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Clark Fork and Bitterroot Rivers Channel Migration Mapping

Missoula County

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Executive Summary

This report contains the results of a Channel Migration Zone (CMZ) mapping effort for 69 miles of the Clark Fork River and 22 miles of the Bitterroot River in Missoula County, Montana. From the Missoula County Line about five miles upstream of Rock Creek down to Milltown, the stream corridor is highly impacted by multiple transportation lines, including active and abandoned railroads, Interstate 90, and a Frontage Road. Construction of this transportation infrastructure included channel relocation, straightening, and isolation of historic river segments from the river. This section of river was strongly impacted by the 2018 flood with markedly rapid lateral migration rates. Avulsions are not uncommon, some of which have included a complete relocation of the primary river thread out into floodplain areas.

Over a century of development along the riverbanks in Missoula has essentially locked the river into place, such that the mapped CMZ is largely confined to the active channel. Caras Park was built on a side channel that was active in the mid- 1950s. The Kelly Island area below Reserve Street is one of the most complex sections of the project area. This section of river is characterized by multiple active channels, large wood recruitment, and a complex mosaic of older swales. Just below Reserve Street, this corridor is forced through an abandoned railroad grade that artificially confines channel locations, creating some issues upstream of the structure. Just downstream, rapid channel migration caused infrastructure damage in 2018, and the current planform shows some risk of major change in the future that could reactivate channels near the Orchard Homes subdivision.

For several miles below the Bitterroot River confluence, there is broad exurban development on the Clark Fork River floodplain, some of which has occurred within the CMZ. Further downstream, the Smurfit Stone Mill Site closely confines the river against the west valley wall by a long armored berm, restricting much of the CMZ from river access. Concerns regarding berm stability and river re-claiming of its historic CMZ in this area are real, as the site abruptly narrows the CMZ such that there are areas where armor damage is common. Additionally, outfalls/berms at the mill site have been built on 1955 channel swaths which may create additional risk of berm failure in these locations. Downstream of Smurfit Stone, a major avulsion has resulted in continued adjustments characterized by rapid channel migration rates, threats to infrastructure, and development of the risk of another avulsion.

The segment of the Bitterroot River that lies within Missoula County is diverse in terms of CMZ character. Above Maclay Ranch Road, the river flows through a broad largely undeveloped valley bottom that allows for largely unconfined channel migration which has created a broad successional riparian forest. Further downstream, both geologic and human encroachments have narrowed the corridor and reduced the vibrancy of those ecological functions.

Our objective with the mapping and interpretations provided in this document is to assist river corridor landowners and other stakeholders in understanding the nature of Clark Fork River lateral migration, focusing not only on the challenges that channel migration creates but also the critical contributions that these processes provide towards long-term river heath, resiliency, and ecological vibrancy.

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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 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.

CD – Conservation District.

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

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

DNRC – Department of Natural Resources and Conservation.

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

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

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

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

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

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

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

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

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

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

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

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

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

Morphology - Of or pertaining to shape.

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

Planform - The configuration of a river channel system as viewed from above, such as on a map.

RDGP - Reclamation and Development Grants Program, DNRC.

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

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

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

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

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

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

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

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

1 Introduction

The Missoula County Channel Migration Zone (CMZ) mapping project is an update of several CMZ studies on both the Clark Fork and Bitterroot Rivers starting in 2009. This effort focused on updating the previous work to take advantage of more recent imagery and high-resolution LiDAR data to assess impacts from recent flooding in 2018. The project encompasses approximately 69 miles of Clark Fork River corridor, extending from the Missoula county line just upstream of Beavertail Hill State Park at River Mile (RM) 246 downstream to RM 185 near Huson. An additional 22 miles of the Bitterroot River were mapped from the county line near Florence downstream to the Clark Fork River confluence near Missoula.

Note: All river mile references in this report are based on Montana Fish Wildlife and Parks stationing.

Funding for the study was split between the Missoula Conservation District and the Missoula Valley Water Quality District.

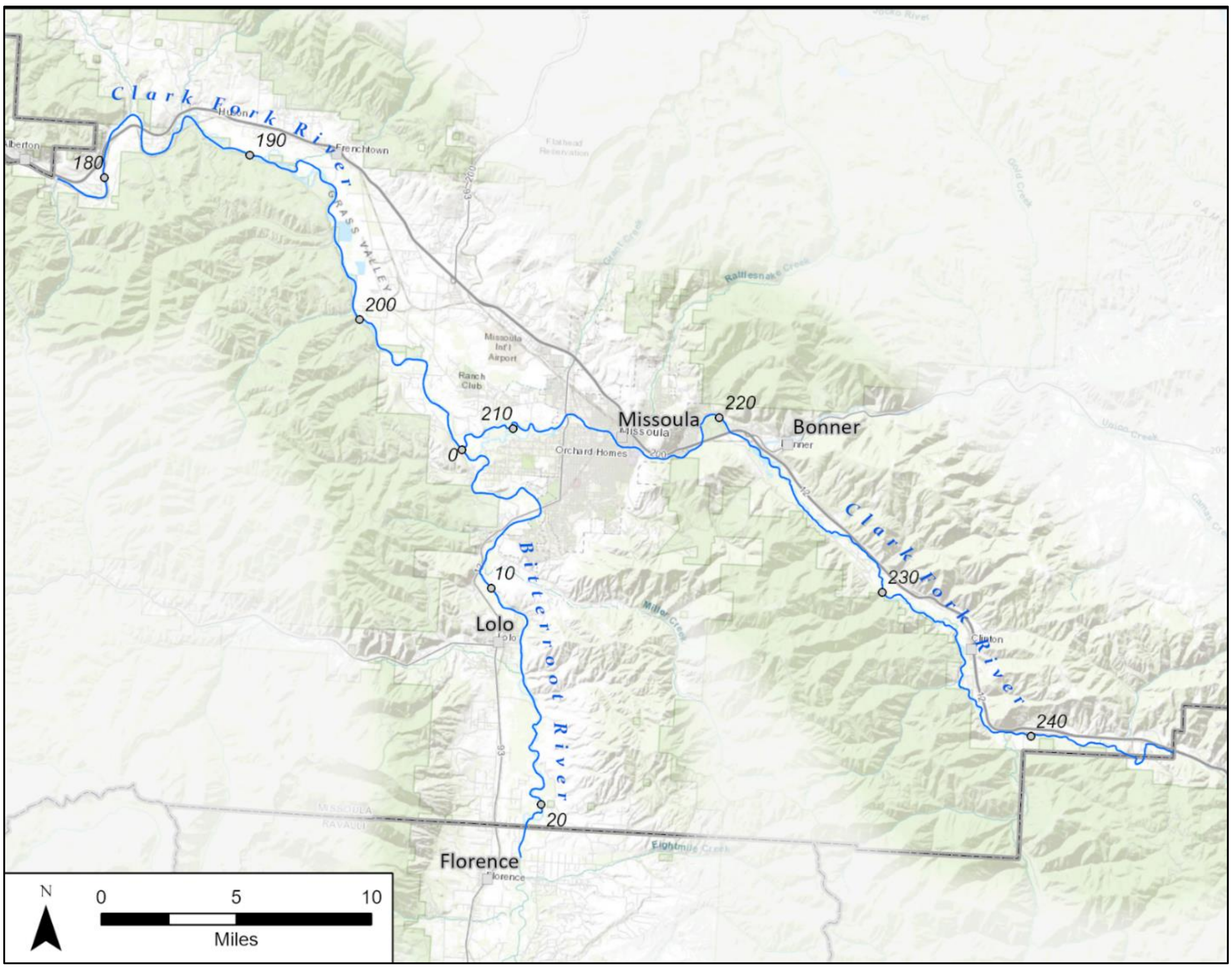

Figure 1. CMZ mapping extent on the Clark Fork and Bitterroot Rivers (MTFWP river miles).

1.1 Other Relevant Studies

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

1.1.1 Clark Fork River CMZ Pilot Bitterroot River Confluence to Huson (AGI and DTM, 2009)

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.

1.1.2 Milltown to Bitterroot Confluence Core Dataset Development

In 2014, 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 by DTM Consulting, Inc. A full CMZ mapping effort was not undertaken for this reach.

1.1.3 Clark Fork River Channel Migration Zone Mapping: Drummond to Milltown (Boyd and Thatcher, 2016)

In 2016 DTM and AGI mapped the Clark Fork River CMZ from Drummond to Milltown for the USFWS. This project focused on CMZ encroachment by transportation infrastructure. The most recent imagery used in this effort was from 2013. The results showed the construction of transportation corridors (2 rail lines, I-90, and the Frontage Road) displaced the river over almost 1,000 acres to its present course. Almost a quarter of the CMZ has become isolated from these features. Twenty one percent of the banklines in this reach were armored in 2013.

1.1.4 Smurfit Stone Channel Migration Zone Investigation (Boyd and Thatcher, 2016)

In 2016 we were asked to consider the relationship of the Smurfit Stone site to the Clark Fork River Channel Migration Zone (Boyd and Thatcher, 2016). The primary findings of that evaluation showed that about 257 acres of the core CMZ (Historic Migration Zone and Erosion Hazard Area) were occupied by Smurfit Stone facilities in 2013, mainly treated wastewater storage ponds. Another 13 acres of land at Smurfit Stone were behind bank armor and this isolated from the CMZ.

1.1.5 Historical Migration Zone and Floodplain Analysis of the Clark Fork River (Ferranti, 2009)

In 2009, University of Montana student Pete Ferranti evaluated the Historic Migration Zone and floodplain conditions in support of setback concepts in Missoula County as a class project.. The results showed that the Clark Fork River "is very capable of occupying areas outside of the floodplain, thus providing incentive to look beyond inundation risks when developing setbacks."

1.2 The Project Team

This project work was performed by Karin Boyd of Applied Geomorphology (AGI) and Tony Thatcher of DTM Consulting (DTM). Over the past 15 years, we have been collaborating to develop CMZ maps for numerous rivers in Montana, to provide rational and scientifically-sound tools for river management. It is our goal to facilitate the understanding of rivers regarding the risks they pose to infrastructure, so that those risks can be managed and hopefully avoided. Furthermore, we believe the mapping supports the premise that managing rivers as dynamic, deformable systems contributes to ecological and geomorphic resilience while supporting sustainable, cost-effective development.

1.3 What is Channel Migration Zone Mapping?

The goal of Channel Migration Zone (CMZ) mapping is to provide a cost-effective and scientifically based tool to assist land managers, property owners, 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 river dynamics. CMZ mapping is therefore intended to identify those areas of risk, to reduce the risk of project failure while minimizing the impacts of development on natural river process and associated ecological function. The mapping is also intended to provide an educational tool to show historic stream channel locations and rates of movement in any given area.

CMZ mapping is based on the understanding that rivers are dynamic and move laterally across their floodplains through time. As such, over a given timeframe, rivers occupy a corridor area whose width is dependent on rates of channel shift. The processes associated with channel movement include lateral channel migration and more rapid channel avulsion (Figure 2).

