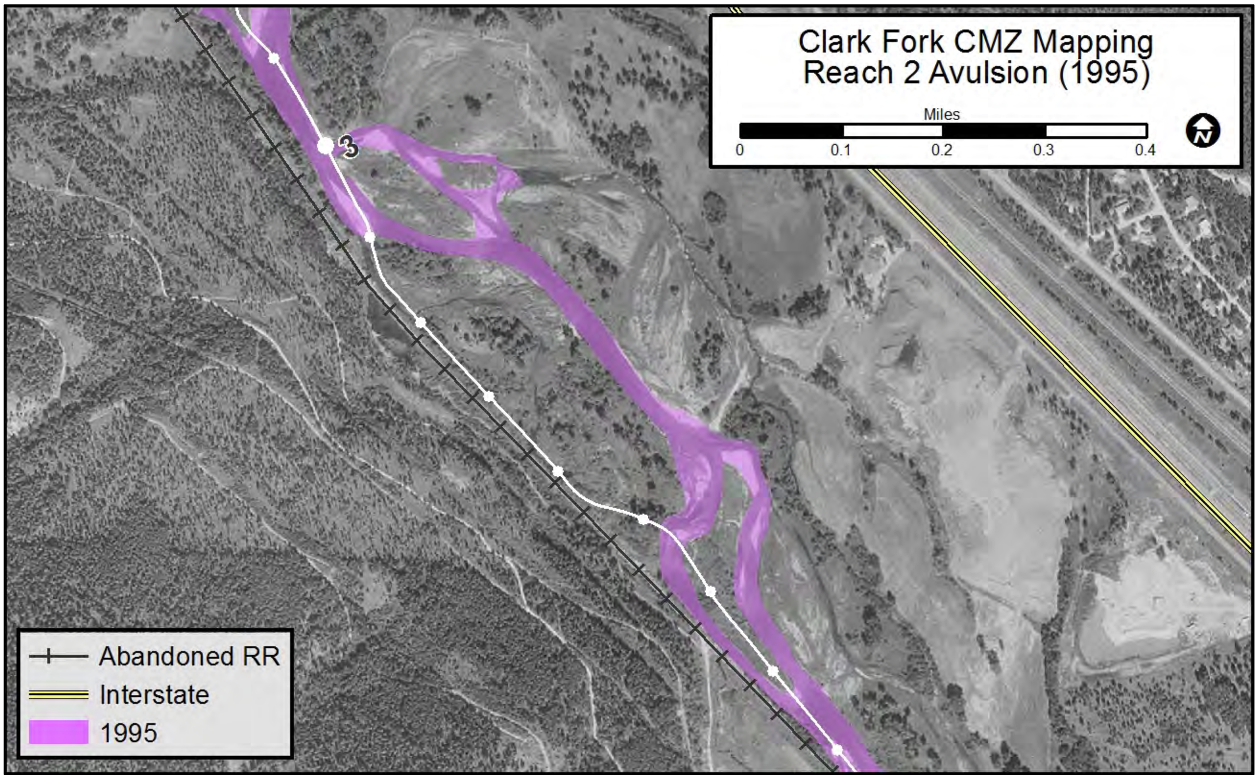

Figure 3-8. 1995 imagery showing the site of an avulsion that was approximately 0.4 miles long; site is approximately three miles upstream of Milltown Dam site.

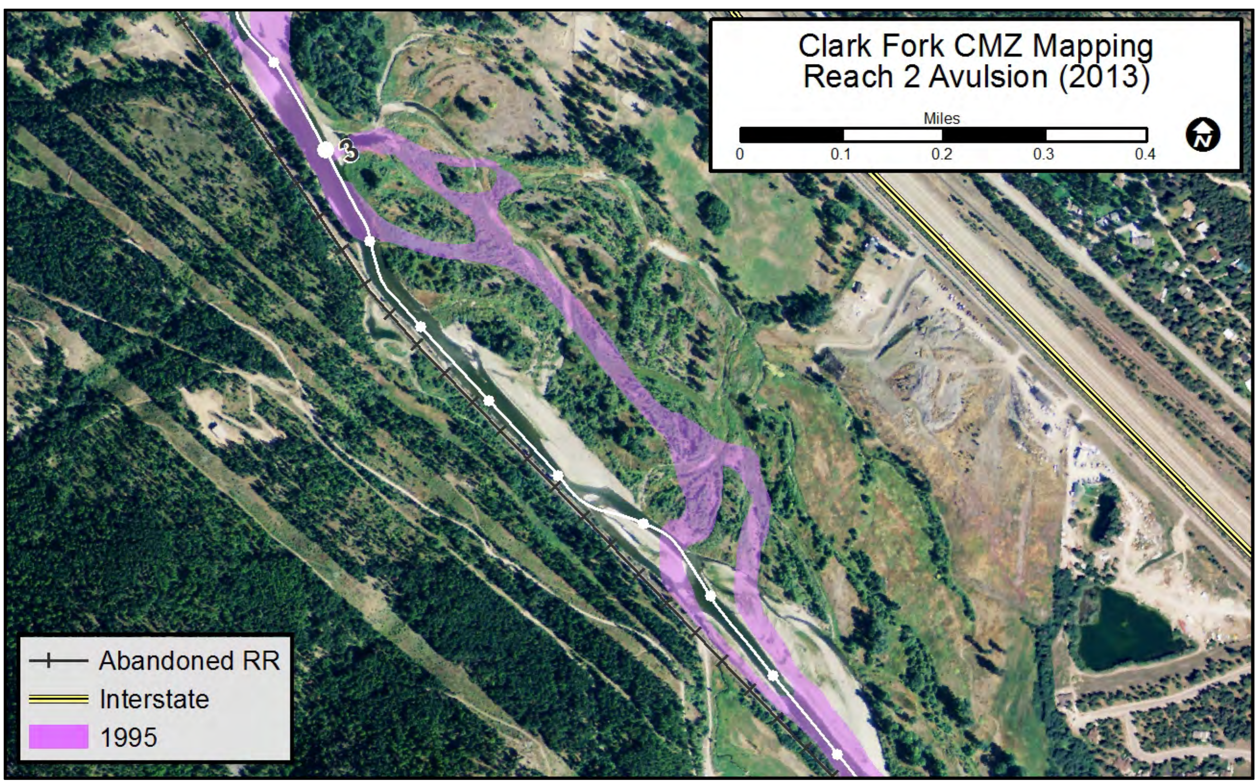

Figure 3-9. 2013 image of same site shown in Figure 3-8, showing avulsion of river into floodplain channel and against railroad embankment.

3.6 Restricted Migration Area Mapping

Restricted Migration Areas (RMAs) are those areas that, although mapped within the CMZ, have been identified as isolated from the active corridor due to transportation infrastructure or bank armor. This project area shows extensive isolation due to both transportation encroachments and bank protection.

Mapping restricted migration areas has been, in some ways, the most challenging aspect of this project. In many sites, it appears that the river was relocated at least twice, once for the rail line and then again for the Interstate. Because of the large footprint of the transportation lines, it is impossible to accurately trace the pre-rail line river channel through the confined river valley. General Land Office surveys from 1875 are of some help, but one of the rail lines (Northern Pacific) was already in place at that time. As a result, the migration areas mapped as restricted are limited to those that can be shown to have been within the CMZ area since the mid-1950s. The pre-1950 CMZ is discussed in a more narrative form, with some attempts to quantify that more comprehensive impact of development in the valley bottom.

3.7 GIS Data

All of the information described above were developed, compiled, and analyzed within ESRI ArcGIS software. An ArcMap project file and accompanying ESRI Personal GeoDatabase are provided along with Layer files to assist with symbolizing certain data sets. The individual GIS data layers are described below.

GeoDatabase Contents (clarkforkcmz.mdb):

- Banklines (Feature Dataset)
  - Banklines_1955 – Clark Fork River banklines as digitized on 1955 aerial photography. Banklines approximating a bankfull water condition were digitized at a scale of 1:3,000. Bankfull is defined as the stage above which discharge commences to flow out onto the floodplain and generally correlates with the extent of woody vegetation.
  - Banklines _1956_61 – (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 1956 (upstream portion) and 1961 (downstream portion) aerial photography.
  - Banklines_1972 - (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 1972 aerial photography.
  - Banklines_1995 - (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 1995 DOQ aerial photography.
  - Banklines_2005 - (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 2005 NAIP aerial photography.
  - Banklines_2011 - (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 2011 NAIP aerial photography.
  - Banklines_2013 - (See Banklines_1955 for complete description) Clark Fork River banklines as digitized on 2013 NAIP aerial photography.

  - Banklines_2013_Rch – Same as Banklines_2013, but the polygons have been split and attributed by study reach.
  - Centerline_2011 – Clark Fork River primary channel centerline as digitized on 2011 aerial photography. This centerline has an assigned Measure and can be used to apply stationing to the centerline.
- CMZ (Feature Dataset)
  - CMZ - Composite Channel Migration Zone (CMZ) data layer. The "CMZ" field should be used for attributing the data set (AHZ Mod = Avulsion Hazard Zone Moderate Risk, Channel = 2013 channel, EHA - Erosion Hazard Area and Restricted indicates if erosion is currently restricted by bank armor or infrastructure, HMZ - Historic Migration Zone and Restricted indicates if the area is currently behind bank armor or infrastructure, Island = HMZ that is an island in the 2013 channel), RMA Field identifies areas behind bank armor or infrastructure. RMA_Cause describes the reason for RMA. Armor Field indicates areas that are behind a specific type of armor. Armor_Purpose indicates what the armor is protecting (i.e., then intent of the armor).
  - HMZ - A composited footprint of all the channel traces, including islands. By definition, this is the Historic Migration Zone.
  - Migration_Vectors - 1955 to 2013 channel migration measurements.
  - Historic_Restricted_Corridor – Remnant channel segments and intervening floodplain areas outside of the CMZ that appear to have been historically within the active channel corridor (pre-1883), but are now beyond the CMZ boundary due to engineered relocations of the river.
- Misc (Feature Dataset)
  - Bank_features - This data set contains the locations of bank protection features mapped in the field by USFWS personnel between 2012 and 2015.
  - Erosion - This data set contains the locations of bank erosion features mapped in the field by FWP personnel between 2012 and 2015.
  - Reach_Breaks - Locations of study reach breaks.
  - Reach_Polys - Locations of study reach breaks.

3.8 Error Discussion

This methodology acknowledges the following set of potential sources of error: resolution of aerial photography, accuracy of aerial photographic rectification, accuracy of the locations of digitized centerlines and the density of migration rate measurements. While these error sources could all potentially contribute to CMZ mapping zone uncertainty, the reach-based averaging technique removes the influence of any site-specific digitizing or image rectification errors by averaging the measured bank migration rates for the entire reach. The data compilation methodology acknowledges the inherent errors and the variable nature of the stream migration process and does not rely on any specific measurement to set the buffer widths for a reach.

It is important to note that site-specific studies that are intended to predict channel migration on a local, short-term scale would require a greater level of analysis, potentially including detailed rate measurements, hydraulic computations linking erosion rates to flow conditions, geomorphic analysis of bendway evolution, sediment characterization, and geotechnical characterization of materials.

4 Data Analysis

Migration rate measurements were analyzed on a reach scale to characterize typical rates of movement over river segments that are geomorphically similar. For example, migration rates in confined canyon areas are low due to the bedrock controls on channel movement. Near Beavertail Hill, migration in some places has exceeded 600 feet since 1955. It is therefore critical to assign predicted erosion extents to geomorphically similar stream segments so that results effectively capture different migration trends through the project area. This required segmenting the project area into reaches.

The reaches used in this analysis are numbered sequentially from the Blackfoot River confluence upstream and are described in Table 2 and shown in Figure 4-1.

4.1 The Erosion Hazard Area

To address anticipated future migration beyond the historic corridor boundary, an erosion buffer has been added to the 2013 channel margin. This area is considered prone to channel occupation over the life of the CMZ (100 years) and is based on mean migration rates for a given channel segment or reach. It is important to note that ***the migration rates reflect post-1950 conditions***, which as described previously represent a highly altered stream corridor.

To determine the buffer distance, migration rates from 1955 to 2013 were measured throughout the corridor. A total of 293 measurements were made through the entire project length and these measurements were summarized statistically by reach (Figure 4-2). The minimum channel migration distance kept in the dataset was 70 feet, which is about one half of the typical channel width; anything less than that was considered to be too small to measure given the resolution of the imagery. The 100 year buffer distance was calculated as 100 times the annual mean migration rate for each entire reach (Table 3 and Figure 4-3).

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).

Table 2. Project Reach Descriptions

Reach	*D/S RM*	*U/S RM*	*Length (mi)*	*Bank Length (ft)*	*Location*	*Comment*
Reach 1	0	2.6	2.6	27,456	Milltown Dam Reservoir/ Remediation Area	Historic Milltown Dam Impoundment
Reach 2	2.6	8.4	5.8	61,248	Donovan Creek to Milltown Dam Reservoir	Confined between I-90 on north and valley wall/abandoned railroad on south. Substantial residential development in fp. One large post-1975 avulsion against rail line post-1975 at RM 3.1. Substantial riprap against abandoned rail line (now used as road).
Reach 3	8.4	17.5	9.1	96,096	Rock Creek to Donovan Creek	Channel follows left bank valley wall through much of reach. One major avulsion between 1995 and 2011 at RM 10.2; major secondary channel capture between 1972 and 1995 at RM 11.5.
Reach 4	17.5	22.1	4.6	48,576	Just below Beavertail Hill to Rock Creek	E-W trending corridor with confinement between active rail line to north and valley wall to south.
Reach 5	22.1	23.7	1.6	16,896	Beavertail Hill State Park	Short dynamic section at Beavertail Hill State Park.
Reach 6	23.7	31.6	7.9	83,424	I-90 Bridge near Ravenna to Beavertail Hill	Highly encroached transportation corridor.
Reach 7	31.6	46.8	15.2	160,512	I-90 Bridge crossing just below Rattler Gulch to Ravenna	Relatively high sinuosity with multiple armored meanders constructed as mitigation for I-90. Frontage Road is on north side of river. Extensive channel relocation for transportation infrastructure.
Reach 8	46.8	53	6.2	65,472	Drummond to Bridge below Rattler Gulch	Moderately confined reach with confinement increasing in downstream direction. Multiple large meander scars on floodplain southwest of Drummond. One moderate avulsion (bendway cutoff) at RM 50.1 between 1995 and 2011.