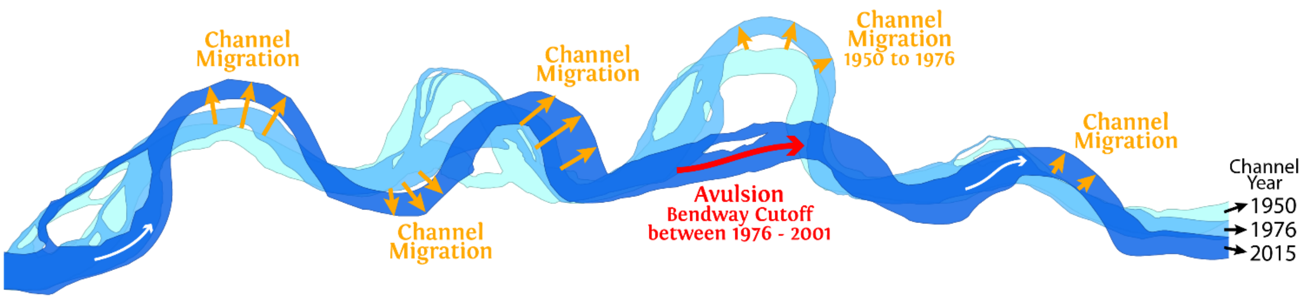

Figure 2. Typical patterns of channel migration and avulsion evaluated in CMZ development.

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. This is defined by first mapping historic channel locations to define the Historic Migration Zone, or HMZ (Figure 2). Using those mapped banklines, migration distances are measured between suites of air photos, which allows the calculation of average migration rate (feet per year) at any site. These results are evaluated statistically in terms of data distribution to determine an appropriate statistic to use to predict future migration. The mean migration rate is commonly used, however if there are substantial data outliers, unique physical or hydrologic conditions, or intended uses, it may be important to consider using a higher percentile value than the mean. The rates are calculated on a reach scale and extended to the life of the CMZ, which in this case is 100 years. This 100-year mean migration distance defines the Erosion Buffer, which is added to the modern bankline to define the Erosion Hazard Area, or EHA.

Channel migration rates are affected by geomorphic influences such as geology, channel type, 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. To address this natural variability, the study area has been segmented into a series of reaches that are geomorphically similar and can be characterized by average migration rates. Reach breaks can be defined by changes in flow or sediment loads at tributary confluences, changes in geologic confinement, or changes in stream pattern. Reaches are typically on the order of five- to 10-miles-long. Within any given reach, dozens to hundreds of migration measurements may be collected.

Avulsion-prone areas are mapped where there is evidence of geomorphic conditions that are amenable to new channel formation on the floodplain. This would include meander cores prone to cutoff (Figure 2), historic side channels that may reactivate, and areas where the modern channel is perched above its floodplain.

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

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

The individual map units comprising the CMZ are as follows:

CMZ = HMZ + EHA + AHZ

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

Each map unit listed above is individually identified on the maps to show the basis for including any given area in the CMZ footprint (Figure 3).

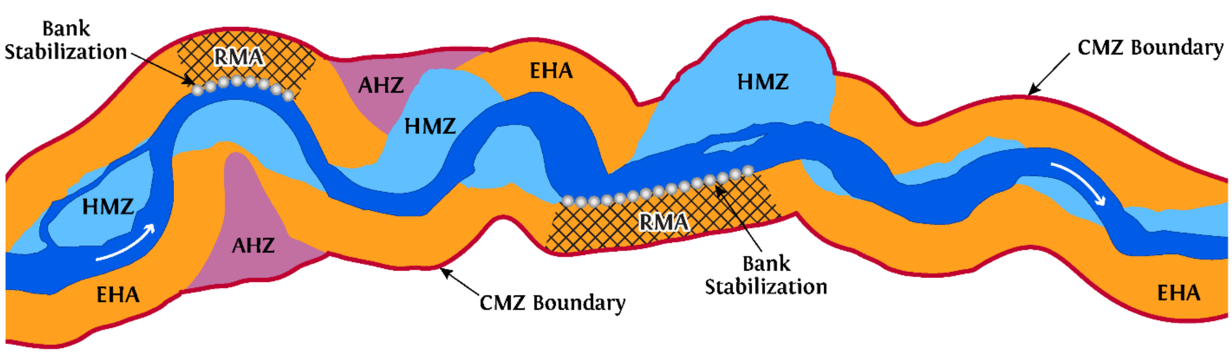

Figure 3. Channel Migration Zone mapping units.

Although the basic concept for Channel Migration Zone mapping efforts is largely the same throughout the country, different approaches to defining CMZ boundaries are used depending on specific needs and situations. These differences in assessment techniques can be driven by the channel type, different project scales, the type and quality of supporting information, the intended use of the mapping, etc. For this study, the CMZ is defined as a composite area made up of the existing channel, the collective footprint of mapped historic channel locations shown in the 1955, 1964 (Bitterroot only) 1972, 1995, 2005, 2011, 2017, and 2018/19 imagery (Historic Migration Zone, or HMZ), and an Erosion Hazard Area (EHA), that is based on reach-scale average migration rates. Areas beyond the Erosion Buffer that pose risks of channel avulsion are identified as Avulsion Hazard Areas or AHZ. This approach generally falls into the minimum standards of practice for Reach Scale, Moderate to High Level of Effort mapping studies as defined by the Washington Department of Ecology (www.ecy.wa.gov). This approach does not, however include a geotechnical setback on hillslopes; these areas would require a more site-specific analysis than that presented here.

1.4 Relative Levels of Risk

The natural processes of streambank migration and channel avulsion both create risk to properties within stream corridors. Although the site-specific probability of any area experiencing either migration or an avulsion during the next century has not been quantified, the characteristics of each type of channel movement allows some relative comparison of the type and magnitude of their risk. In general, the Erosion Hazard Area delineates areas that have a demonstrable risk of channel occupation due to channel migration over the next 100 years. Such bank erosion can occur across a wide range of flows, and the risk of erosion into this map unit is relatively high. In contrast, avulsions tend to be a flood-driven process; the Avulsion Hazard Area delineates areas where conditions may support an avulsion, although the likelihood of such an event is highly variable between sites and typically depends on floods. Large, long duration floods have the potential to drive extensive avulsions, even after decades of no such events. During the spring of 2011, for example, the Musselshell River flood drove 59 avulsions in three weeks, carving 9 miles of new channel while abandoning about 37 miles of old river channel (Boyd et al, 2012).

1.5 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 Clark Fork and Bitterroot Rivers shows historic patterns of lateral migration and avulsions locally within a broad floodplain surface that has dense networks of historic channels. 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 50 years are assumed to be relatively consistent over the next century. If conditions change significantly, uncertainty regarding the proposed boundaries will increase. These conditions include system hydrology, sediment delivery rates, climate, valley morphology, riparian vegetation densities and extents, and channel stability. Bank armor and floodplain modifications, such as bridges, dikes, levees, or sand and gravel mining could also affect map boundaries.

1.6 Potential CMZ Map Applications

The CMZ 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 stakeholder 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.

<u>Note:</u>

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 a series of hazards associated with river corridors.

1.8.1 Flooding

The CMZ maps do not delineate areas prone to flooding. The difference between mapped flood boundaries and CMZ boundaries can be substantial. In cases where the floodplain is broad and low, the CMZ tends to be narrower than the flood corridor (left schematic on Figure 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.

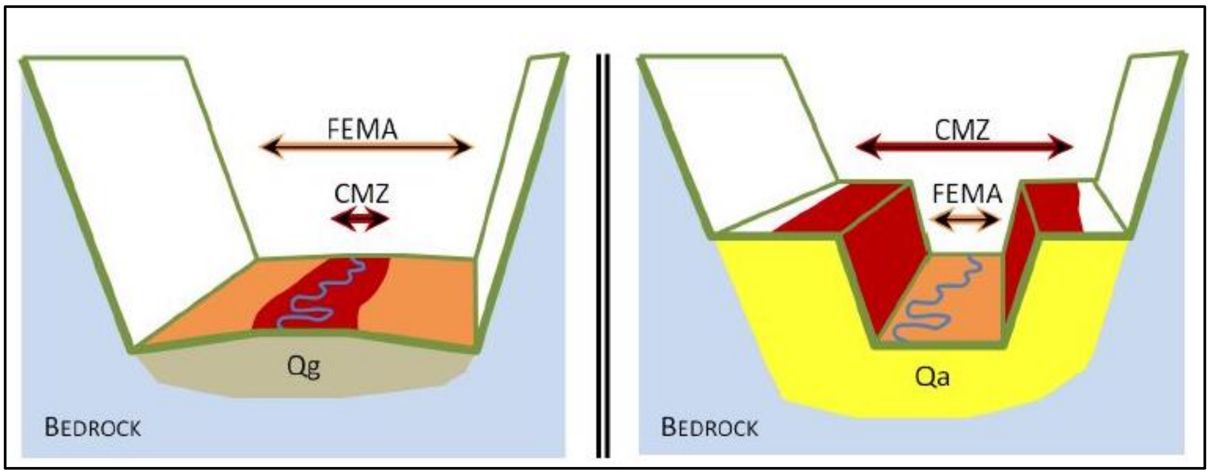

Figure 4. Schematic comparisons between CMZ and flood mapping boundaries (Washington Department of Ecology).

Figure 5 shows a home on the Yellowstone River in Yellowstone County that was undermined during the 2019 flood. This has been a chronic problem in river management, as landowners assume that if their home is beyond the mapped floodplain margin, it is removed from all river hazards. After experiencing massive 2005 flood damages in Saint George Utah (Figure 6), 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. Billings Montana home located on ground mapped out of the Yellowstone River floodplain that was undermined in June of 2019 (Billings Gazette).

Figure 6. Photos from a 2005 flood event in Saint George Utah, where homes several feet above the mapped floodplain were destroyed by channel migration (www.Utahfloodrelief.com).

An example floodplain map for the Clark Fork River near Frenchtown is shown in Figure 7. 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. On the Clark Fork and Bitterroot Rivers, the floodplain footprint envelopes depict a complex series of active channels, gravel pits, and floodplain areas that may be dissected by roads. The combined risks of flooding and channel migration on the Clark Fork River should both be considered threats to human health and safety.

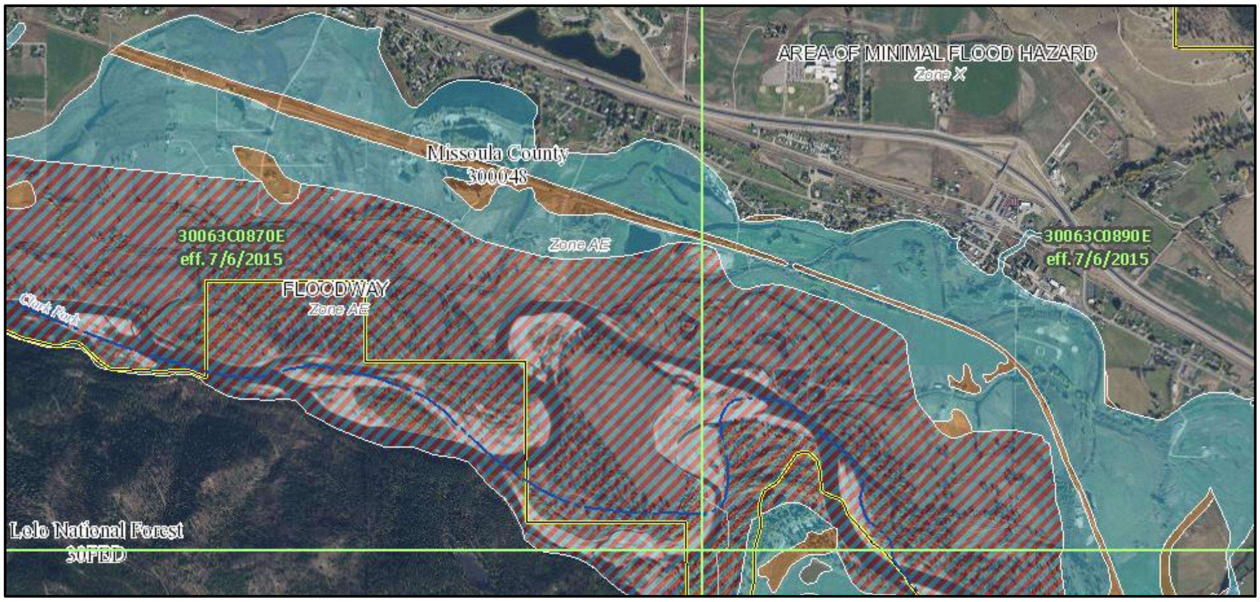

Figure 7. FEMA flood map near Frenchtown (fema.gov).

1.8.2 Ice Jams

Another serious river hazard, especially in Montana, is ice jamming. Over 4,514 ice jams have been recorded in Montana since 1894, which is the most in the United States (http://dphhs.mt.gov/). Although ice jams are most common in Montana during February and March, ice jam flooding has happened on the Clark Fork River as early as November. 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.

In February 1996, an ice jam at Milltown Dam destroyed a bridge and some houses on the Blackfoot River, encouraging federal agencies to remove the Milltown Dam in 2010 (Missoulian.com). Just upstream a jam at Turah caused water to back up into irrigation ditches and flooded homes and I-90 east of Clinton (https://icejam.sec.usace.army.mil). A rapid drop in temperatures on the Clark Fork in November 2014 caused the river to rapidly ice over, causing flooding near Bearmouth, and in Missoula above the Madison Street Bridge (Missoulian.com, Figure 8 and Figure 9). The Army Corps of Engineers Ice Jam Database lists eight records between 1930 and 2014 for the Clark Fork River and eight records between 1958 and 1996 for the Bitterroot River in Missoula County.

Figure 8. Ice on the Clark Fork River in Missoula, 2014 (Missoulian.com).

Figure 9. Ice jam flooding on the Clark Fork River near Bearmouth, 2014 (Missoulian.com).

1.8.3 Landslides

The only mapped landslide that extends into project segments of the Bitterroot and Clark Fork Rivers is a small landslide just upstream of the mouth of Rock Creek on the south valley wall. That said, even relatively small hillslope failures can deflect stream courses and create hazards that may exceed the boundaries of the mapped Channel Migration Zone.

1.9 Disclaimer and Limitations

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

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

1.10 Acknowledgements

We would like to extend our gratitude to Travis Ross, Elena Evans, and their supporting staff of Missoula County for their assistance in data transfer, contract management, scheduling, and document review. Andrew Wilcox of the University of Montana was very generous with his time in providing us information on the status of studies related to geomorphic impacts of Milltown Dam removal. Some extremely useful photos of the 2018 flood were provided by the Civil Air Patrol and we extend our thanks to them. Chris Boyer of Kestrel Aerial Services flew the project reach during the flood and many of his photos are used in this document to demonstrate CMZ concepts. We have worked with Chris on numerous projects and find his work to be unparalleled in documenting fluvial processes at work. Special thanks to Missoula Conservation District and the Missoula Valley Water Quality District for providing funding for this study.

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 Naming the Rivers

The Clark Fork and Bitterroot Rivers can have various names on historic maps. This reflects rapid development beginning in the 1800s that resulted in the renaming of the rivers from their original indigenous names.

Prior to indo-european settlement, the Clark Fork basin was inhabited by several native peoples, including the Bitterroot Salish, Blackfeet, Pend d'Oreille, and the Kalispell. Lewis and Clark explored this section of river in 1806 on their return trip from the Pacific, and the river was ultimately named for William Clark, although they referred to it as the Flathead River. William Ferris of the American Fur Company called it the Arrowstone River in 1833. The General Land Office surveys of the 1880s typically map the Clark Fork as the Deer Lodge River from its headwaters to its confluence with the Little Blackfoot at Garrison and as the Hellgate River below Garrison to Missoula (Figure 10). By the 1920's the name Clark Fork River was established for the section of River from the confluence of Silver Bow and Warm Springs Creek downstream to where it flows into Lake Pend Oreille near Sandpoint, Idaho.

An early Salish word for the Bitterroot River was "In-shi-ttogh-tae-tkhu," which means "Willow River." In 1842 a trapper named Alexander Ross noted that the Salish also referred to it as Spet-lum, which means "place of the bitterroot" (Aarstad and others, 2009). Jesuit priests called it the St Mary's River in the early 1800s. By the time of the Washington Territory survey of the mid-1800s, the name Bitterroot had been adopted.

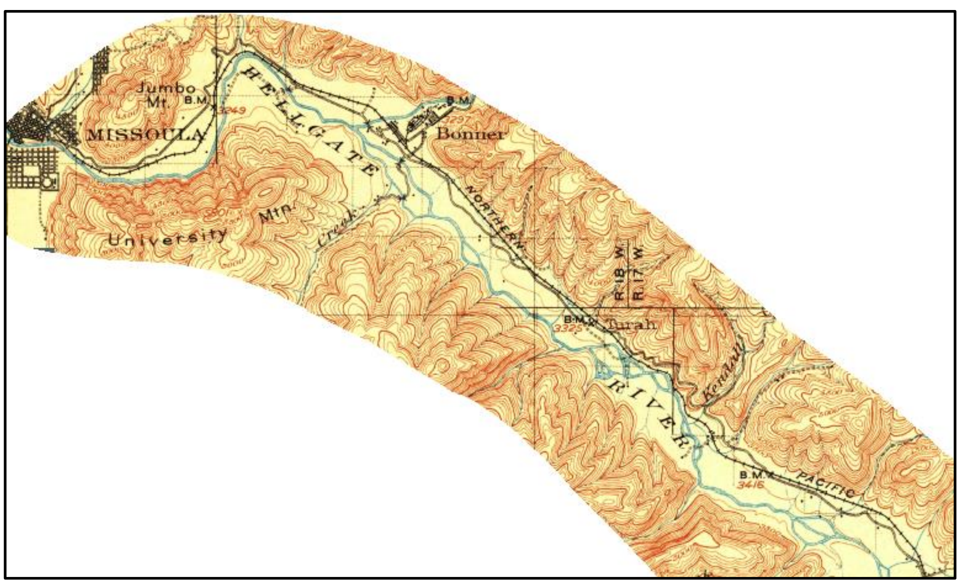

Figure 10. USGS 1903 showing Hellgate River.

2.2 Geography

Figure 11 shows a contributing watershed map for the project area. Upstream of Bonner, the southeasternmost segment of the Clark Fork River drains about 3,670 square miles of the Upper Clark Fork watershed, including major tributaries of Rock Creek, Flint Creek, the Little Blackfoot River, and Silverbow Creek. This portion of the watershed reaches the Continental divide at its easternmost extent near Butte where it serves as the headwaters of the central Columbia River Basin. At Bonner, the drainage area increases by 2,309 square miles (38%) as the Blackfoot River enters the Clark Fork. Just below Missoula, the Bitterroot River confluence contributes another 2,856 square miles of catchment to the Clark Fork. Ultimately, the maximum contributing drainage area at Huson is about 9,151 square miles.

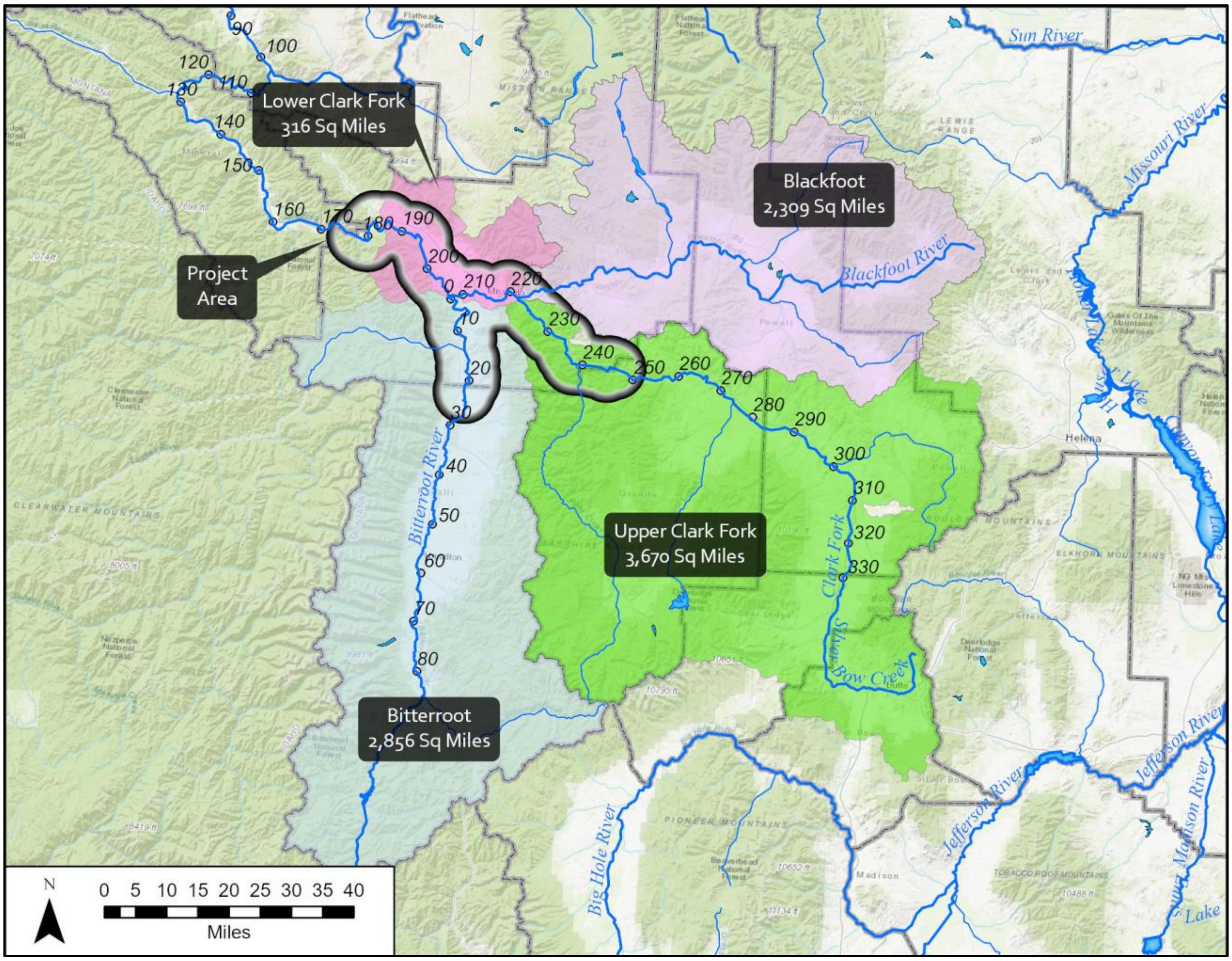

Figure 11. Clark Fork River watershed above Huson.

2.4 Geology and Glacial History

The river valleys in the project area range from narrowly confined corridors upstream of Missoula to very wide floodplains downstream. Valley width is controlled by bedrock geology, which is largely made up of erosion-resistant Precambrian rocks. Figure 12 shows a simplified geologic map of the project area, with Precambrian rocks consistently forming valley margins. The valley bottoms themselves contain both modern river alluvium, as well as older alluvial deposits. This general physiography controlled the location and extent of Glacial Lake Missoula, which was a ~2,000 foot deep glacial lake that formed about 12,000 years ago when the Cordilleran Ice Sheet dammed the river near the Idaho border (glaciallakemissoula.org). The lake repeatedly filled and then emptied via huge outwash floods, leaving its signature from the upper Bitterroot to the mouth of the Columbia River west of Portland. Figure 13 shows the estimated inundated area as mapped by the BLM, with water extending throughout the river bottoms of the project area, inundating valley bottoms according to their geologically-controlled width. In some areas upstream of Missoula, Glacial Lake Missoula deposits are exposed along the Clark Fork River streambank adjacent to I-90 (Figure 14).