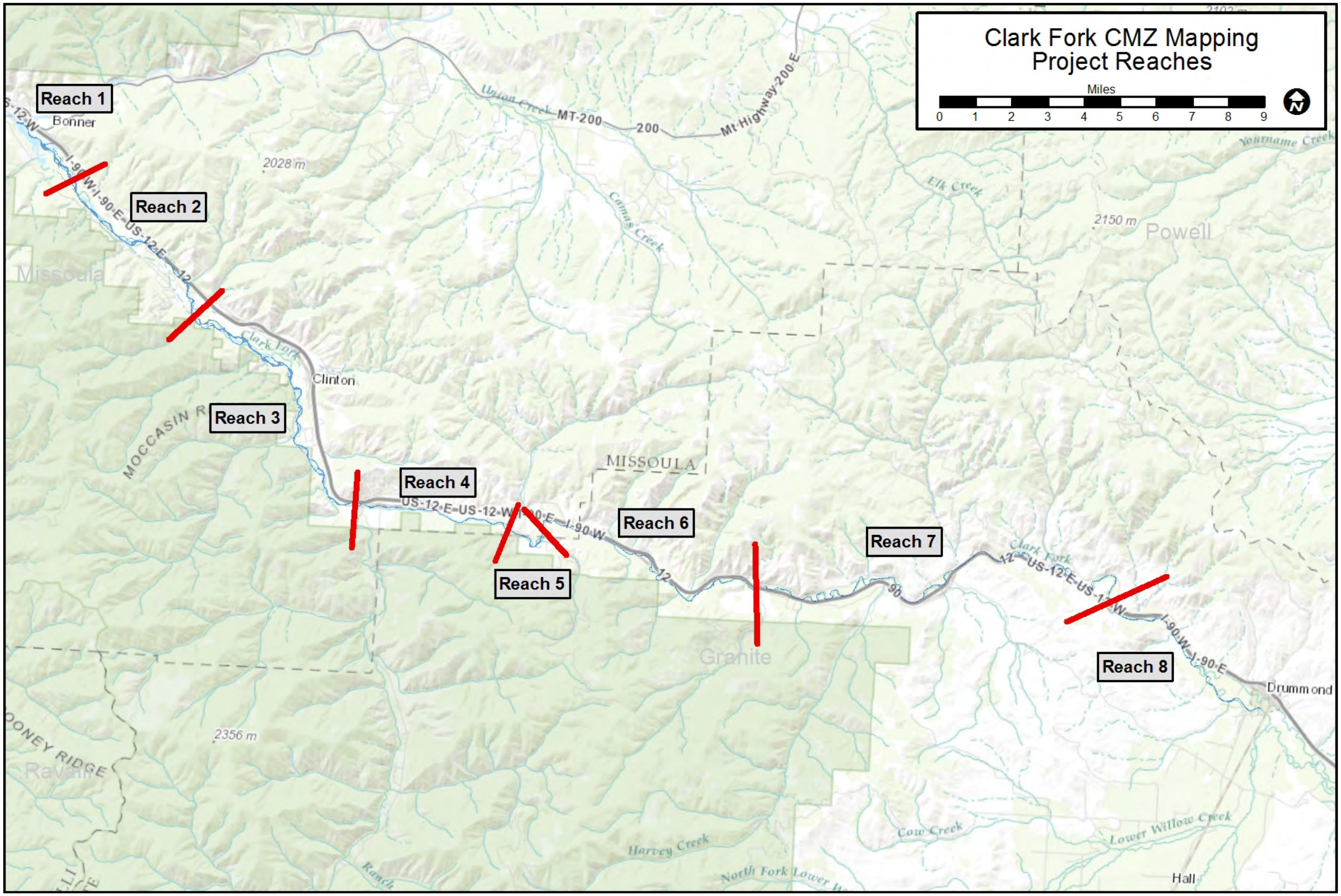

Figure 4-1. Clark Fork project reach delineation used in CMZ data analysis.

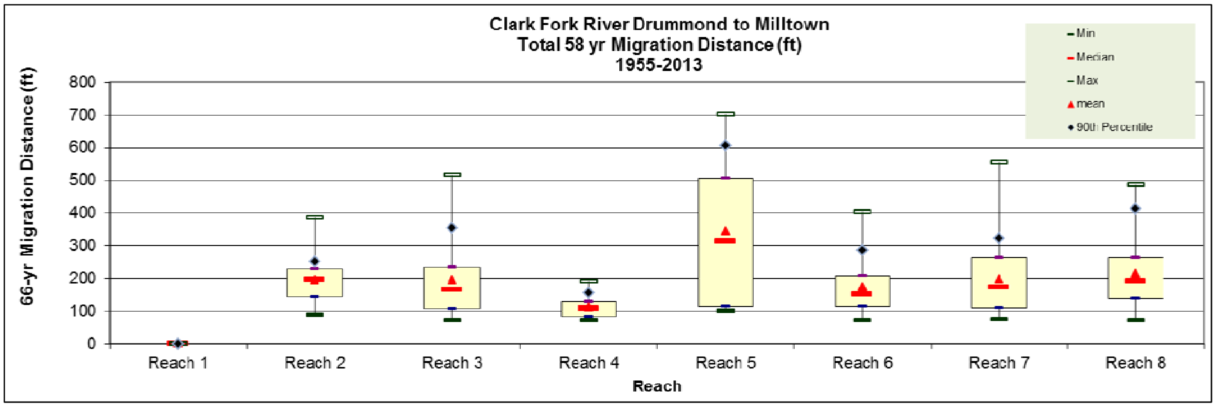

Figure 4-2. Box and Whisker plot showing data summary for Clark Fork River migration measurements.

Table 3. Summary of migration data showing EHA Buffer distance in right column.

Reach	Number of Measurements	Mean Migration Distance (ft)	Mean Migration Rate (ft/yr)	Max Migration Distance (ft)	Max Migration Rate (ft/yr)	90th Percentile Migration Rate (ft/yr)	100-yr Migration Distance (MEAN) (ft)
Reach 1	0	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	41	192.1	3.3	387.6	5.9	4.3	331
Reach 3	85	192.5	3.3	514.7	7.8	6.1	332
Reach 4	32	110.7	1.9	189.9	2.9	2.7	191
Reach 5	6	340.9	5.9	700.9	10.6	10.5	588
Reach 6	35	171.0	2.9	402.9	6.1	4.9	295
Reach 7	63	196.4	3.4	552.6	8.4	5.6	339
Reach 8	31	213.2	3.7	486.6	7.4	7.1	368

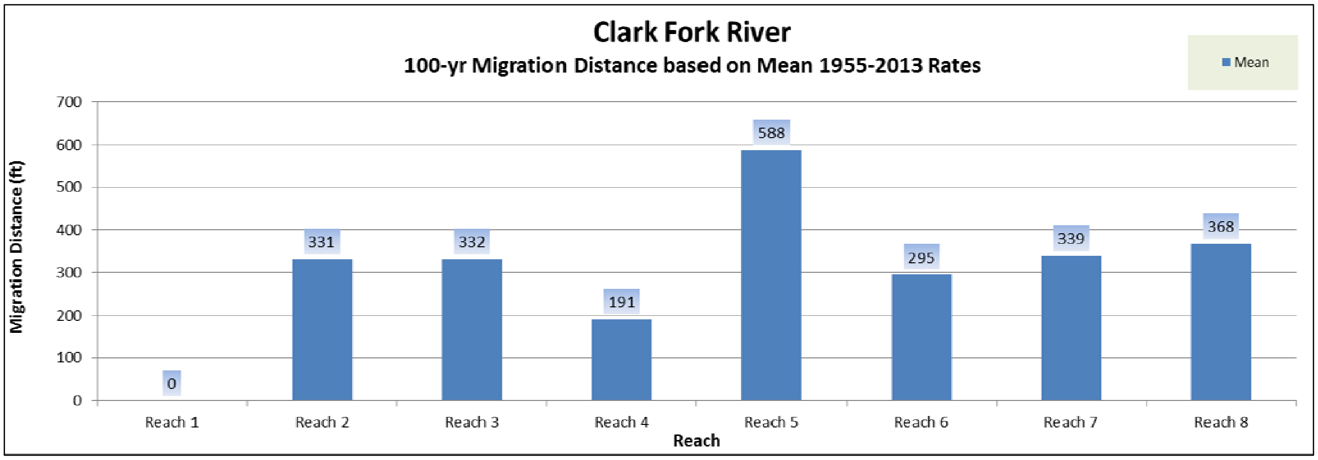

Figure 4-3. Erosion Hazard Area (EHA) buffers assigned to each reach.

Figure 4-2 and Figure 4-3 show that the highest rates of bank movement is in Reach 5, where erosion buffers are almost 600 feet wide. Most of the other reaches have 100 year buffer widths on the order of 200-400 feet. In the Milltown Dam impoundment area (Reach 1), no migration rates were measured due to the pre-2000 reservoir conditions. As a result, the CMZ in Reach 1 is largely defined by the historic reservoir footprint.

5 Mapping Results

The Channel Migration Zone (CMZ) developed for the Clark Fork River is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations since 1955 (Historic Migration Zone, or HMZ), and an Erosion Buffer (Erosion Hazard Area or EHA) that encompasses areas demonstrably prone to channel erosion over the next 100 years. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Zones or AHZ.

Channel Migration Zone (CMZ) = Historic Migration Zone (HMZ) + Erosion Hazard Area (EHA) + Avulsion Hazard Zone (AHZ)

The map units developed in the process of creating these maps include the following:

1. ***Active Channel:*** The active channel is shown in DARK BLUE, and reflects the channel course in 2013.
2. ***Historic Migration Zone (HMZ):*** This unit is shown as LIGHT BLUE on the map, and reflects the area where active channels of Clark Fork River have existed between 1955 and 2013.
3. ***Erosion Buffer:*** The erosion buffer is shown in ORANGE. This reflects a calculated erosion buffer based on almost three hundred measurements of channel migration.
4. ***Avulsion Hazard Zone (AHZ):*** These are areas where topographic conditions suggest potential channel relocation or reactivation. Areas of moderate risk are mapped in GREEN. These units have a high level of transparency as they are beyond the CMZ Core.
5. ***Restricted Migration Area (RMA):*** These are areas where transportation infrastructure and/or bank armor have isolated areas that would be contained within the natural CMZ from the channel. RMA areas are CROSSHATCHED.

Figure 5-1 shows an example of the CMZ mapping results.

5.1 Restricted Migration Areas

Between Drummond and Milltown, the Channel Migration Zone of the Clark Fork River has been extensively encroached upon by transportation infrastructure and additional bank armor that protects other land uses such as agriculture (Figure 5-1 and Figure 5-2). In total about 850 acres or 30 percent of the 1955-2013 CMZ area has become restricted, with the most extensive restrictions in Reach 6, where over half of the CMZ is no longer accessible to the river. This is likely a conservative number due to additional pre-1950 impacts of the rail lines which included channel straightening and relocation.

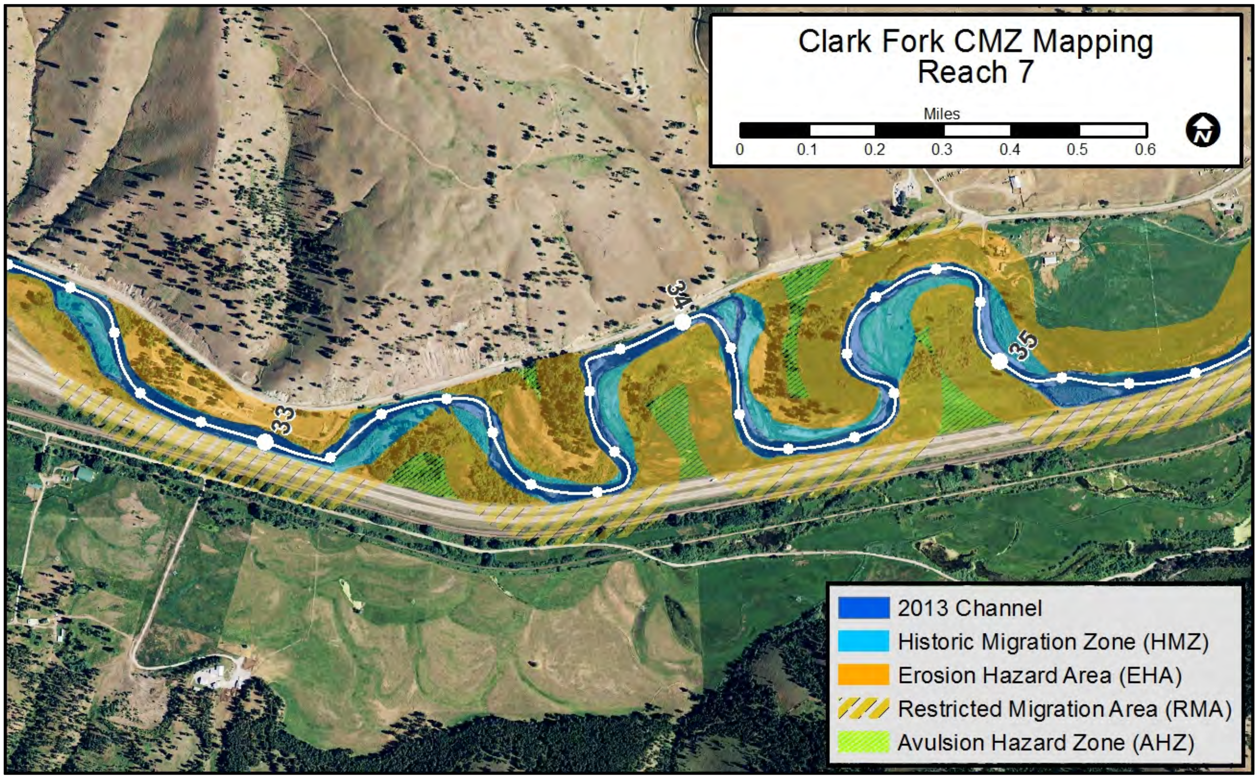

Figure 5-1. Example CMZ map segment showing CMZ map units including areas restricted by transportation infrastructure and other armoring (cross hatch).

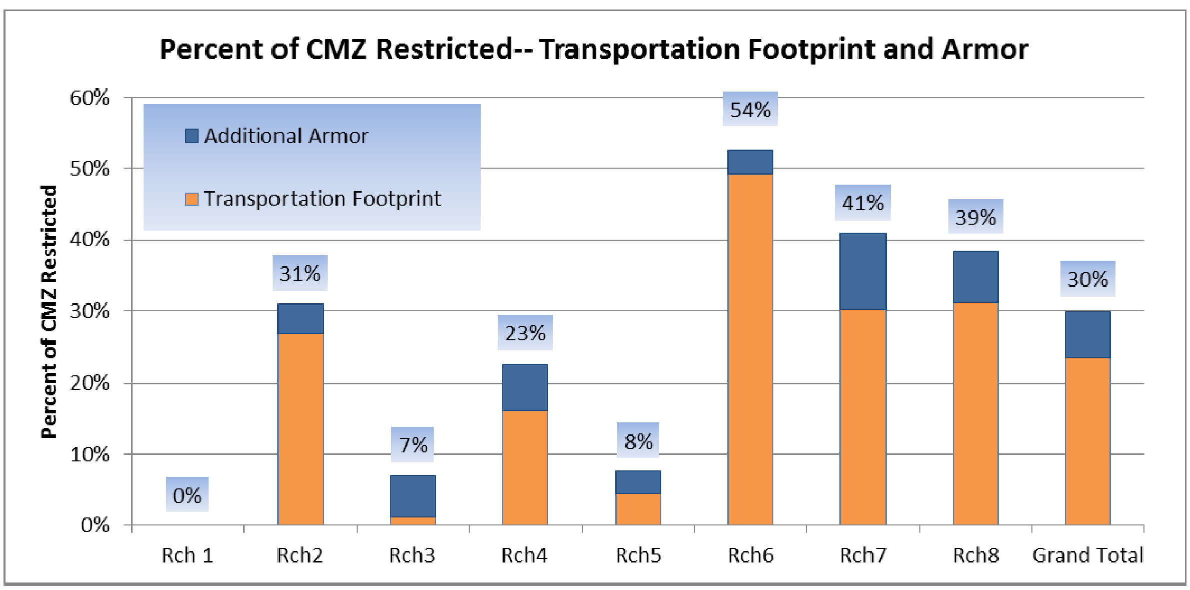

Figure 5-2. Portion of post-1955 Channel Migration Zone restricted by transportation footprint as well as armor protecting other land uses.