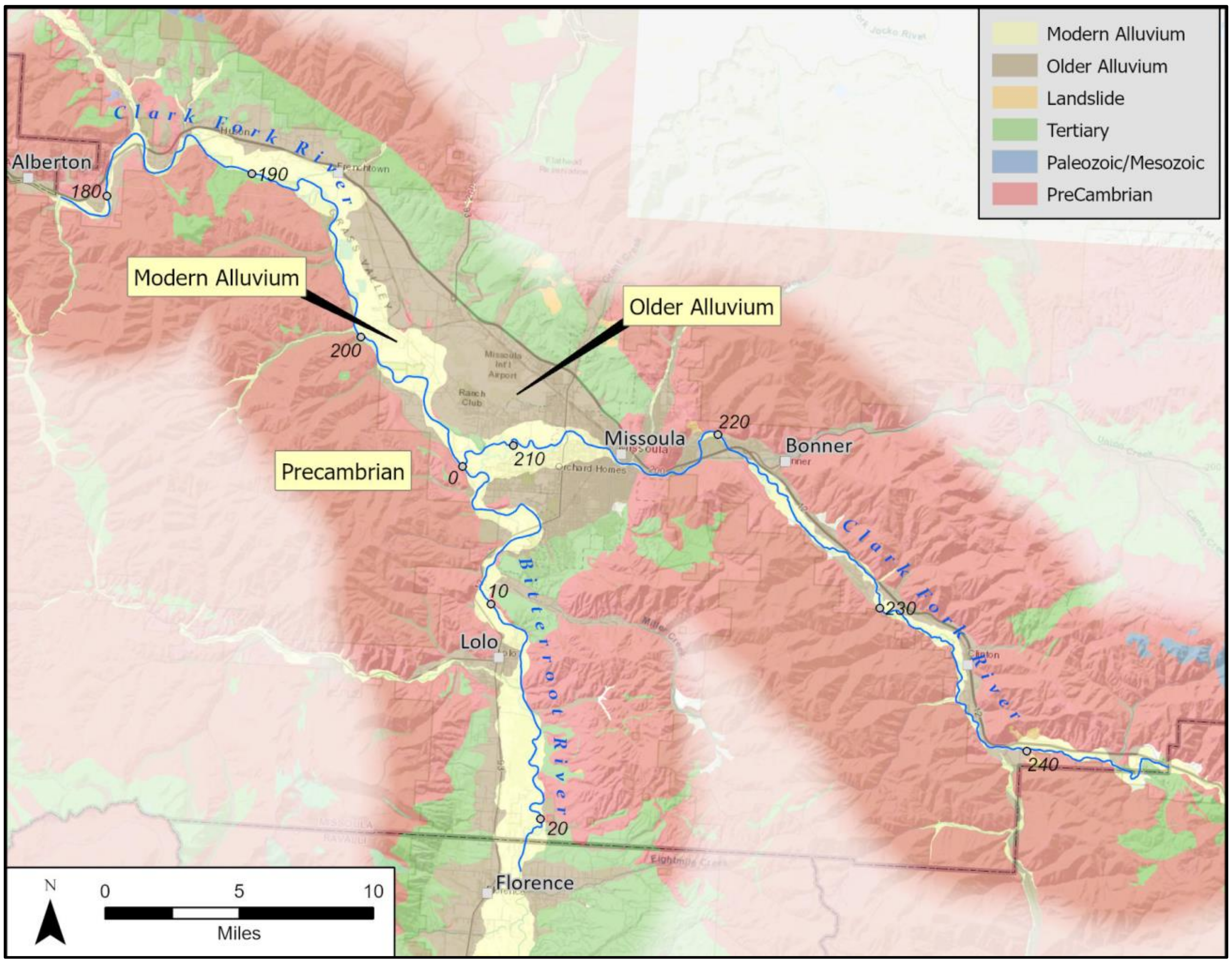

Figure 12. Simplified geologic map of the project area.

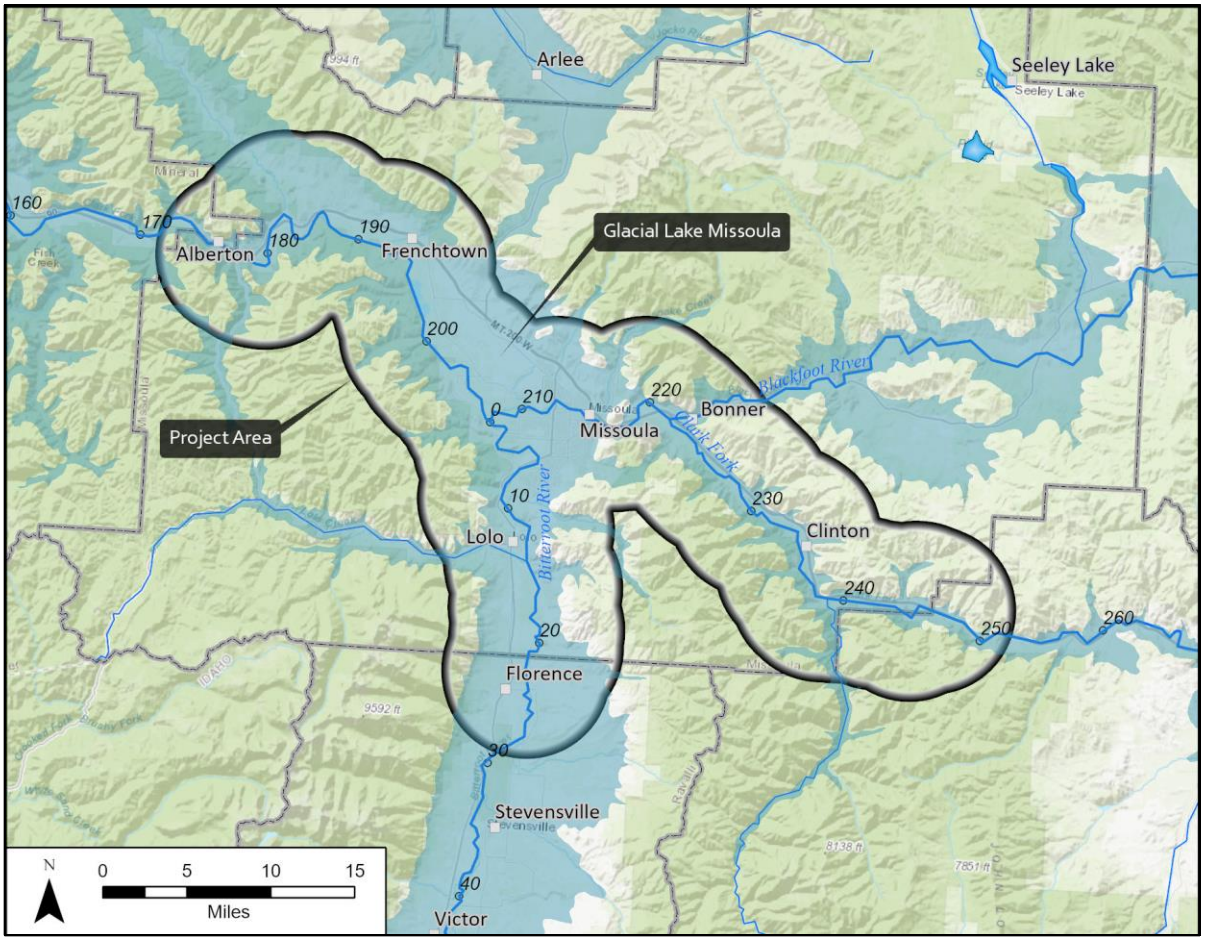

Figure 13. Estimated area of Glacial Lake Missoula inundation (blue shading) around Missoula (BLM).

Figure 14. Fine-grained glacial Lake Missoula deposits forming Clark Fork River bankline as seen from I-90.

2.5 Flood History

As a major tributary of the Columbia River headwaters system, the Clark Fork River floods primarily due to spring snowmelt or ice jams. The flood of record at Missoula occurred in 1908 due to extensive springtime rain and snow. During the early spring of that year, hard rain fell for weeks. It also snowed; the Memorial Day parade was cancelled in Butte due to too much snow (cfwep.org). On June 2nd, with snow on the ground, almost an inch of rain fell in Butte, kicking off the onset of this epic flood. About thirty miles east of Missoula a railroad track washed out and a train derailed, killing a man. On June 4th, another nine inches of rain fell in Butte. By June 5th, landslides and washouts had shut down train travel. On June 6th, the Higgins Street Bridge in Missoula collapsed, "joining every other bridge in Missoula County" (cfwep.org). There was great concern that the recently built Milltown Dam would fail, but it remained intact even though an estimated 15 feet of water was going over the spillway. Part of the structure was blasted to let more water through. Within the project area, the long-term legacy of the 1908 flood was the delivery and trapping of vast amounts of toxic mine tailings that were sent down the river when a multitude of small tailings ponds in the upper watershed around Butte failed.

Other major floods recorded on the mainstem Clark Fork River above and below Missoula are shown in Figure 15 and Figure 16 respectively, with all floods over an estimated 10-year flood frequency labeled by date. Note that the Clark Fork River Above Missoula USGS gage (12340500) is located above Missoula and below the confluence with the Blackfoot River, while the Clark Fork River Below Missoula gage (12353000) is located below the confluence with the Bitterroot River. Flood frequencies were taken from a recent hydrologic analysis (Pioneer Technical Services, 2020). For reference, the 1908 flood is estimated to have peaked at 48,000 cfs upstream of Missoula.

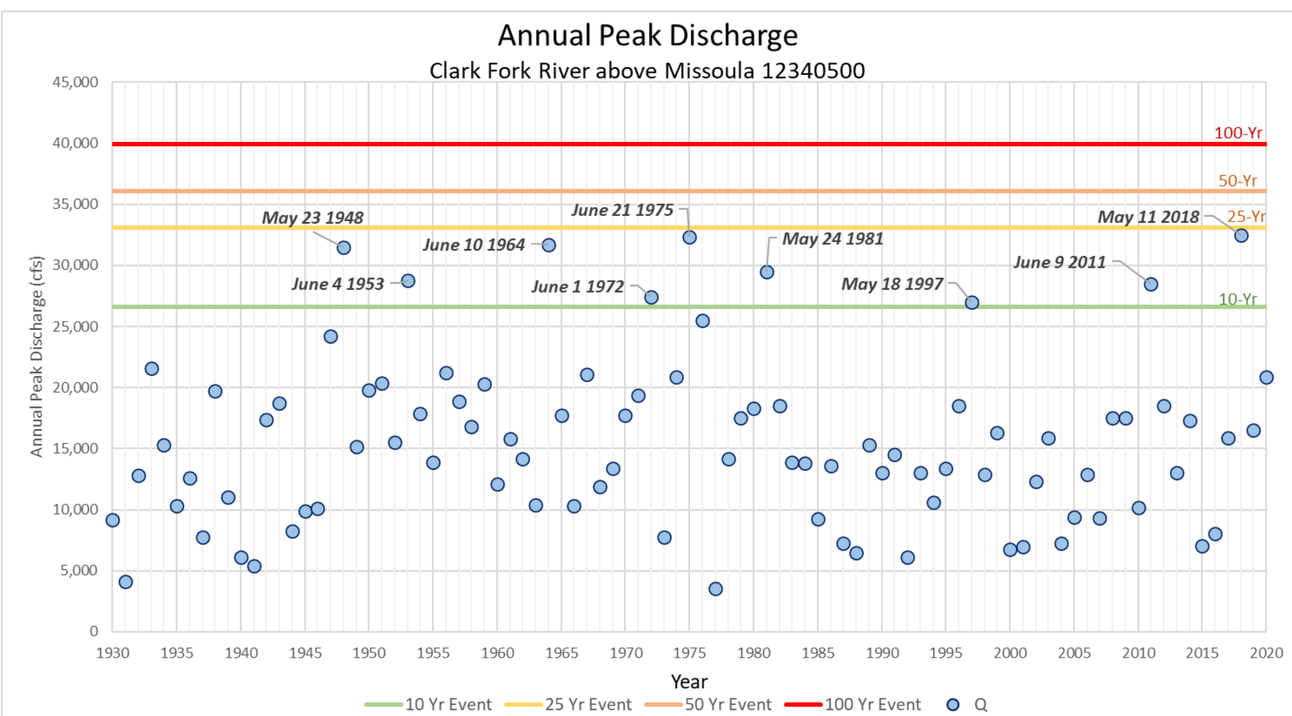

Figure 15. Annual peak floods for USGS 12340500 Clark Fork River Above Missoula (below Blackfoot confluence) with floods over an estimated 10-year event labeled.