5.1.1 CMZ Restrictions due to Transportation Infrastructure

In order to determine the role the various transportation corridors play in CMZ restrictions, the restricted areas were attributed in terms of cause of restriction. This could be achieved in different ways due to the sub-parallel nature of the embankments. As the railroad lines and I-90 corridor cross each other multiple times, their relative proximity to the river also changes (Figure 5-3, Figure 5-4, and Figure 5-5). For this data workup, the RMA acreage associated with each transportation element reflects the footprint of the infrastructure itself as well as any native ground behind that infrastructure (Figure 5-6). As shown in Figure 5-6, the attributes define slivers of restricted areas associated with a given type of transportation, which include the abandoned railroad, active railroad, I-90, and other roads. As the most riverward transportation line in Figure 5-6 is the abandoned railroad, it could be considered the ultimate cause of restriction; the data are summarized in this timeline-based fashion in Section 5.1.2. For this section, the data are summarized by polygon area to characterize the individual influence of each transportation element on the CMZ footprint.

Figure 5-3. Main transportation corridor elements including (from left)—Milwaukee Line, BNSF Line, abandoned rail line, I-90, and Frontage Road on right.

Figure 5-4. View across river (south) showing restrictions of CMZ by rock riprap, I-90, and rail line.

Figure 5-5. CMZ restriction by the Frontage Road.

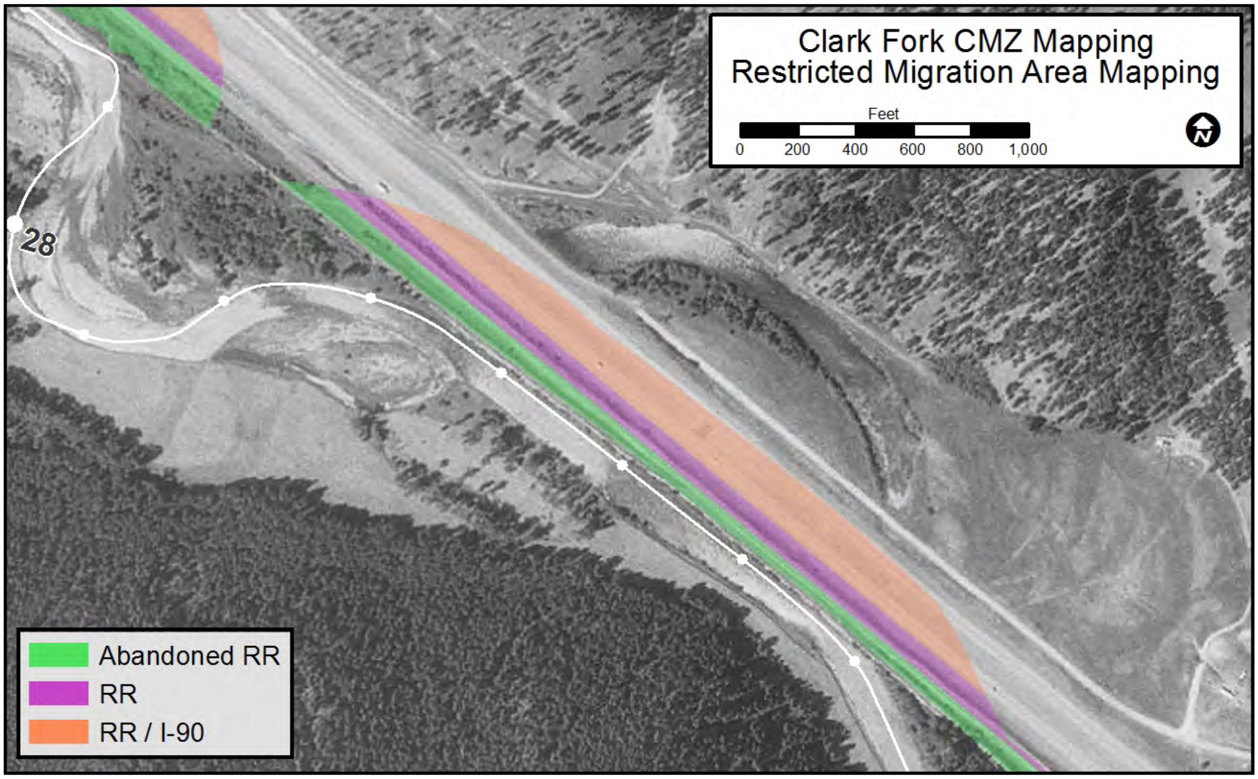

Figure 5-6. Restricted Migration Area (RMA) mapping showing restricted areas attributed to transportation infrastructure elements; "RR/I90" refers to RMA under the I-90 corridor footprint that is also behind the rail line.

Figure 5-7 and Figure 5-8 show the extents of CMZ restrictions from transportation infrastructure using the methods described above. The most extensive restrictions are in Reaches 6 through 8, which extend from Drummond to Beavertail Hill State Park. In Reach 6, almost one half of the CMZ is restricted by transportation infrastructure alone. Where I-90 is behind the rail line such as in Figure 5-6, it is summarized as I-90, reflecting its footprint in the CMZ.

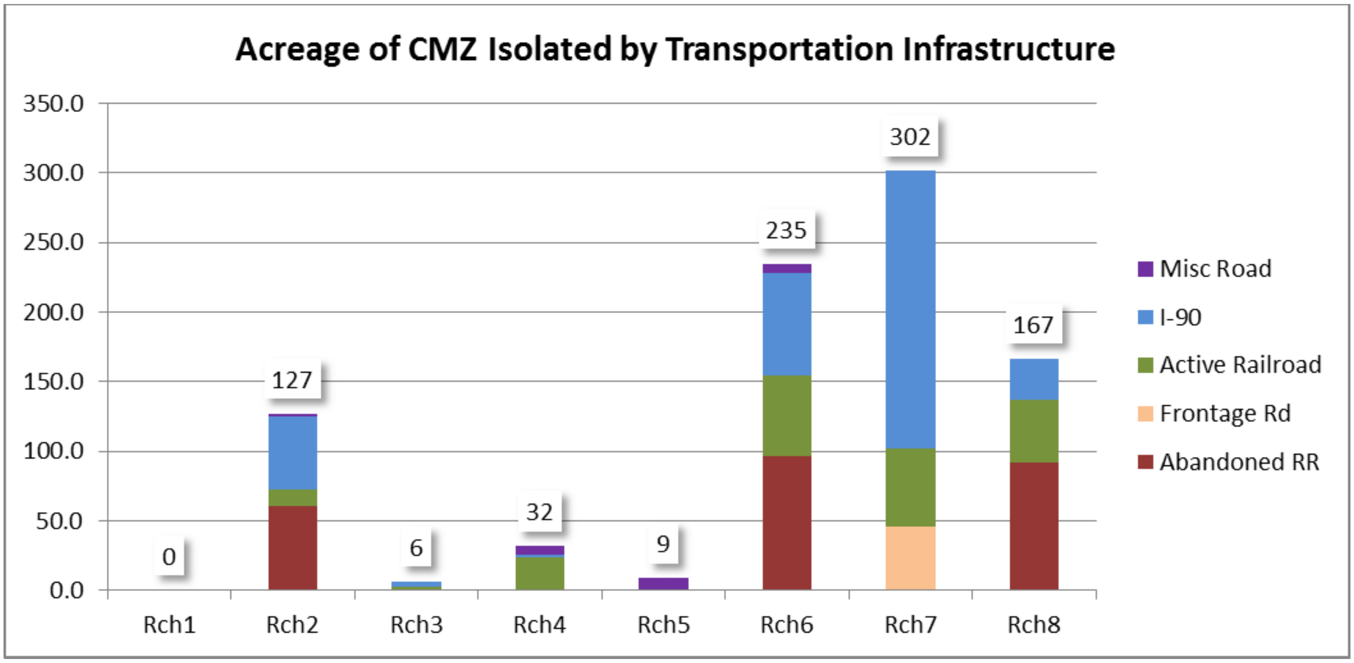

Figure 5-7. Total acreage of CMZ isolated by various types of transportation infrastructure.

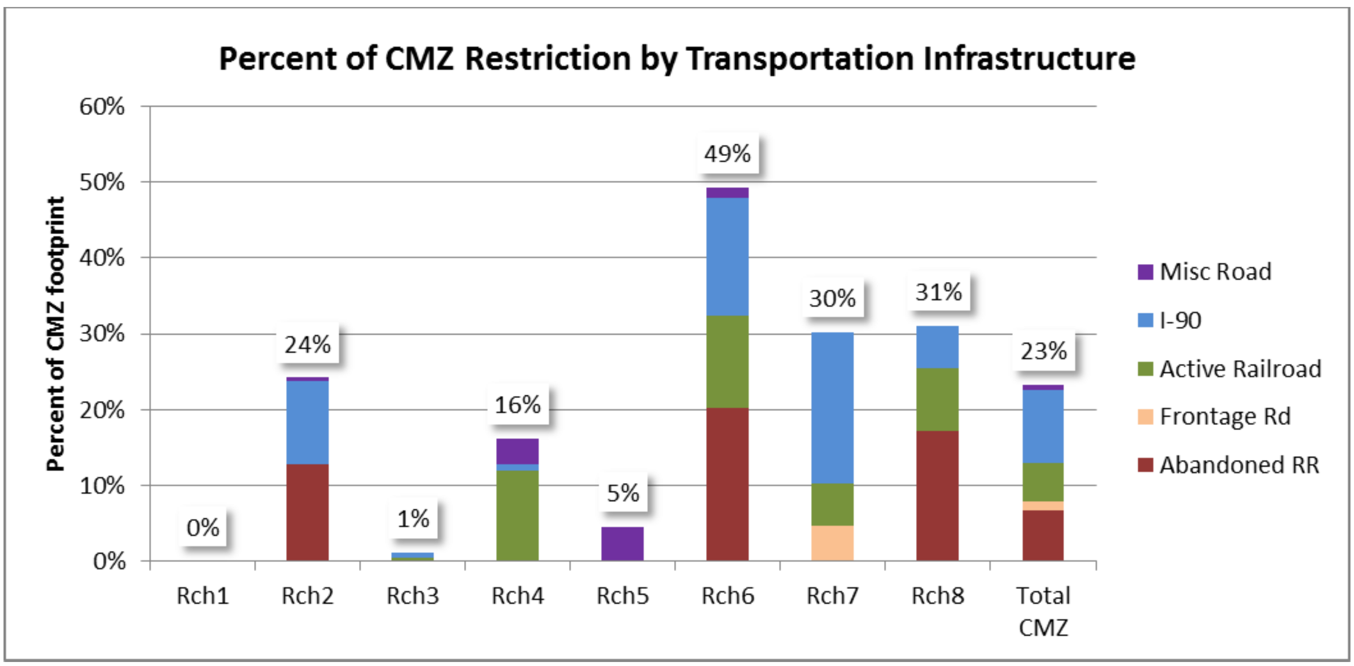

Figure 5-8. Percent of CMZ restricted by various types of transportation infrastructure.

A summary of the entire Restricted Migration Area (RMA) dataset indicates that the I-90 corridor alone restricts about 360 acres or 10 percent of the entire CMZ (Figure 5-9 and Figure 5-10). About 93 of those acres of I-90 restriction are also behind a rail line; whereas 270 areas are not. It is also interesting to note that the abandoned rail line restricts about 249 acres of the modern CMZ, 186 acres of which are not affected by other infrastructure. Many of these areas isolate undeveloped floodplain and thus could potentially provide excellent CMZ restoration opportunities (Figure 5-11).

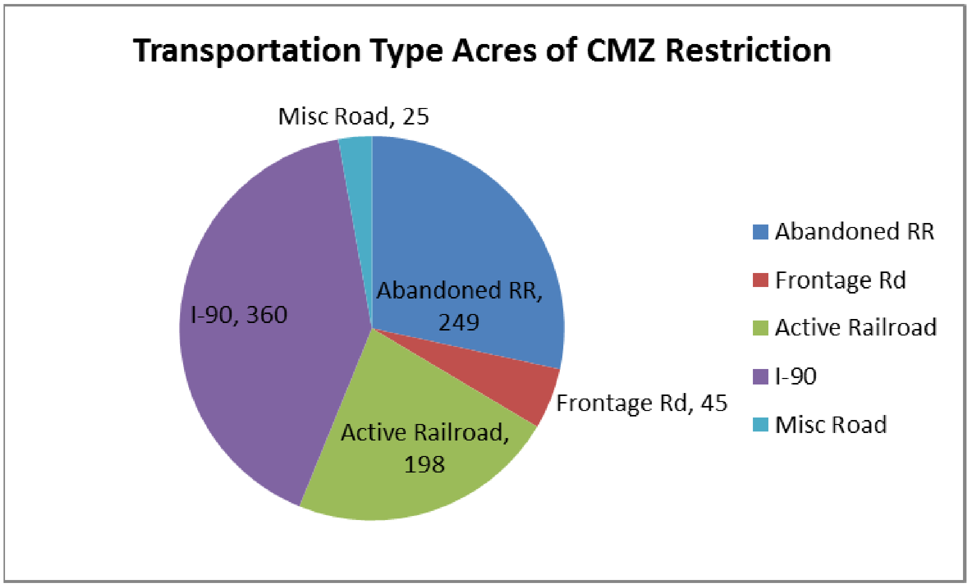

Figure 5-9. Acreage of total CMZ restrictions by transportation infrastructure type.

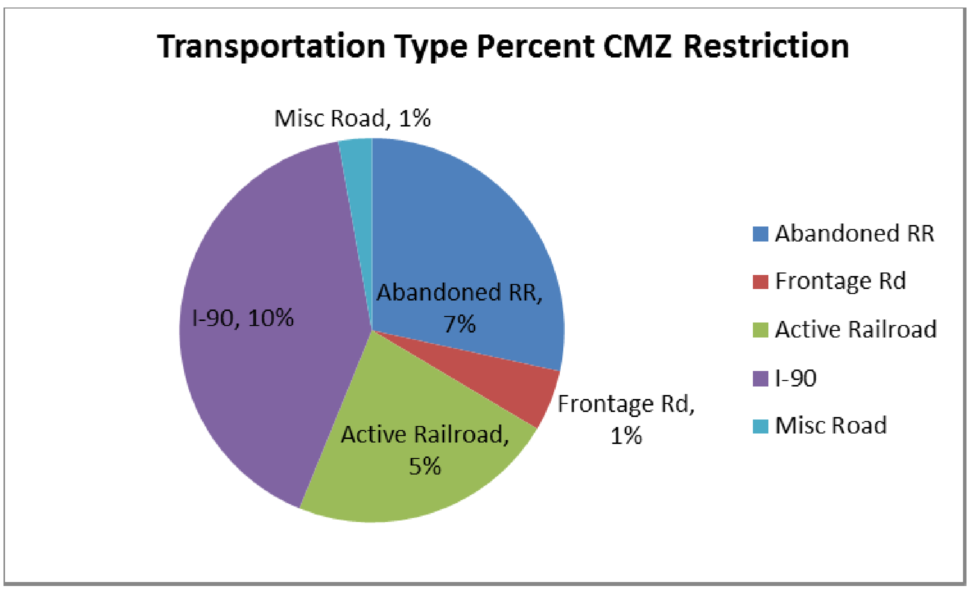

Figure 5-10. Percent of total CMZ restrictions by transportation infrastructure type.