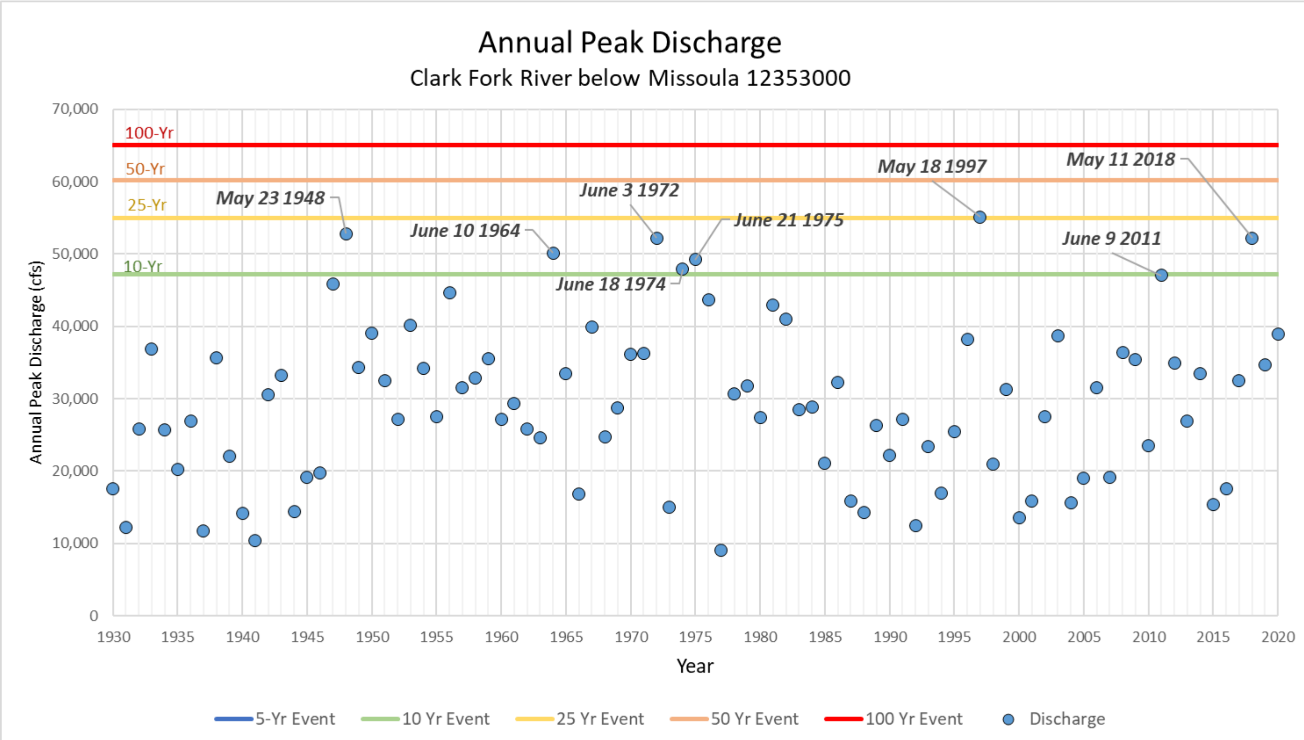

Figure 16. Annual peak floods for USGS 12353000 Clark Fork River Below Missoula with floods over an estimated 10-year event labeled.

Although the majority of floods labeled in Figure 15 and Figure 16 coincide temporally, several do not, including 1953, 1974, and 1981. This is due to the locations of the gages in relationship to the confluences of the Blackfoot and Bitterroot Rivers. To give some context as to where and when flooding occurred in the project reach, major flood years are summarized in Table 1 and Figure 17. The floods are color coded in terms of their relative intensity, showing which were driven by the Upper Clark Fork, Bitterroot, or Blackfoot Rivers. A total of 16 flood years are summarized. The highest flooding frequency has been on the Clark Fork River below the confluences of all three tributaries ("Clark Fork below Missoula"), which experienced floods in excess of a 10-year event 9 times. Four of those post-1908 floods (1948, 1972, 1997, and 2018) exceeded a 25-year event.

2.5.1 The 2018 Flood

One flood of note in the plots is the recent flood of 2018, which, upstream of the Bitterroot River confluence, was the biggest event since the epic flood of 1908. Upstream of Missoula it was almost a 25-year event, and flows exceeded a 5-year event for 18 days in early May. The river reached major flood stage in Missoula and resulted in evacuation orders for about 60 homes in the Orchard Homes area of Missoula. A mobile home was washed off its foundation below the Reserve Street Bridge (Figure 18), and concerns were raised regarding the integrity of old holding pond berms at Smurfit Stone near Frenchtown.

Table 1. Major flood events on Clark Fork and Tributaries color coded by relative size.

Major Flood Year	Clark Fork Above Blackfoot River*	Clark Fork above Missoula, Below Blackfoot	Clark Fork Below Missoula, Below Bitterroot	Blackfoot	Bitterroot	Major Drivers and Impacts
1908						*System-wide: bridges lost, structures lost, Higgins Ave Bridge collapsed*
1947						*Rain on snow in early May; timber top of dam at Bonner lumber mill failed.*
1948						*Western Missoula was saturated by the flood waters. High waters in the Bitterroot Valley forced evacuations and the closure of the Bell, Victor, Tucker, Bass and Florence crossings north of Hamilton. Blackfoot River peaked at 16,300 cfs*
1953						*Driven by 18,300 cfs flood on Blackfoot River*
1956						*Driven by >10-yr Bitterroot River flood*
1964						*Blackfoot River peaked at 19,200 cfs (~50-year event)*
1972						*Blackfoot River peaked at 15,700 cfs*
1974						*Driven by >10-yr Bitterroot River flood*
1975						*Driven by 18,100 cfs flood on Blackfoot River (>25-year event)*
1981						*Driven by Upper Clark Fork Flooding, 12,000 cfs peak at CFR Gold Creek gage*
1986						*Upper Clark Fork Flooding 9,700 cfs at Turah Bridge*
1996						*Upper Clark Fork Flooding 12,4000 cfs at Turah Bridge*
1997						*Blackfoot River peaked at 16,200 cfs*
2003						*Bitterroot River peaked at 21,600 cfs*
2011						*Upper Clark Fork and Blackfoot Flooding: 13,300 at Turah Bridge on Clark Fork and 17,100 cfs on Blackfoot*
2018						*Blackfoot peaked out at 18,800 cfs, Clark Fork at Turah Bridge peaked at 12,300 cfs*
# floods	*6*	*10*	*9*	*9*	*8*	

**** Turah or Gold Creek***

10-25 Yr Event	*25-50 Yr Event*	*50-100 Yr Event*

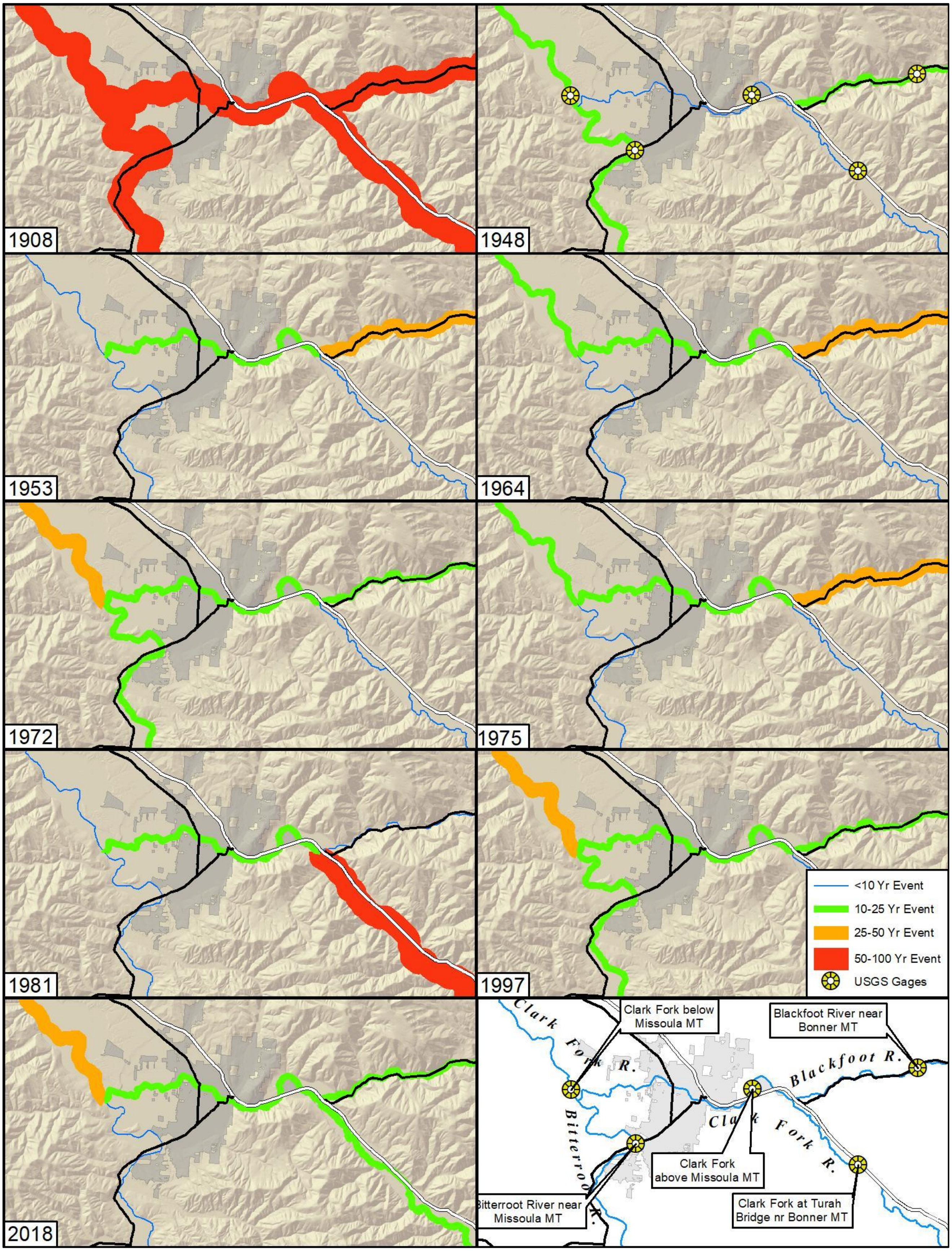

Figure 17. 10-year and greater flood events on Clark Fork and Tributaries flood magnitude by river segment.

2.6 Dikes and Levees

Apart from the downtown Missoula area (Reach CF05) and Smurfit Stone (Reach CF09), there are no mapped dikes or levees in the project area. Downtown Missoula is extensively leveed, including both certified and uncertified structures. The Smurfit Stone mill site includes an extensive river-side and internal dike/levee system. These systems are discussed in greater detail, along with their impacts on the CMZ and river corridor management in Section 4.5 – Restricted Migration Area, Section 5 – Reach Descriptions, and in Section 0 – Milltown and Smurfit Stone.

Figure 18. Destruction of a mobile home below Reserve Street Bridge in May 2018 (weather.com).

2.7 Bank Armor

Bank armor locations and extents were compiled from a variety of sources including field mapping, interpretation of aerial photography, and third party reports. As such, it is likely a conservative estimate of the actual 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 current data set. Additionally, the bank armor inventory has no assessment of condition or functionality. The bank armor consists of rock riprap, barbs, and other revetments such as root wad structures and concrete rubble.

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

2.8 Transportation Infrastructure

Upstream of Missoula, the Clark Fork River corridor has experienced over 100 years of progressive encroachment due to the construction of a series of transportation projects in the valley bottom. Two rail lines were constructed in the late 1800s and early 1900s. The Northern Pacific was first, having been authorized by President Abraham Lincoln in July of 1864. 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. In 1970 the Northern Pacific was merged to become the Burlington Northern. This line is currently active and closely follows the river corridor. In many places, however, it has been relocated since its original construction, leaving remnant, discontinuous berms throughout the project reach.

The Chicago, Milwaukee, St. Paul and Pacific Railroad—otherwise known as the Milwaukee Road, began operating between Milwaukee and Waukesha, Wisconsin in 1850. In Montana, the Deer Lodge to Alberton section was built between 1908 and 1909 (Rails to Trails Conservancy, 2004). The Milwaukee Road had over 650 miles of electrified track, supporting both freight and passenger trains. Electric engines were used between Harlowton Montana and Avery, Idaho (Graetz, 2003). 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.

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, the highway has largely been maintained as a Frontage Road. This system was constructed in the mid-1920s and tends to follow the north valley wall through the project reach.

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.

Each of these transportation lines has encroached into the natural Channel Migration Zone (CMZ) of the river (Figure 19). In numerous places, the construction included relocating and straightening the river.

Figure 19. Main transportation corridor elements including (from left)—Milwaukee Line, BNSF Line, abandoned rail line, I-90, and Frontage Road on right.

3 Methods

The development of the Clark Fork and Bitterroot River Channel Migration Zone (CMZ) mapping is based on established methods used by the Washington State Department of Ecology (Rapp and Abbe, 2003), and closely follows methodologies used on over 1,300 miles of rivers in Montana to date.

3.1 Aerial Photography

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

As this project is an update and integration of several early project phases, some of the imagery series are not complete for both the Clark Fork and Bitterroot Rivers. General information for each of the imagery suites are shown in Table 2 and discussed below. In general, the imagery spans from 1955 to 2019.

Table 2. Aerial photography used for the Clark Fork and Bitterroot River Channel Migration mapping study.

Year	Source	Scale	Image Date(s)	Notes
1955	USDA	1:20,000	NA	Orthomosaic
1964	USDA		NA	Bitterroot Only
1972	USDA	1:40,000	NA	Orthomosaic
1995	USDA DOQ		NA	County line to Milltown only
2005 NAIP	USDA	~ 1 meter resolution		Digital Download, Compressed County Mosaics (color)
2011 NAIP	USDA	~ 1 meter resolution		Digital Download, Compressed County Mosaics (color)
2017 NAIP	USDA	~ 1 meter resolution		Digital Download, Compressed County Mosaics (color)
2018	WorldView-3 Archive Satellite Imagery	30cm	8/13/2018 (Upstream) & 7/22/2018 (Downstream)	Fills in missing 2019 NAIP imagery. Purchased from Land Info Worldwide Mapping. 4-band pan-sharpened, color and infra-red Geotif.
2019 NAIP	USDA	~ 1 meter resolution		Digital Download, Compressed County Mosaics (color). Bitterroot and Missoula to Frenchtown only.

Imagery before 1995 consists of high resolution scans from archival imagery from the USDA. The individual images were merged into a single orthorectified mosaic for each time period. Starting with the Digital Orthophoto Quad imagery from the mid-1990s and continuing with the National Agricultural Imagery Program (NAIP) in 2005, the USDA provides orthorectified images for download. NAIP is generally flown every two years in Montana. The 2019 NAIP collection was incomplete due to wildfire smoke restricting visibility. A north/south band was collected covering all the Bitterroot River in Missoula County and the Clark Fork River from the Orange Street bridge downstream to Frenchtown (Figure 20). To capture the impacts of the 2018 flooding for the missing 2019 NAIP areas, 2018 WorldView-3 archived satellite imagery acquired through Land Info Worldwide Mapping. The imagery was delivered as both color and false color infra-red, orthorectified, 30-cm pan-sharpened tiles (Figure 21). This effort was needed to capture channel migration resulting from the 2018 flooding.

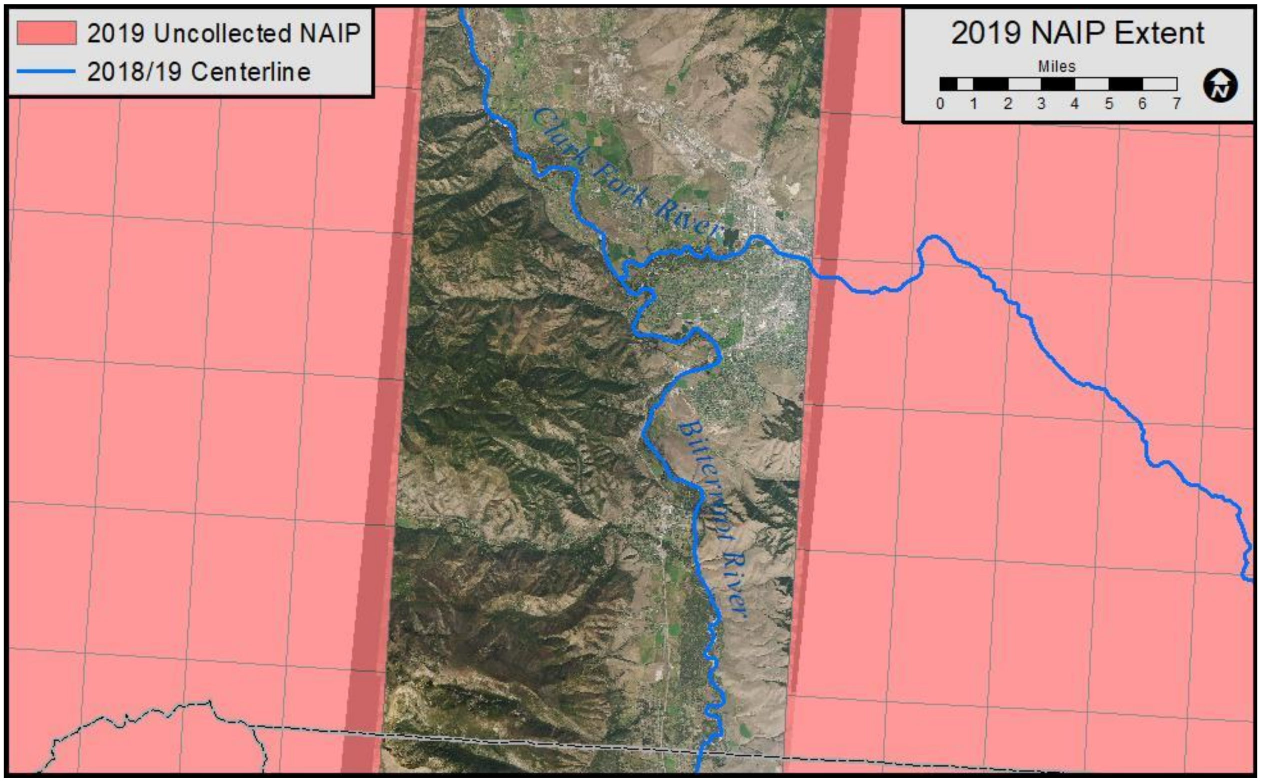

Figure 20. Incomplete 2019 NAIP imagery (red) completed with 2018 WorldView-3 satellite imagery.

Figure 21. Example 30-cm WorldView 3 ~1.5 miles upstream of Blackfoot River confluence.

Figure 22 to Figure 27 provide imagery examples at the same location along with the associated digitized bankfull channel boundaries.

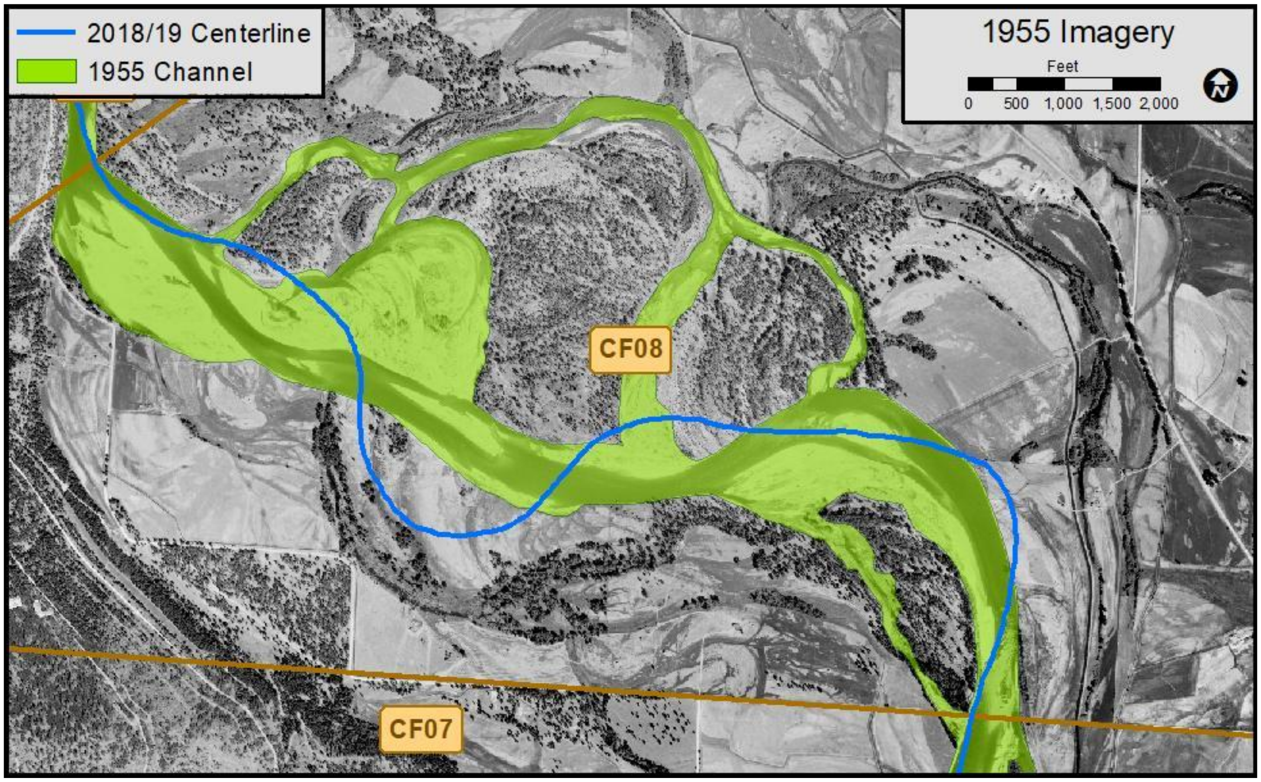

Figure 22. Example 1955 imagery at Council Grove State Park.