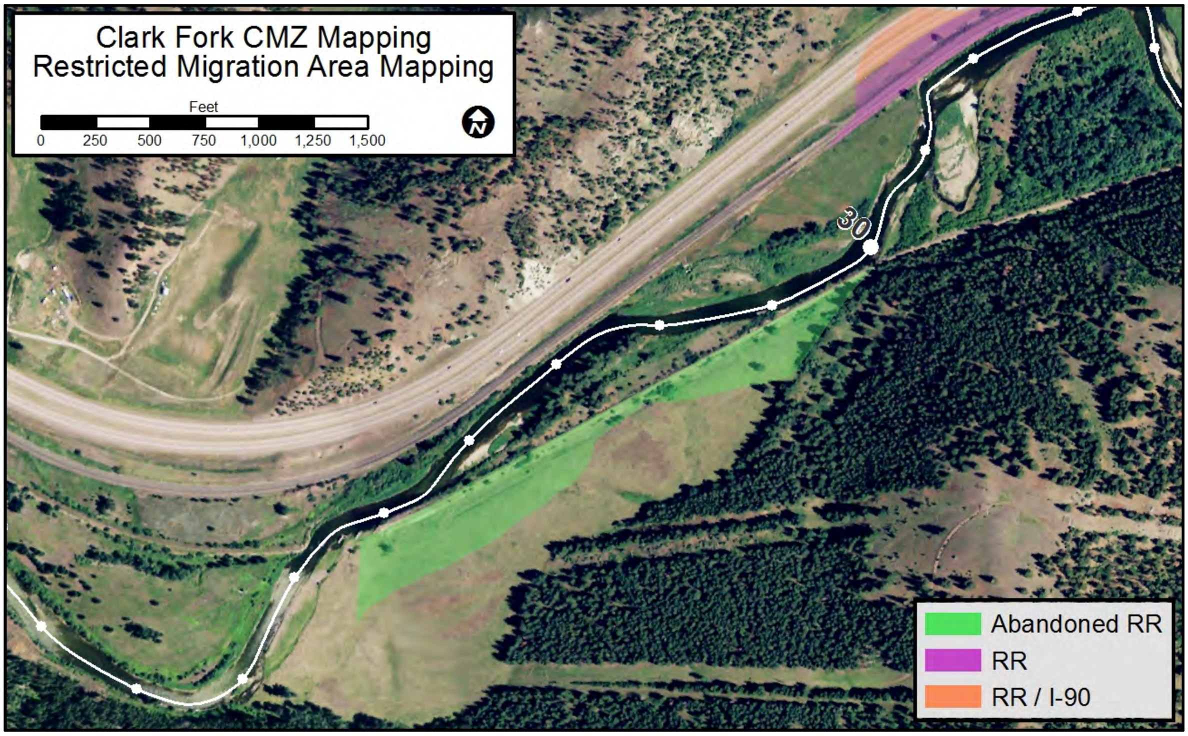

Figure 5-11. Area of CMZ restriction by abandoned rail line showing potential opportunity for CMZ restoration.

5.1.2 CMZ Restriction Timeline

In order to characterize the progressive loss of CMZ area, the data were re-summarized in terms of the date of original CMZ area loss. By the early 1900s, about 540 acres of the CMZ had been restricted by the two rail lines (Figure 5-12). Between 1909 and the 1960s, there was little additional impact because the Frontage Road largely follows the north valley wall with only minimal encroachment into the CMZ. All of that isolation was in Reach 7. Several decades later, the construction of I-90 resulted in more than 270 acres of additional CMZ area becoming restricted from the river, most of which was in Reach 7. These areas are new restrictions, and do not include those areas that had already been isolated by the railroad.

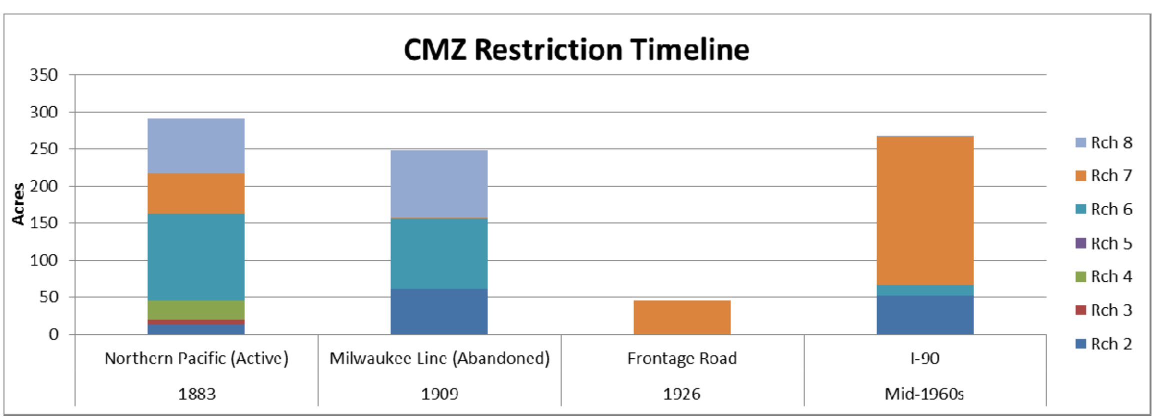

Figure 5-12. General timeline of transportation-related CMZ restrictions.

5.1.3 Additional CMZ Restrictions due to Bank Armor

Bank armor has been constructed throughout the project reach to protect a variety of land uses (Figure 5-13). A field inventory of armor type and extent was provided by Dan Brewer of the USFWS for Reach 2 through Reach 8, which extends from the upper end of the old Milltown Reservoir site to Drummond. The results show that there are a total of 21.4 miles of bank armor in those reaches, which covers about 21 percent of the entire bankline of the main channel (Table 4). The vast majority of bank armor is rock riprap (17.6 miles), with lesser extents of toe rock (3.8 miles). Armor densities are greatest in Reaches 2, 6, 7, and 8, where between 24 percent and 29 percent of the total bankline is armored (Figure 5-14).

The mapped armor extents have been used to help quantify additional areas of the natural Channel Migration Zone that have become restricted from active channel processes. Results show that in addition to the direct impacts of the transportation corridor and its armor, another 7 percent of the CMZ is restricted by additional bank protection that either protects non-transportation related land uses or slivers of land between the transportation embankments and the river (Figure 5-15 and Figure 5-16). Most of the bank armor that is not on the transportation embankments is protecting agricultural ground.

About 27 acres of CMZ have become isolated by armor that is adjacent to, but not on the railroad embankment. Similarly, there are another 20 acres of CMZ restricted by armor that is riverward of I-90. Most of these areas are relatively thin slivers of land that do not provide much CMZ restoration opportunity.

Figure 5-13. View upstream showing full bank rock riprap protection agricultural land.

Table 4. Field inventoried bank armor lengths.

Reach	*D/S RM*	*U/S RM*	*Length (mi)*	*Bank Length (ft)*	*Armor Length (ft)*	*Percent Armored Banks*
Reach 1	0	2.6	2.6	27,456	No Data	No Data
Reach 2	2.6	8.4	5.8	61,248	17,379	28%
Reach 3	8.4	17.5	9.1	96,096	5,383	6%
Reach 4	17.5	22.1	4.6	48,576	6,451	13%
Reach 5	22.1	23.7	1.6	16,896	232	1%
Reach 6	23.7	31.6	7.9	83,424	20,865	25%
Reach 7	31.6	46.8	15.2	160,512	46,693	29%
Reach 8	46.8	53	6.2	65,472	16,025	24%
Total			53	532,224	113,027	21%

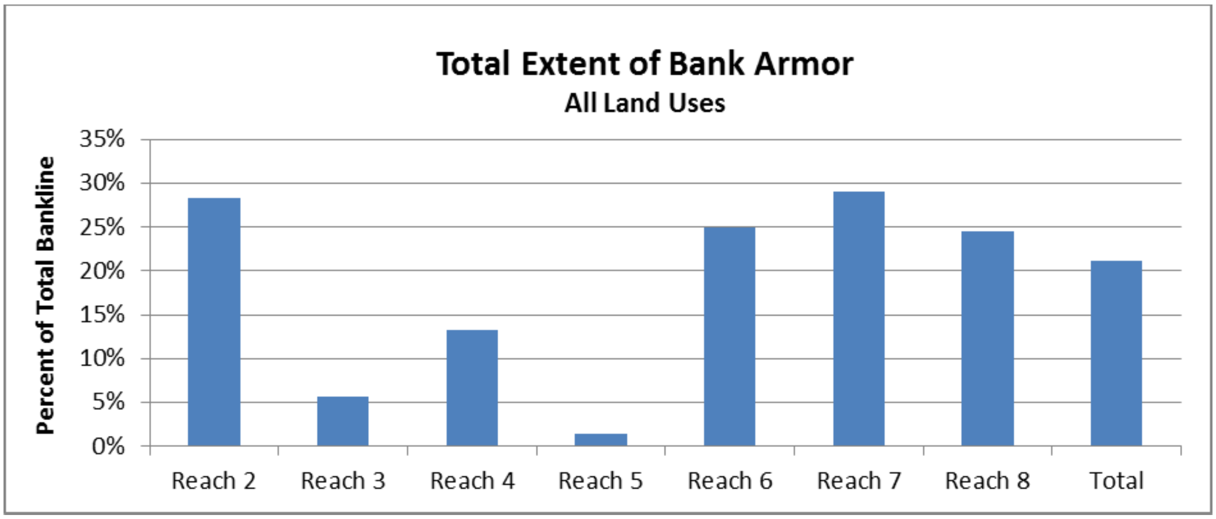

Figure 5-14. Percent of total bankline armored by either toe rock or full-bank rock riprap, Reaches 2-8.

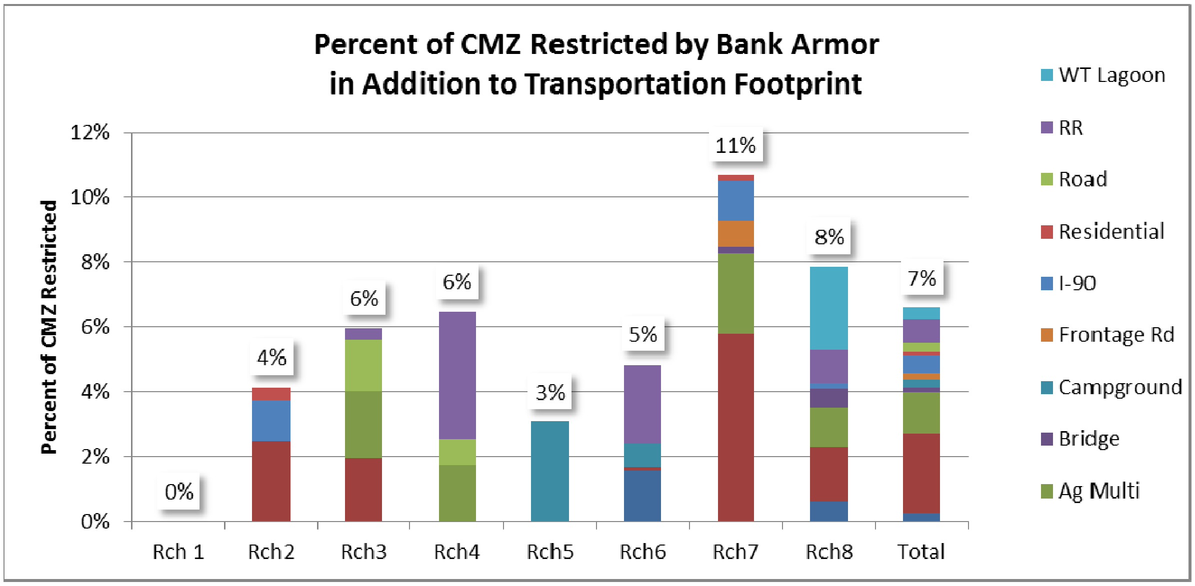

Figure 5-15. Bank-armor-derived CMZ restrictions that are in addition to those caused by transportation embankment footprints.

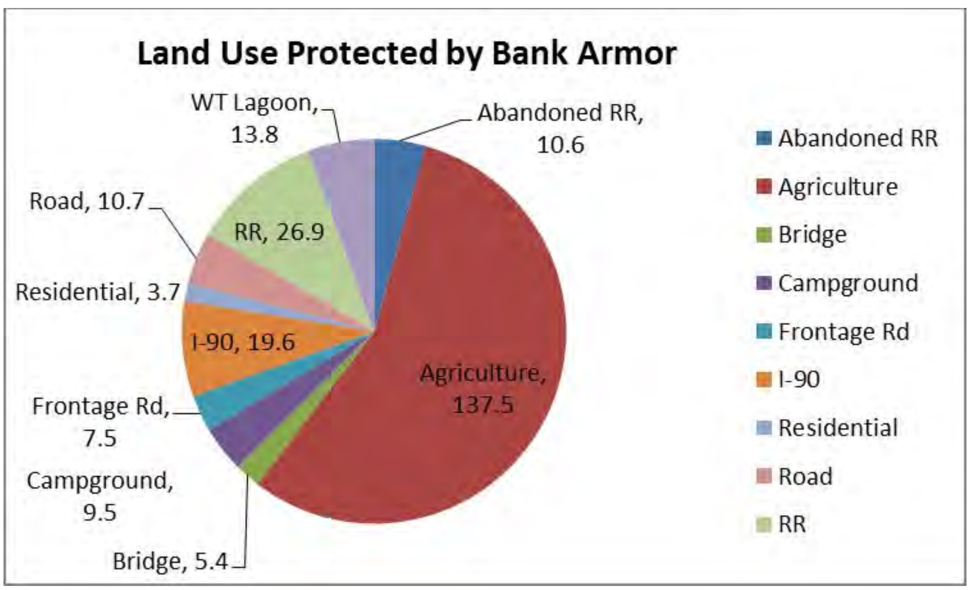

Figure 5-16. Total acreage of CMZ restricted by bank armor not on transportation embankment.

5.2 Historic Channel Relocations Not Captured In CMZ

It is apparent from imagery that the original construction of the rail line through the project reach included extensive relocation and straightening of the Clark Fork River. General Land Office Survey maps show some of this change (Figure 5-17), although the Northern Pacific Rail Line was already in place during that survey so some impacts had already taken place. There are numerous channel scars in floodplain areas that have become isolated from the river by the original 1883 railroad (Figure 5-18).

Construction of the Interstate in the 1960s included additional relocations and reductions in overall channel length. Because of the nature of the impacts, it is difficult to trace the pre-railroad channel course. A rough estimate of the length suggests that between Drummond and Milltown, the river has been straightened from an original length of about 58 miles to 52.7 miles today, which is about a 9 percent reduction in channel length. This value is highly approximate and is based on a course visual evaluation of channel remnants on the imagery.

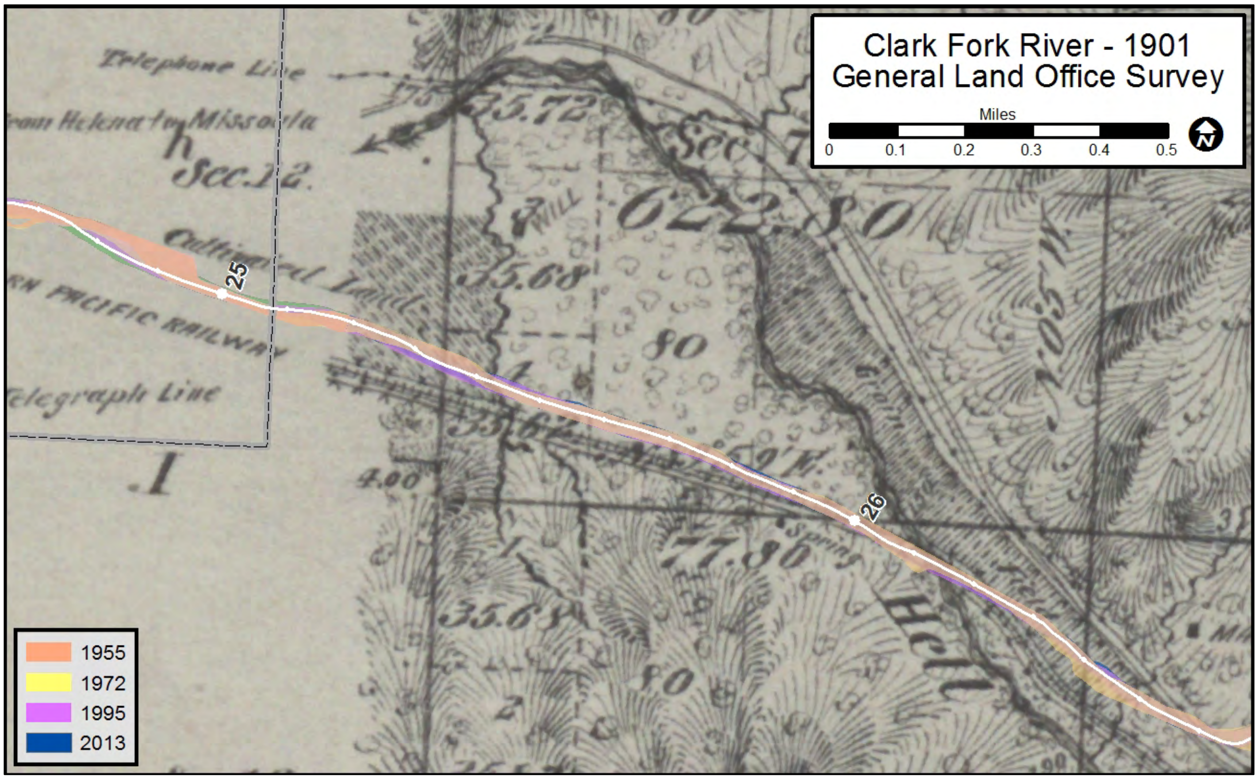

Figure 5-17. General Land Office Survey map showing area where historic river course was straightened.

Areas that encompass channel remnants and intervening floodplain beyond the modern CMZ boundaries that appear to have been intentionally abandoned with relocation of the river have been digitized to help assess pre-development conditions and subsequent impacts (Figure 5-19). These mapped areas are a very coarse estimation of the total area between the modern CMZ and the historic channel traces. In reality, these areas represent both pre-development historic migration areas as well as floodplain, but they provide a sense of the extent of channel relocation in each reach. The greatest extent of relocation was in Reach 4 where the river was displaced over about 280 acres of ground. In total, the displacement was on the order of 880 acres; that is the amount of channel and intervening area between the modern CMZ and the floodplain channel remnants (Figure 5-20).

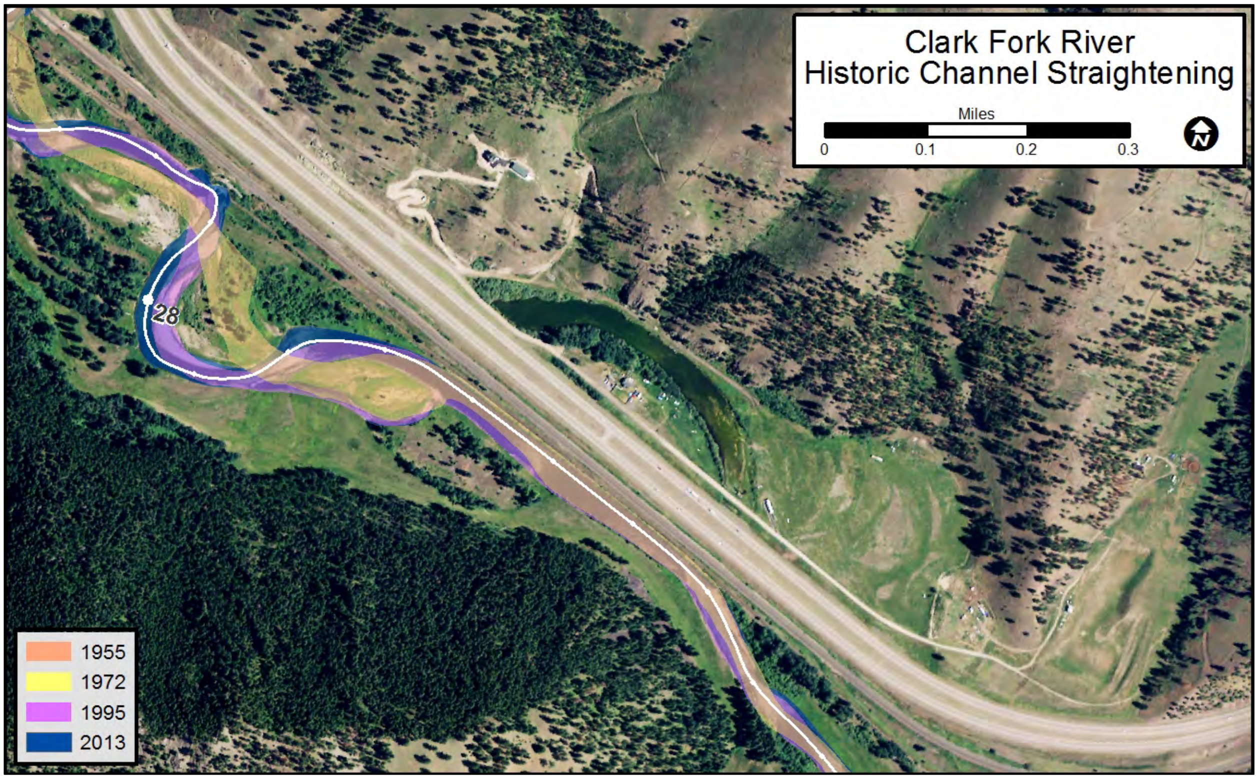

Figure 5-18. Channel remnant in isolated floodplain area.

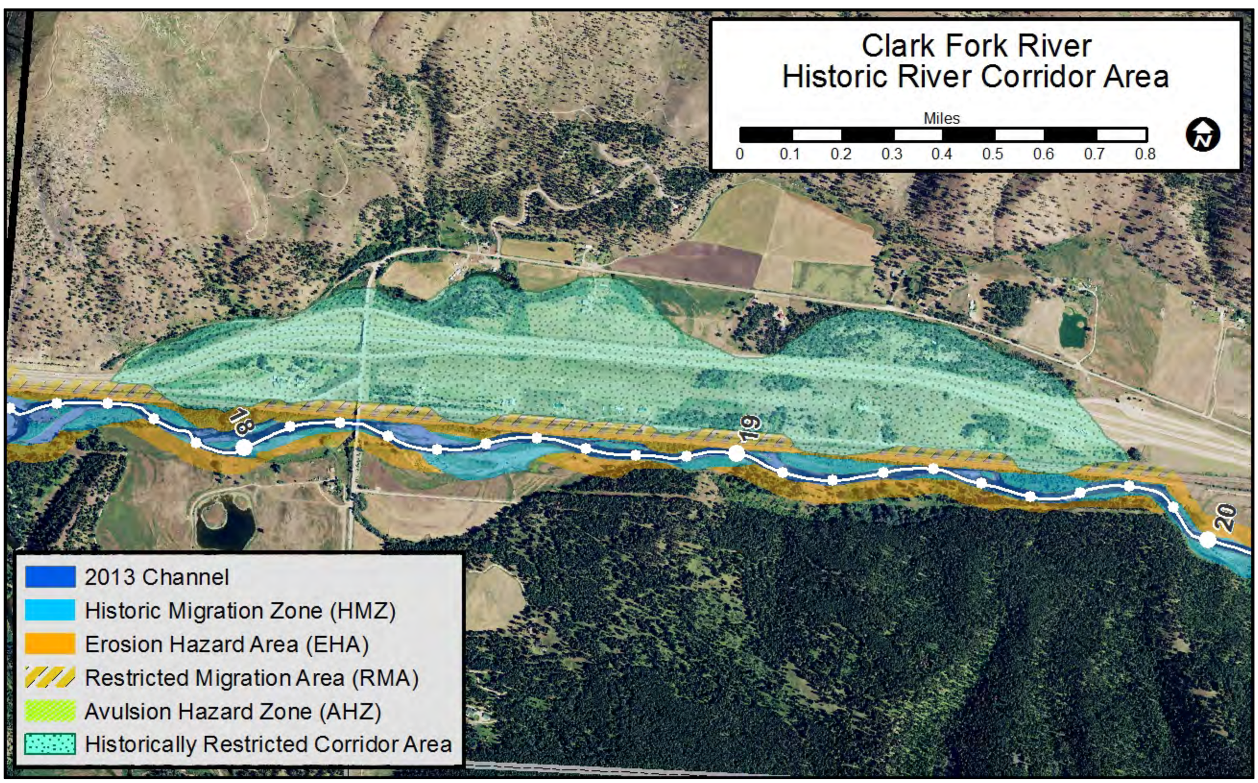

Figure 5-19. Mapped Isolated Historic River Corridor Area.

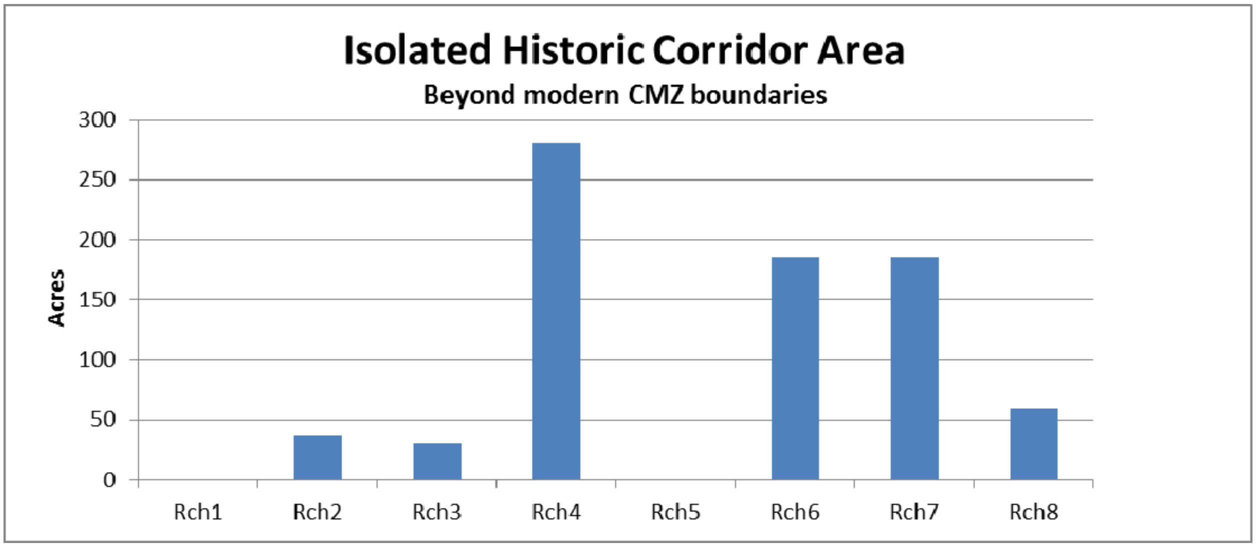

Figure 5-20. Isolated areas and channel remnants and intervening floodplain beyond modern CMZ boundaries.

5.3 Bank Erosion Inventory and Risks to Infrastructure

Bank erosion was inventoried for extent and severity for Reaches 2 through 8. Bank erosion extents range from a low of 6 percent in Reach 4 to 14 percent in Reach 3 (Table 5 and Figure 5-21). In total, about 11 percent of the bankline was mapped as eroding, with 2 percent of the bankline mapped as severely eroding.

Table 5. Summary of bank erosion inventory.

Reach	*Bank Length (ft)*	*Mild Erosion (feet)*	*Moderate Erosion (feet)*	*Severe Erosion (feet)*	*Mild Erosion (pct)*	*Moderate Erosion (pct)*	*Severe Erosion (pct)*	*Total Erosion*
Reach 1	27,456	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Reach 2	61,248	-	7,887	-	0%	13%	0%	13%
Reach 3	96,096	494	8,611	3,879	1%	9%	4%	14%
Reach 4	48,576	754	1,661	457	2%	3%	1%	6%
Reach 5	16,896	-	1,480	550	0%	9%	3%	12%
Reach 6	83,424	409	4,323	1,385	0%	5%	2%	7%
Reach 7	160,512	1,944	11,144	6,233	1%	7%	4%	12%
Reach 8	65,472	987	3,994	618	2%	6%	1%	9%
Total	532,224	4,588	39,100	13,122	1%	7%	2%	11%

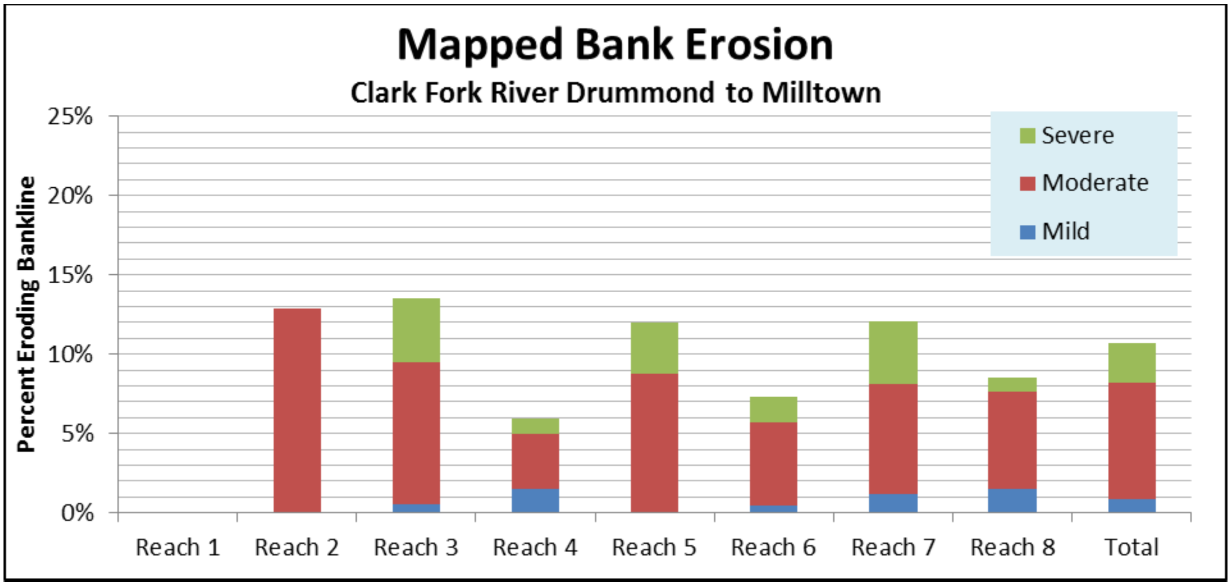

Figure 5-21. Percent eroding bankline by reach (no data were available for Reach 1).