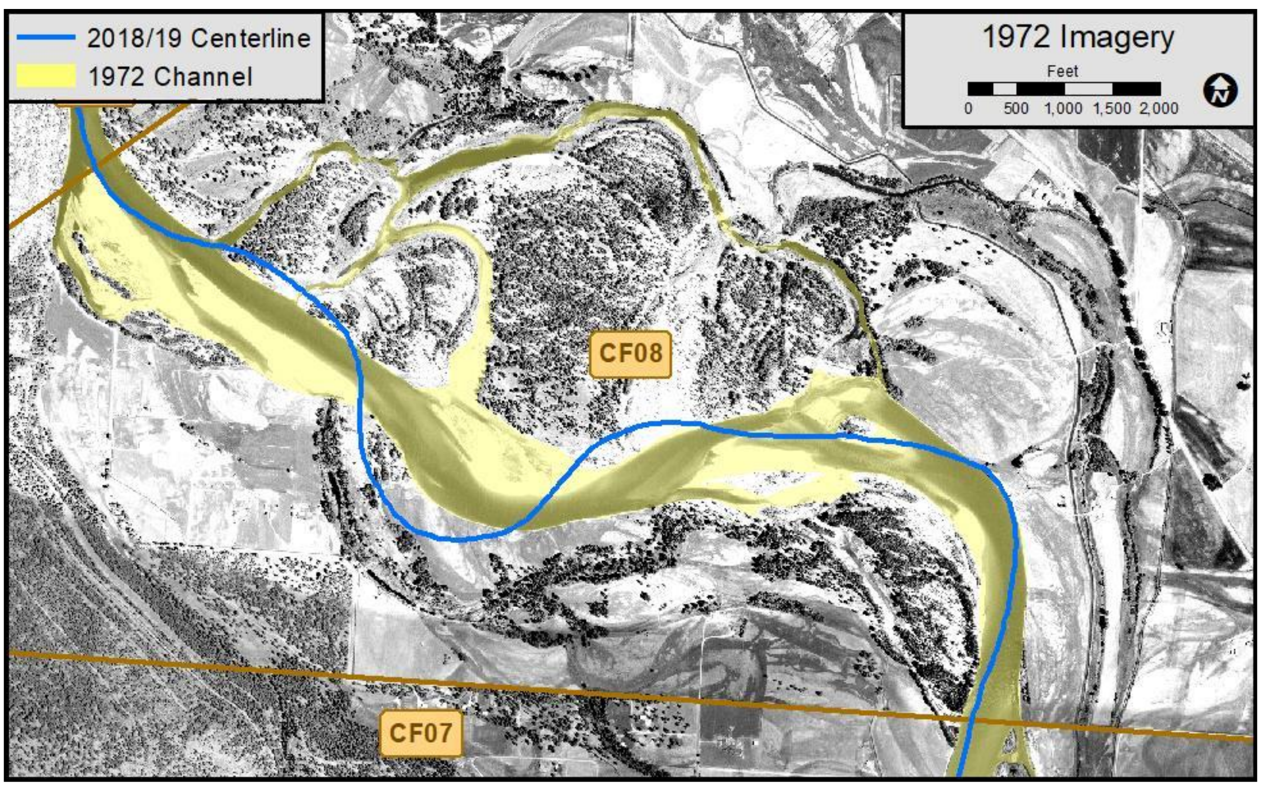

Figure 23. Example 1972 imagery at Council Grove State Park.

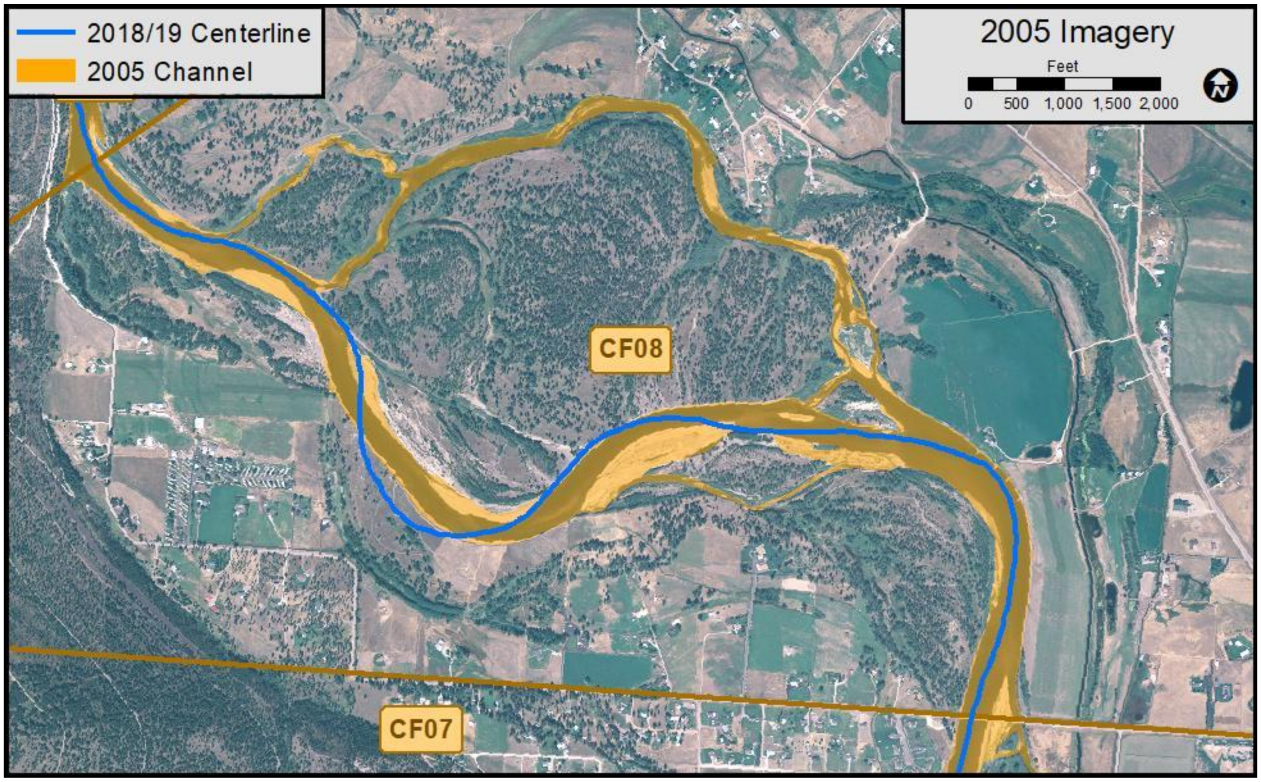

Figure 24. Example 2005 NAIP imagery at Council Grove State Park.

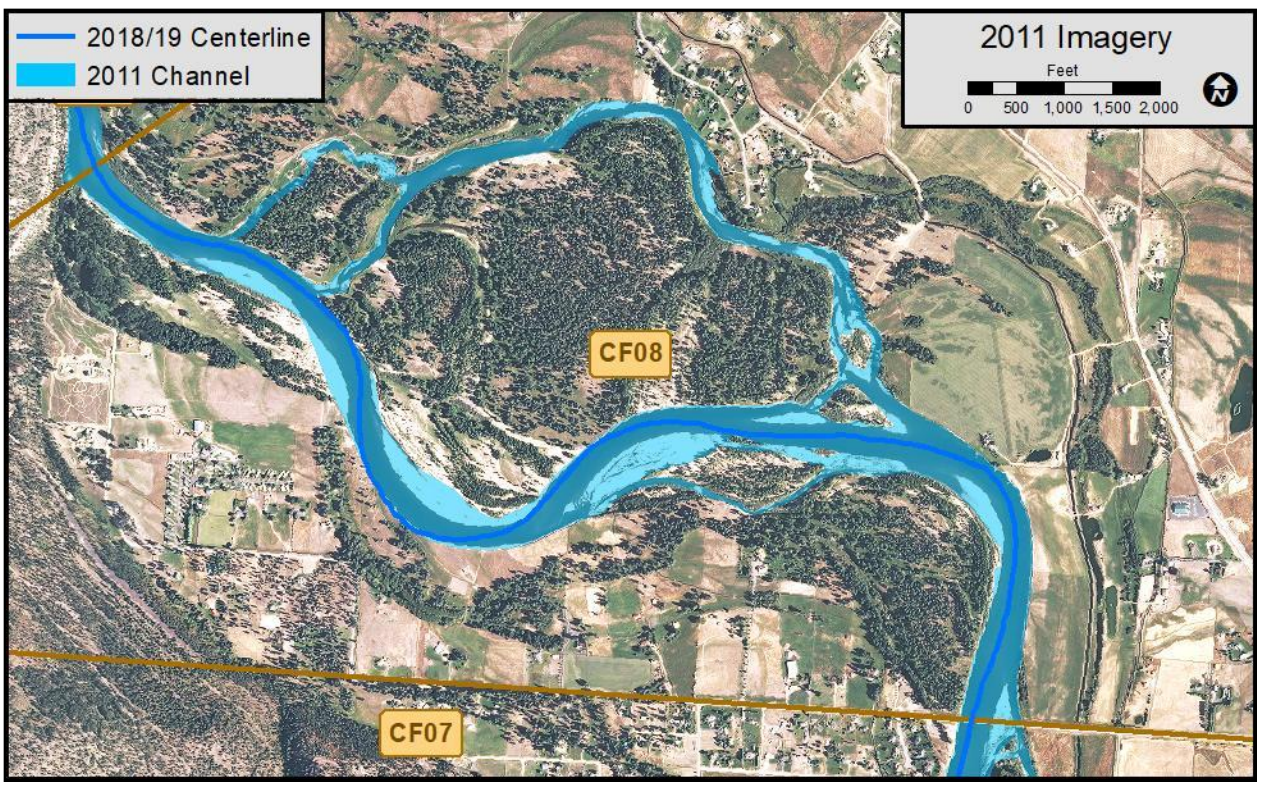

Figure 25. Example 2011 NAIP imagery at Council Grove State Park.