5.4 Impacts of CMZ Development on Riparian and In-Stream Habitat

Development within the Channel Migration Zone has the potential to substantially impact riparian and instream habitat conditions. These impacts relate to lost area for channel migration to occur, reduced rates of change and habitat formation/rejuvenation, and the potential for channel destabilization.

5.4.1 Impacts to Riparian Vegetation

The most significant impact of CMZ development on riparian vegetation in the project reach is the loss of riparian habitats due to transportation infrastructure footprints. A total of 877 acres or 24 percent of the CMZ has been consumed by transportation embankments, and the vast majority if not all of this area was likely floodplain riparian habitat prior to development.

Riparian impacts also relate to the process of channel movement and riparian rejuvenation. Development in the corridor has included the construction of at least 21.4 miles of bank armor to protect various land uses including transportation and agriculture. This armor has arrested channel migration over about 21 percent of the bankline, which results in reduced rates of riparian recruitment on open bar areas and associated riparian forest regeneration.

5.4.2 Impacts to Fish Habitat

The noted impacts to the riparian system above also affect aquatic habitat due to the loss of large wood availability and recruitment rates to the river. Furthermore, aquatic habitats have been impacted by channel relocation. Relocations have resulted in much more of the bankline being comprised of valley wall bluff habitat, which can create very different habitat conditions relative to alluvial river margins. Reduced bank migration rates affect sediment recruitment and potentially the quality and extent of rearing habitat in the river. And lastly, straightening of the channel reduces the potential for habitat creation and sustenance through the processes of bendway formation and lateral scour. Lateral scour pools are typically the most common pool type in an alluvial river such as the Clark Fork, such that artificial channelization can effectively remove the vast majority of pool habitats. No detailed assessment of pool loss was performed for this effort, however a pool inventory through the project reach would provide insight as to major drivers of pool formation including lateral scour, large wood, or bedrock exposures, which would then provide a sound bases for assessing the impacts of CMZ development on aquatic resources.

5.4.3 Impacts to Channel Stability

With the available information it is impossible to determine whether the impacted CMZ on the Clark Fork River has led to geomorphic stability. In other systems, however, extensive armoring has been shown to cause channel downcutting, resulting in lost floodplain connectivity, side channel connectivity, and riparian health. Whether or not this has occurred on the Clark Fork is not clear, although bank armor extents of 21 percent of the total bankline coupled with channel straightening has likely driven substantial geomorphic adjustments within the channel. A more detailed evaluation of channel and floodplain morphology would help determine if there is some armoring and/or channelization threshold in this system that results in measurable geomorphic response.

6 Channel Migration Zone Summary by Reach

The following section contains a general summary of the CMZ mapping results in each of the eight project reaches. Larger-scale reach maps can be found in Appendix A: Reach Maps.

6.1.1 Reach 1: Historic Milltown Dam Reservoir

Reach 1 is about 2.5 miles long and is located in the impoundment area of the old Milltown Dam. Within this reach the Channel Migration Zone is dominated by a broad Historic Migration Zone that captures the river footprint since 1955. Discreet side channels on the south side of the floodplain have been mapped as potential avulsion areas. This area was the focus of a massive dam removal/restoration project between 2003 and 2012 as part of a Superfund Cleanup effort that included the removal of contaminated reservoir sediments and reconstruction of several miles of channel and about 200 acres of floodplain (Figure 6-2). The system was reconstructed as a deformable, dynamic river/floodplain, so that the CMZ is minimally restricted in this reach. Bank erosion and armor inventory data were not available for Reach 1.

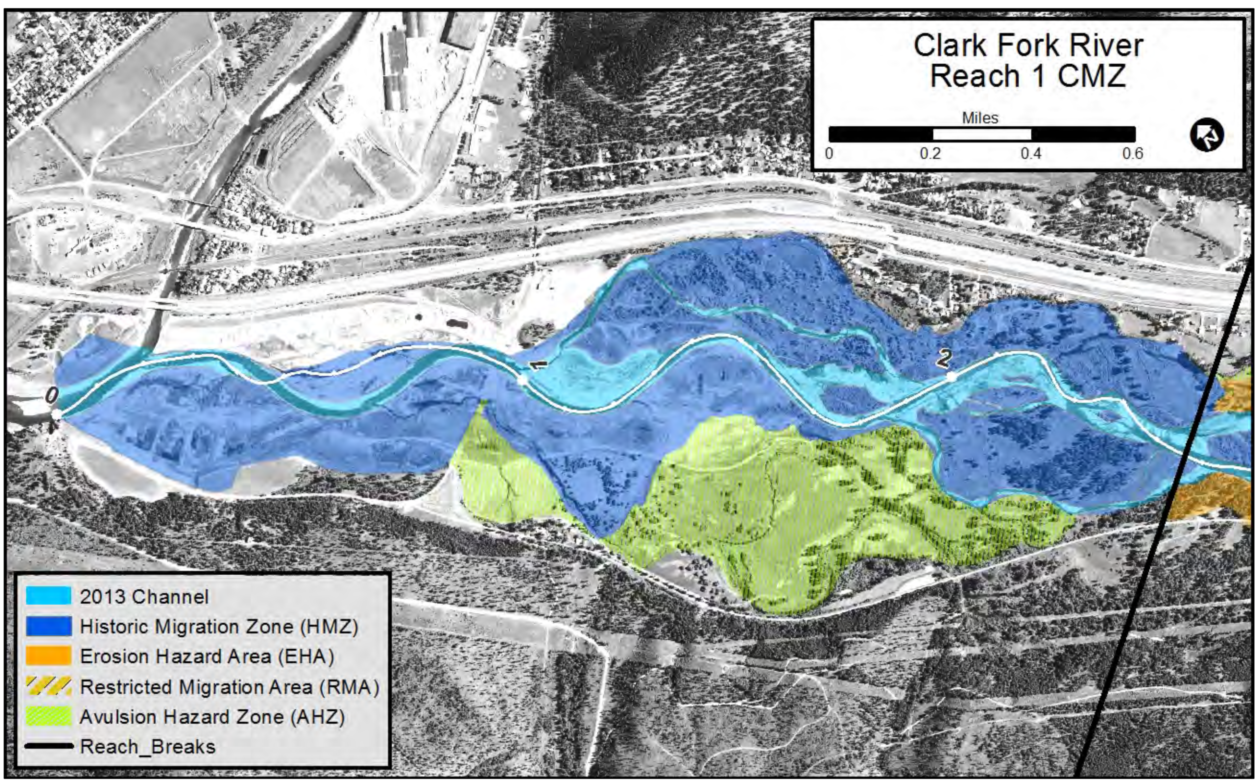

Figure 6-1. Reach 1 Channel Migration Zone (2013 imagery).

Figure 6-2. View downstream of Reach 1 showing Milltown Dam Removal and Restoration Site shortly after project completion (River Design Group).

The overall project goal of the project was to "Restore the confluence of the Blackfoot and Clark Fork Rivers to a naturally functioning, stable system" (Westwater Consultants and others, 2005).

Opportunities for Reach 1 are substantial in that the river is largely unconfined through the old reservoir, and site recovery is underway. Recommendations for Reach 1 include allowing unimpeded channel deformation in this area to the greatest extent possible, while accommodating monitoring and maintenance strategies as defined in the restoration effort. There is a ~1 mile long historic channel on the south side of the abandoned rail line embankment (now Crystal Creek Rd) in the uppermost portion of Reach 1 (upstream of RM 2.0) which could be evaluated for potential connectivity and habitat improvements. The current connectivity of this historic channel is unknown but wetlands mapping indicates that it supports freshwater emergent wetlands.

Overall, Reach 1 has some of the greatest potential for long term natural habitat formation through channel movement, scour, and woody debris recruitment. As a result, it should be carefully managed to limit impacts to those processes.

6.1.2 Reach 2: Donovan Creek to Milltown Dam Reservoir

Reach 2 is located in the vicinity of Turah. The reach is 5.8 miles long and has substantial rural residential development in the valley bottom. The river closely follows transportation infrastructure through the reach, including the Interstate in the upper portion of the reach and the Milwaukee Line in the lower portion of the reach. As a result, about 31 percent of the CMZ has been restricted, and 28 percent of the banks are armored. The calculated erosion buffer for Reach 2 is 331 feet and there are numerous structures within the mapped Erosion Hazard Area. About 13 percent of the bankline was mapped as actively eroding, and the severity of that erosion was considered moderate.

The abandoned Milwaukee line on the southwest side of the river between River Miles 3 and 5 isolates about 50 acres of historic floodplain and channel area that hosts emergent wetland swales and dense riparian vegetation. Breaching of the old berm in this area could provide restoration opportunity, however residential development behind the berm may limit project feasibility. The most extensive encroachment into the CMZ is upstream between River Miles 5 and 7.5, where the river flows essentially straight against the Interstate to the northeast and residential developments to the southwest.

At RM 2.7R there are structures within the Erosion Hazard Area that are currently within 300 feet of a side channel that was abandoned by the main thread between 1995 and 2001. This channel segment now conveys seasonal flow and still creates a risk of migration into those properties.

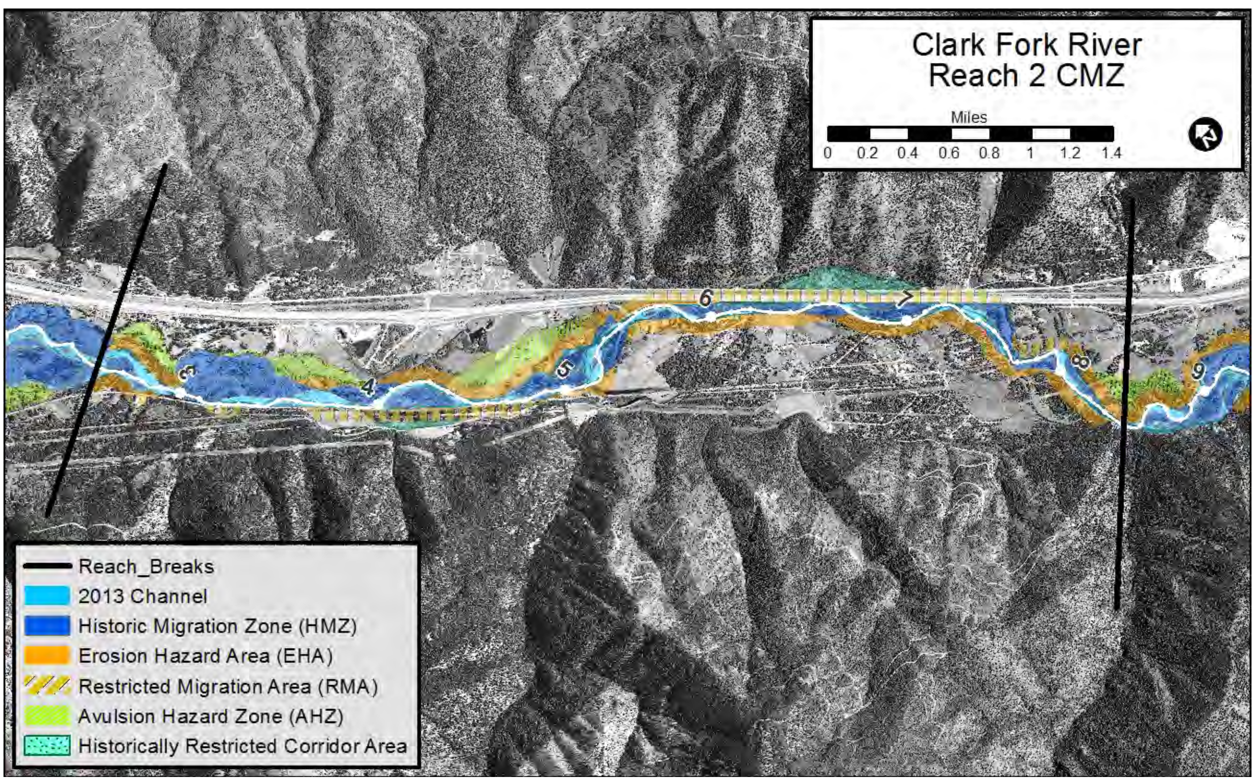

Figure 6-3. Reach 2 Channel Migration Zone (2013 imagery).

Between RM 3.4 and RM 3.9 there is an ~82 acre conservation easement within the CMZ on the right floodplain area. This area contains a myriad of seasonal side channels and avulsion hazards. Currently, the Clark Fork River flows along the rail line in this area with minimal instream complexity. It is starting to migrate into the eased area, which would have created a high risk if the land had been residentially developed. Securing conservation easements in areas such as this will help reduce risk to landowners and optimize long-term stream function in this otherwise highly-confined system.

At RM 6.0, Turah Road is within 300 feet of the river and the channel is migrating towards the road. There are several structures within the Erosion Hazard Area between the Turah Fishing Access Site and the Turah Road Bridge. Similarly, Hellgate Lane is within the EHA at RM 6.9L, and the bank erosion in this area was mapped as moderately severe. At RM 7.9R, the river has eroded through the abandoned rail grade and the bank has since been armored with riprap. With available data it is unclear whether floodwaters can more easily access the floodplain behind the berm due to the breach, which occurred between 1972 and 1995.

Specific Opportunities in Reach 2 Include:

- CMZ reactivation on the southwest side of the river between RM 3 and RM 5.
- Passive restoration through conservation easements in especially dynamic areas.
- Discouragement of development in the Erosion Hazard Area to reduce the need for additional bank armor.

6.1.3 Reach 3: Rock Creek to Donovan Creek

Reach 3 is located below the mouth of Rock Creek. It is 9.1 miles long, and is one of the most dynamic reaches in the project area. At RM 11.4 there was a major shift in primary channel location between 1972 and 1995, and downstream at RM 10.2 there was a 0.4 mile long avulsion between 1995 and 2011. This avulsion has put a residence at RM 10.1R into the Erosion Hazard Area. At RM 11.6R, about 30 acres of historic floodplain/channel have been isolated from the corridor by the abandoned rail grade. Just upstream of the Schwartz Creek Road Bridge at RM 14.4, the river is eroding on its left bank and will increasingly threaten the left bridge approach. At RM 15.0R, the right bank of the river is severely eroding between two stretches of rock riprap where a residence is located within the EHA. The bank has migrated about 80 feet in this area since 2005. Similarly, at RM 15.8R the river has migrated over 100 feet since 1995 towards a home that is located on the edge of the EHA.

In general, the river closely follows the valley wall on its left bank within Reach 3, and the abandoned Milwaukee Line forms the opposite corridor boundary. The left valley wall is commonly forested and thus provides a potential source of woody debris. Only 7 percent of the CMZ has been restricted, and 6 percent of the banks are armored. The calculated erosion buffer for Reach 3 is 332 feet. The reach has numerous islands and the dynamic nature of the reach appears to be in part driven by sediment loading from Rock Creek which enters the Clark Fork River at RM 17.5.

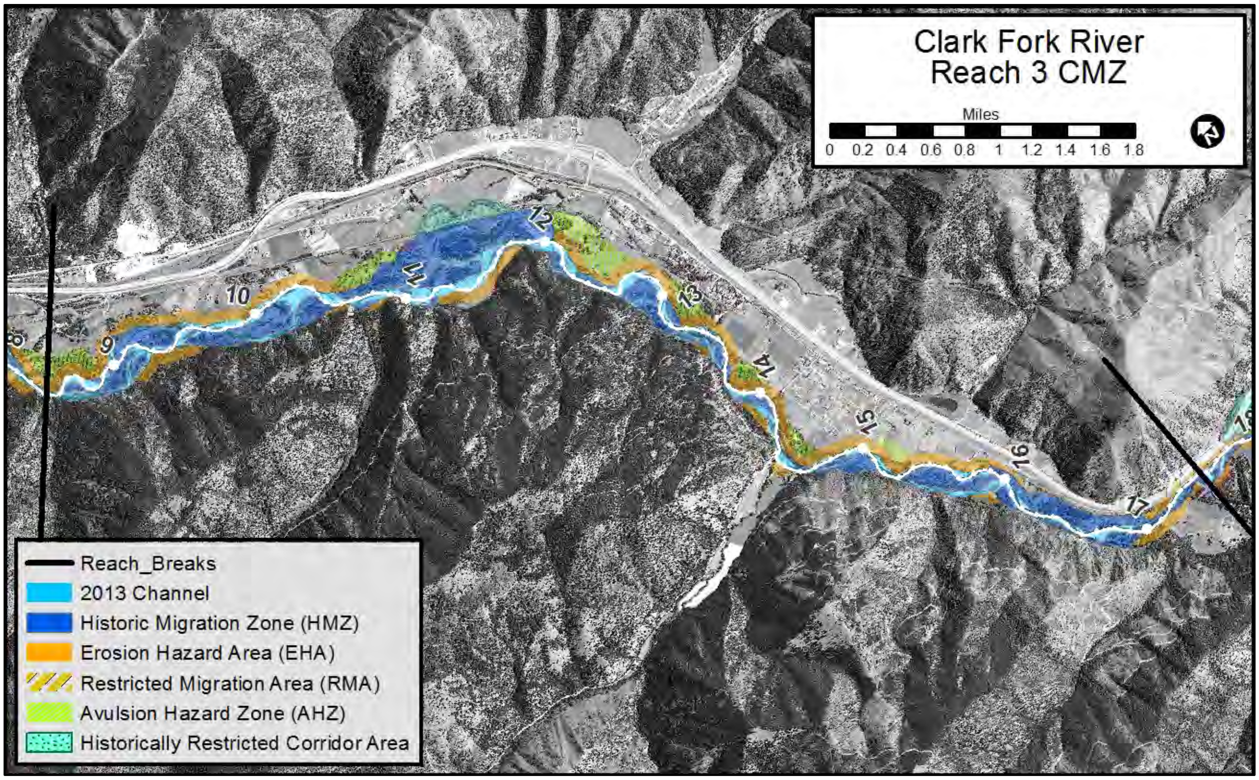

Figure 6-4. Reach 3 Channel Migration Zone (2013 imagery).

Specific Opportunities in Reach 3 Include:

- CMZ reactivation on the north side of the river between RM 11 and RM 12.
- Passive restoration through conservation easements in especially dynamic areas.
- Discouragement of development in the Erosion Hazard Area to reduce the need for additional bank armor.
- Encouragement of riparian recovery within CMZ to reduce risk of additional avulsions.

6.1.4 Reach 4: Below Beavertail Hill to Rock Creek

Reach 4 is located upstream of Rock Creek. The reach is essentially straight, with the river confined against the south valley wall by rail lines on the north side of the river (Figure 6-5). Both the abandoned Milwaukee Line and active BNSF line encroach into the corridor on the north floodplain. The erosion buffer width in Reach 4 is 191 feet, and about 23 percent of the CMZ is restricted. Bank armor covers 13 percent of the bankline. Because the encroaching rail line is still in use, CMZ restoration opportunities are minimal in this reach. In the upper portion of the reach, the CMZ is largely unconfined, although the road that runs west from Beavertail State Park encroaches into the Erosion Hazard Area.

Between RM 17.7 and 19.8 there is a ~240 acre area north of the rail line and Interstate that has channel remnants that were mapped as the active channel on GLO maps from 1874. This area represents over two miles of channel relocation to the south with the construction of the transportation corridor, probably the Northern Pacific Route of the early 1880s. There is another similar HMZ remnant at RM 21.5L that is about 20 acres in size.

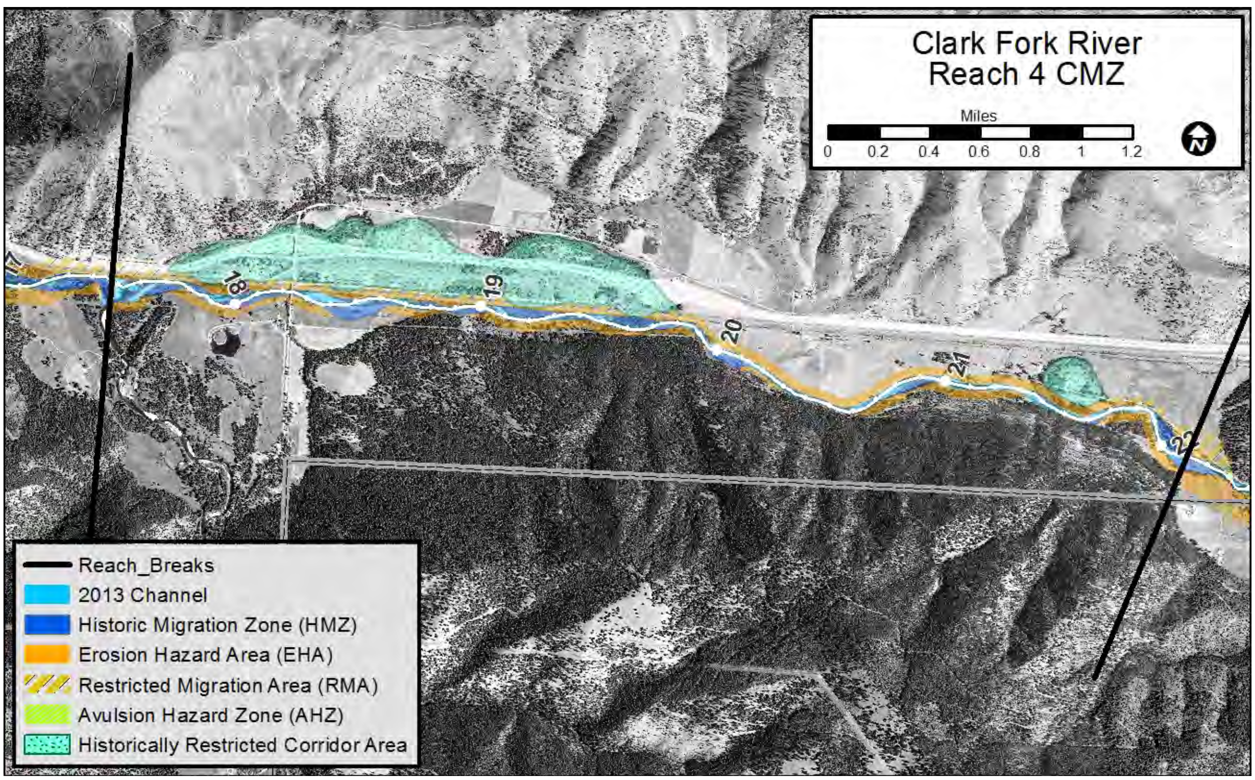

Figure 6-5. Reach 4 Channel Migration Zone (2013 imagery).

Specific Opportunities in Reach 4 Include:

- Seasonal reconnection of historic meander north of rail line at RM 21.5R.

6.1.5 Reach 5: Beavertail Hill State Park

Reach 5 is a relatively short but very dynamic reach in the vicinity of Beavertail Hill State Park. The 1955-2013 measured migration distances in this reach exceed 700 feet at RM 23, where a large meander has migrated south away from Beavertail Hill. As a result, the erosion buffer is almost 600 feet wide. Only 8 percent of the CMZ is restricted in the reach, and all of that is due to the road that leads to the state park. Approximately 1 percent of the bankline is armored in Reach 5, which is the least armoring of any reach in the project area. Much of the campground at the State Park is within the EHA.

The minimal impact to the CMZ in Reach 5 is largely due to the fact that the railroad line was tunneled through Beavertail Hill and the Interstate was excavated through the hill about a half mile north of the river.

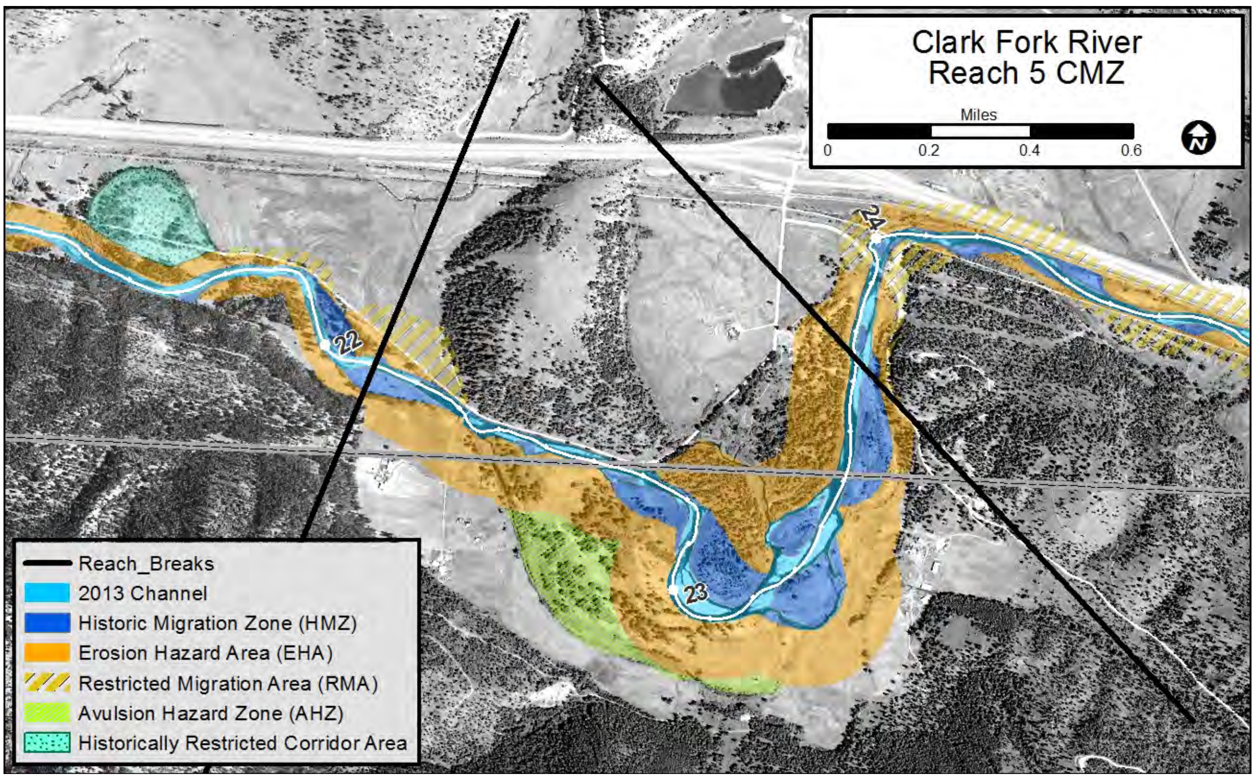

Figure 6-6. Reach 5 Channel Migration Zone (2013 imagery).

Specific Opportunities in Reach 5 Include:

- Grazing management on south floodplain to promote riparian recovery

6.1.6 Reach 6: I-90 Bridge near Ravenna to Beavertail Hill State Park

Reach 6 is located upstream of Beavertail Hill State Park. It is 7.9 miles long and is essentially straight and confined by both the valley wall and transportation embankments. The erosion buffer is 295 feet wide and 54 percent of the CMZ is restricted. About 25 percent of the banks are armored in Reach 6. This reach was clearly straightened with rail line construction. A channel remnant that is over a mile long is located on the north side of the Interstate between RM 25 and RM 26; this channel was mapped as active on GLO maps (Figure 5-17). Another remnant channel is south of the abandoned rail grade between RM 26.2 and 26.8; some of this land is owned by BLM and could provide restoration opportunity in this otherwise highly confined reach. The railroad berm appears to be used as a road although the road is discontinuous; upstream at RM27.5, the bridge on the abandoned rail line has failed, and the embankment is totally eroded out at RM 27.9. At this location (RM 27.9R), the river has eroded through the abandoned line and continues to rapidly erode towards the active rail line, forming two deep scallops in the bank where it is forced to make a 90 degree bend where it approaches the transportation infrastructure. These scallops were mapped as severely eroding. Another area of severe erosion was mapped against the modern rail line just downstream of the bridges at RM 27.35R.

There is another isolated channel remnant north of the Interstate at RM 28.5. At RM 29.4R, a ~400 ft long stretch of rock riprap protects the remnant berm on the downstream limb of a bend. Removal of this riprap would restore CMZ area where the berm is abandoned. Between RM 29.5 and RM 30, about 25 acres of historic floodplain area on the south side of the river has been isolated by the abandoned rail line. This area is on private land, but removal of the berm and associated riprap would more than double the river corridor width.

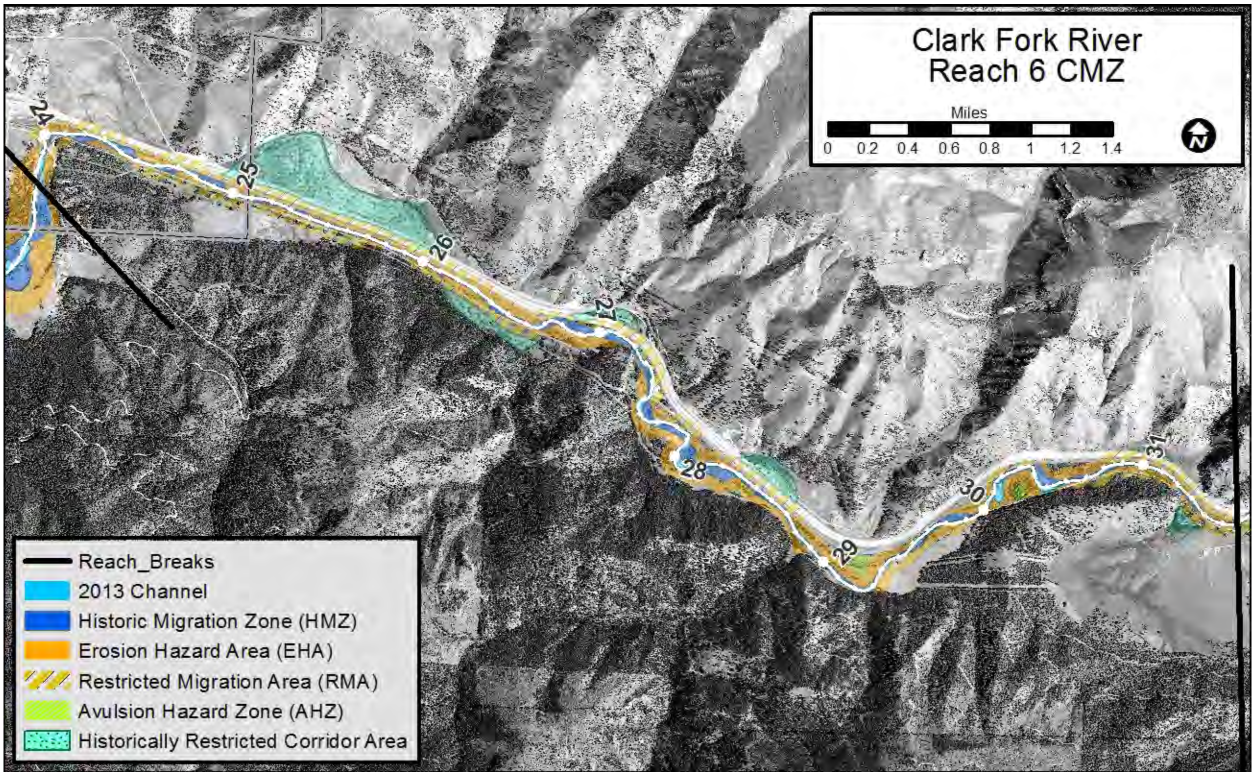

Figure 6-7. Reach 6 Channel Migration Zone (2013 imagery).

Specific Opportunities in Reach 6 Include:

- CMZ reactivation on the south side of the river between RM 26.2 and 26.6.
- CMZ reactivation on the south side of the river between RM 29.3 and 30.

6.1.7 Reach 7: I-90 Bridge crossing just below Rattler Gulch to Ravenna

Reach 7 is 15.2 miles long and shows persistent confinement (CMZ restrictions) by the transportation corridor. The erosion buffer in this reach is 339 feet wide, indicating active migration where the channel has some active corridor width. In most places, however, this corridor has been encroached. About 41 percent of the CMZ is restricted, and almost 30 percent of the streambanks are armored.

At RM 42.4 the river is rapidly migrating towards the Interstate, and will likely require armoring soon. The bank was mapped as severely eroding in the field, and the river is less than 50 feet from the road prism.

Between RM 43.3 and RM 44.1 there are several structures within the Erosion Hazard Area on the north floodplain. The structure at RM 43.9R is at high risk of loss due to rapid migration at the site. That said, the migrating bendway at the site is undergoing an active avulsion (meander cutoff), which will reduce the risk to that property, but increase erosion against the I-90 prism.

The effects of transportation infrastructure on the Clark Fork River are well-demonstrated at RM 44.5, where the bedrock valley wall was excavated to provide a conduit for the river as well as all of the transportation lines. As a result the river is channelized with bedrock and riprap banks for about 1,000 feet, whereas the channel remnant to the south is over 3,000 feet long.

At least two bendways within the upper portion of Reach 7 at RM45 were constructed since 1956, and it appears that these meanders have remained static for decades. There is essentially no topographic or riparian evidence of the relatively straight 1956 channel on either the 1995 imagery or in the field, suggesting that the 1956 channel course was relocated and then completely filled in, graded, and recovered as agricultural land. The relocated bends are conspicuous as they are massively armored with large, full-bank rock riprap, which is unusually costly and aggressive bank protection for hayfields. These conditions suggest that the work was performed to recover lost channel length as part of the Interstate construction, as the lengthened channel is immediately upstream of a channelized segment. However, no record of this work could be found to identify it as mitigation for impacts of the transportation system. Restoring these bendways to a dynamic, unarmored state could potentially provide an excellent restoration opportunity in the reach.

Specific Opportunities in Reach 7 Include:

- Grazing management and active riparian restoration in wide valley segments (RM33-RM37.8, RM 43.2-RM 46.7).
- Removal of rock riprap from RM 44.7 to RM 45.3 to allow migration in undeveloped area.

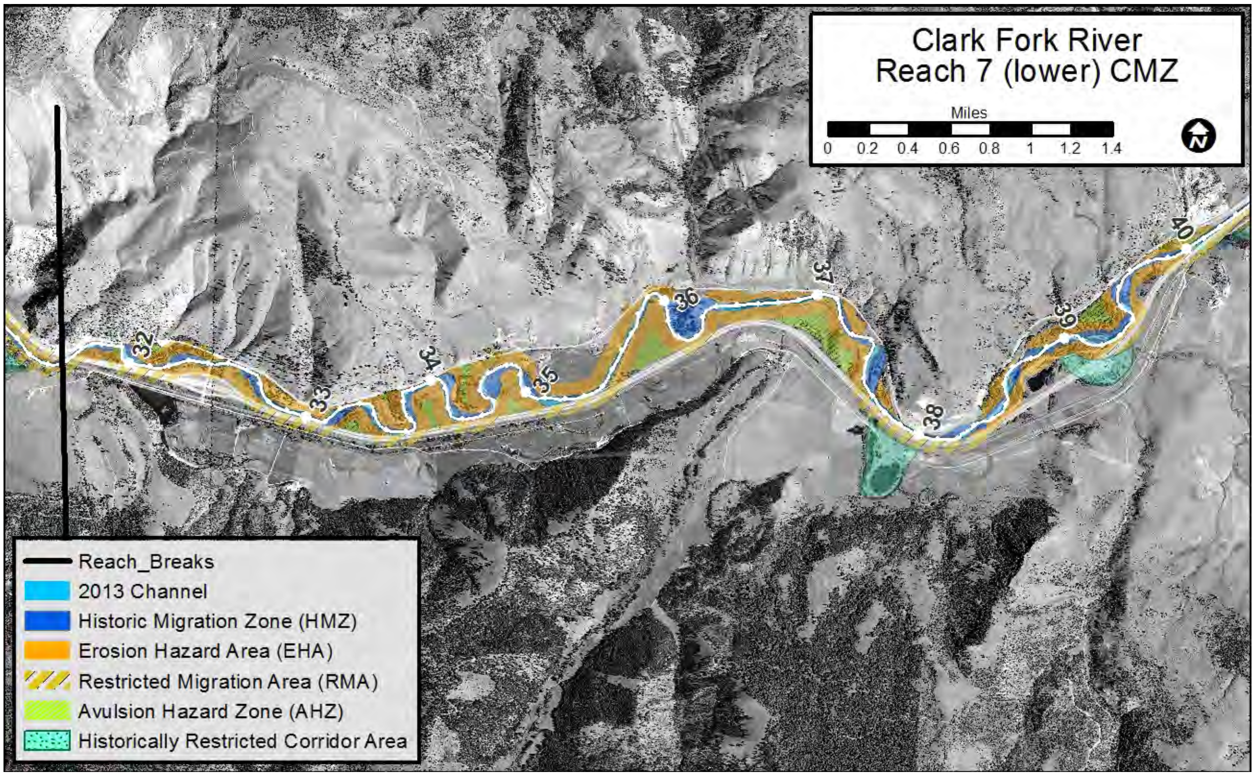

Figure 6-8. Reach 7 (lower) Channel Migration Zone (2013 imagery).

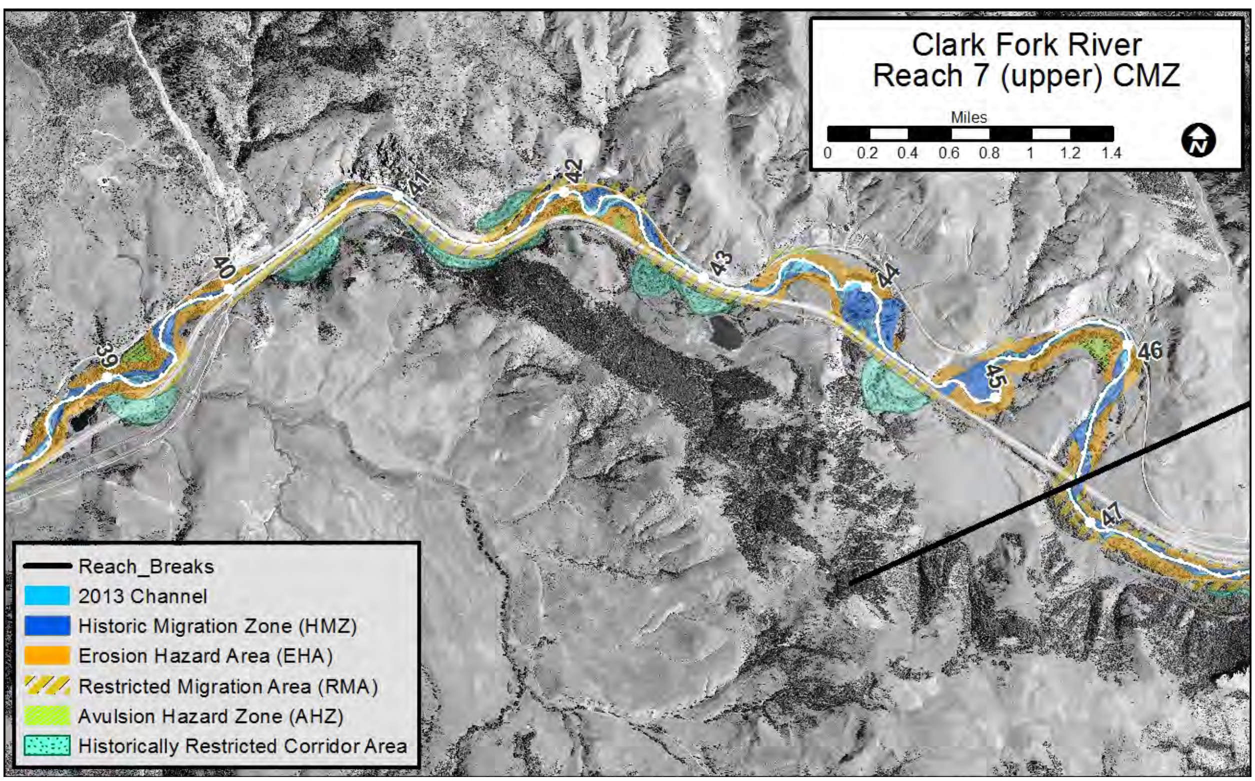

Figure 6-9. Reach 7 (upper) Channel Migration Zone (2013 imagery).

6.1.8 Reach 8: Drummond to Bridge below Rattler Gulch

Reach 8 is below Drummond and is 6.2 miles long. The erosion buffer in this reach is 368 feet wide, indicating active migration where the channel has some active corridor width. About 39 percent of the CMZ is restricted, and almost 25 percent of the streambanks are armored. Reach 8 provides some of the best potential CMZ restoration opportunities in the project area. At RM 48, for example, the abandoned rail line confines the river on its left bank and isolates numerous historic swales and floodplain area. Relocation of this berm (which appears to be used as a road) to the south could potentially restore about 50 acres of historic channel and floodplain area. The situation is similar upstream at RM 49 to RM 51, where over 200 acres of historic floodplain and channels are isolated from the river by the abandoned rail line. There appears to be a large historic channel on the south side of the floodplain in this area that is beyond the CMZ boundary but could potentially provide valuable aquatic and riparian habitat if reactivation were feasible.

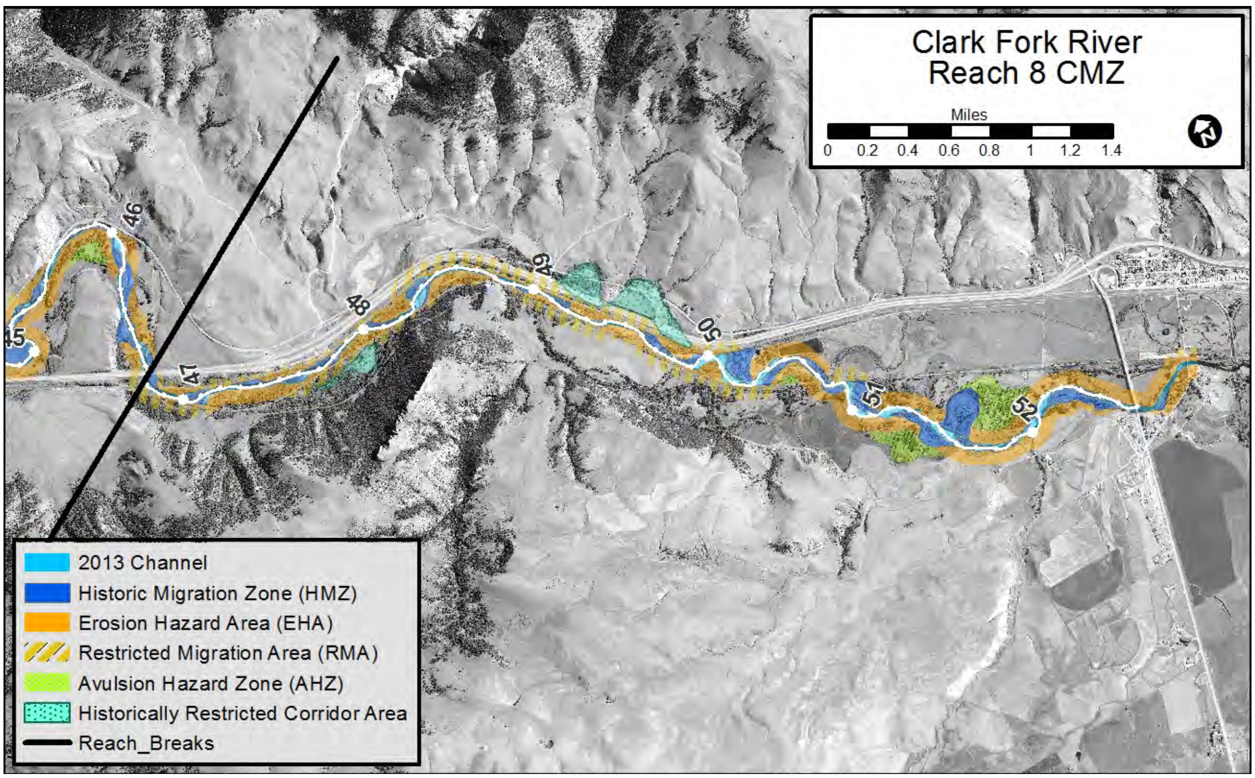

Figure 6-10. Reach 8 Channel Migration Zone (2013 imagery).

Specific Opportunities in Reach 8 Include:

- CMZ reactivation on the south side of the river at RM 48.
- Floodplain channel reactivation south of river and abandoned railroad berm from RM49-RM51.

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Appendix A: Reach Maps