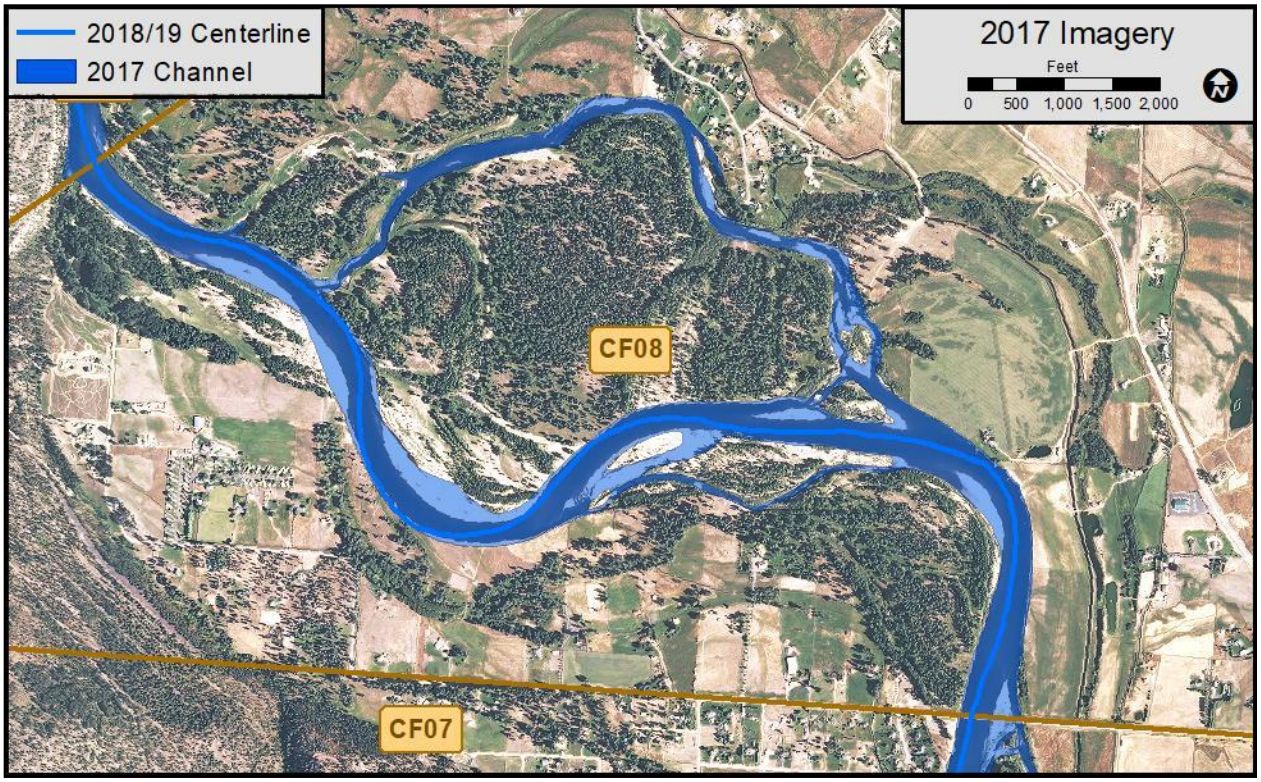

Figure 26. Example 2017 NAIP imagery at Council Grove State Park.

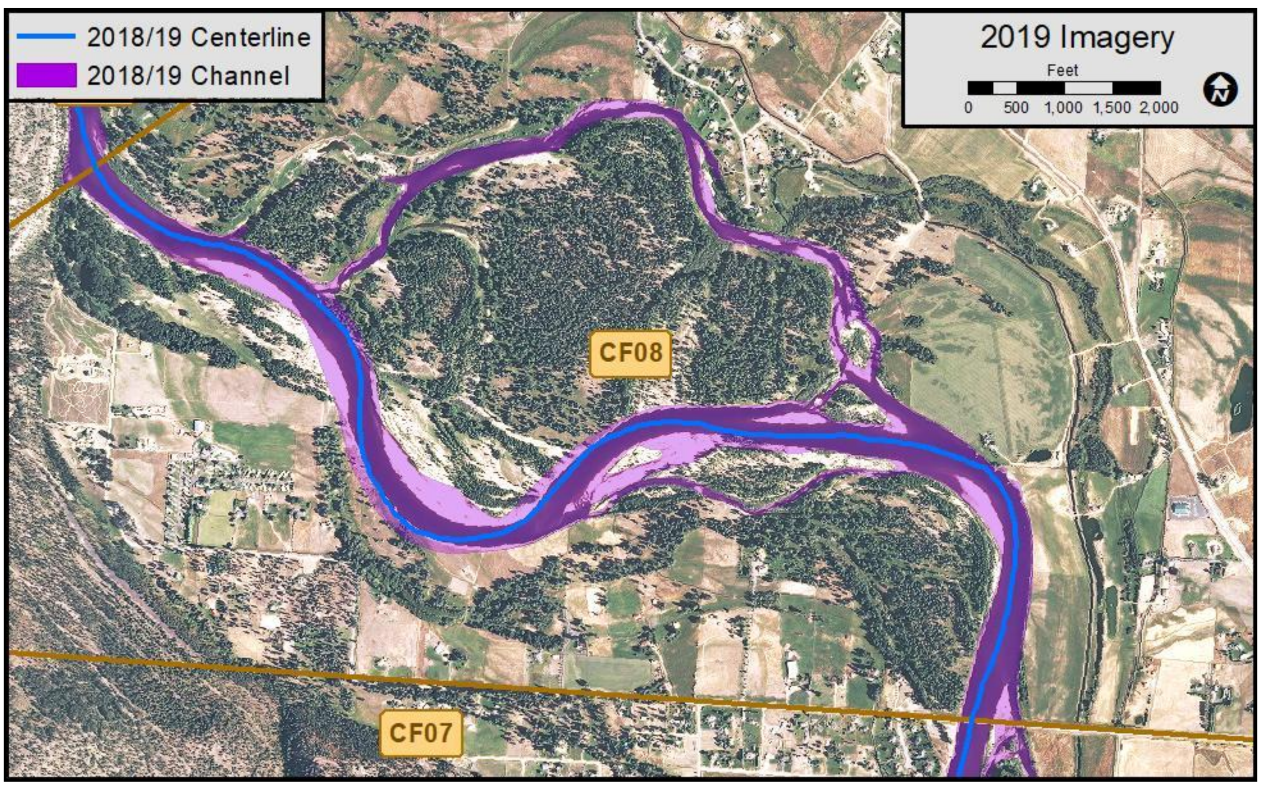

Figure 27. Example 2019 NAIP imagery at Council Grove State Park.

3.2 GIS Project Development

All project data was compiled using ESRI's ArcMap Geographic Information System (GIS) utilizing a common coordinate system - Montana State Plane NAD83 Meters. The orthorectified air photos provide the basis for CMZ mapping. Other existing datasets included roads, 2018 LiDAR, flood studies, scanned General Land Office Survey Maps obtained from Bureau of Land Management, and geologic maps produced by the United States Geological Survey. MT Fish Wildlife and Parks stream stationing at tenth of a mile increments is used as the linear referencing for all discussions.

3.3 Bankline Mapping

Bankline mapping approximating bankfull conditions was developed for each suite of imagery. Most bankline mapping was performed for previous project phases over the past 11 years. New mapping was generated from 2017 (NAIP) and the composite 2018/19 (WorldView/NAIP) imagery. All banklines were digitized at a scale of ~1:3,000. Bankfull is defined as the stage above which flow starts to spread onto the floodplain. Although that boundary can be identified using field indicators or modeling results (Riley, 1972), digitizing banklines for CMZ development requires the interpretation of historic imagery. Therefore, we typically rely on the extent of the lower limit of perennial, woody vegetation to define channel banks (Mount & Louis, 2005). This is based on the generally accepted concept that bankfull channels are inhospitable to woody vegetation establishment. Fortunately, shrubs, trees, terraces, and bedrock generally show distinct signatures on both older black-and-white as well as newer color photography. These signatures, coupled with an understanding of riparian processes, allow for consistent bankline mapping through time and across different types of imagery.

3.4 Migration Rate Measurements

Once the banklines were digitized, they were evaluated in terms of discernable channel migration since 1955. Where migration was clear, vectors (arrows with orientation and length) were drawn in the GIS to record that change. At each site of bankline migration, measurements were collected approximately every 100-150 feet (Figure 28). A total of 765 measurements were collected on the Clark Fork River and 148 on the Bitterroot River. These measurements were then summarized by reach. The results were then used to define a reach-scale erosion buffer width to allow for likely future erosion. Results of this analysis are summarized in Section 4.3.

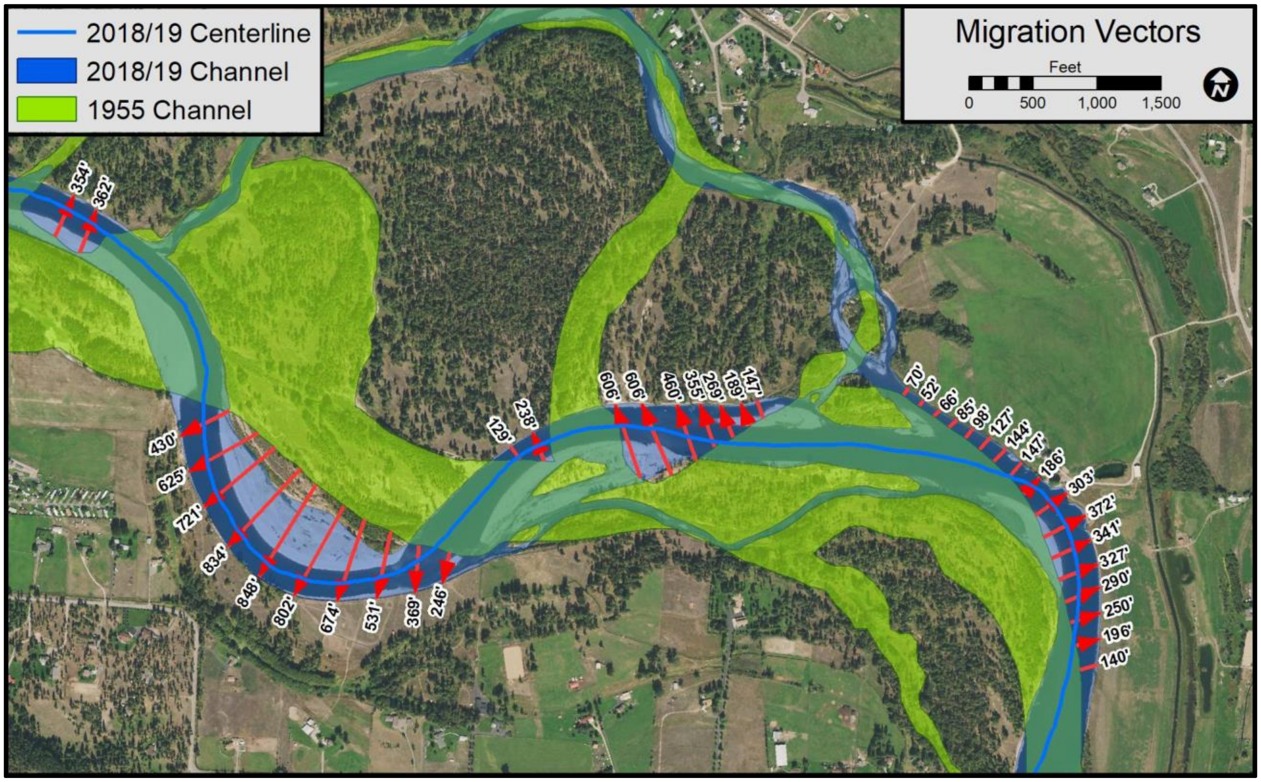

Figure 28. Example of migration measurements between 1955 and 2019 (migration distance in feet).

3.5 Avulsion Hazard Mapping

The Avulsion Hazard mapping captures areas beyond the core CMZ that show some propensity for developing new active channels in floodplain areas, such as at meander cores or 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 two feet above the LiDAR water surface elevation.
- Swales carrying concentrated floodwaters during the 2018 flood.
- Well-defined continuous flow paths that intersect the core CMZ (HMZ and EHA) boundaries
- Tributaries that run parallel to the river.

The Clark Fork River floodplain has a broad network of floodplain swales, especially downstream of Missoula. There has been substantial development in these areas, such that residences are commonly accessed by roads or driveways that cross abandoned channels that have culverts. In mapping the CMZ, these culverts were not presumed to provide long-term avulsion protection, although where major transportation embankments crossed a potential avulsion path, that path was considered severed and thus not accessible for reactivation.

Figure 29 shows several potential avulsion paths that follow historic swales outside the Historic Migration Area (HMZ).

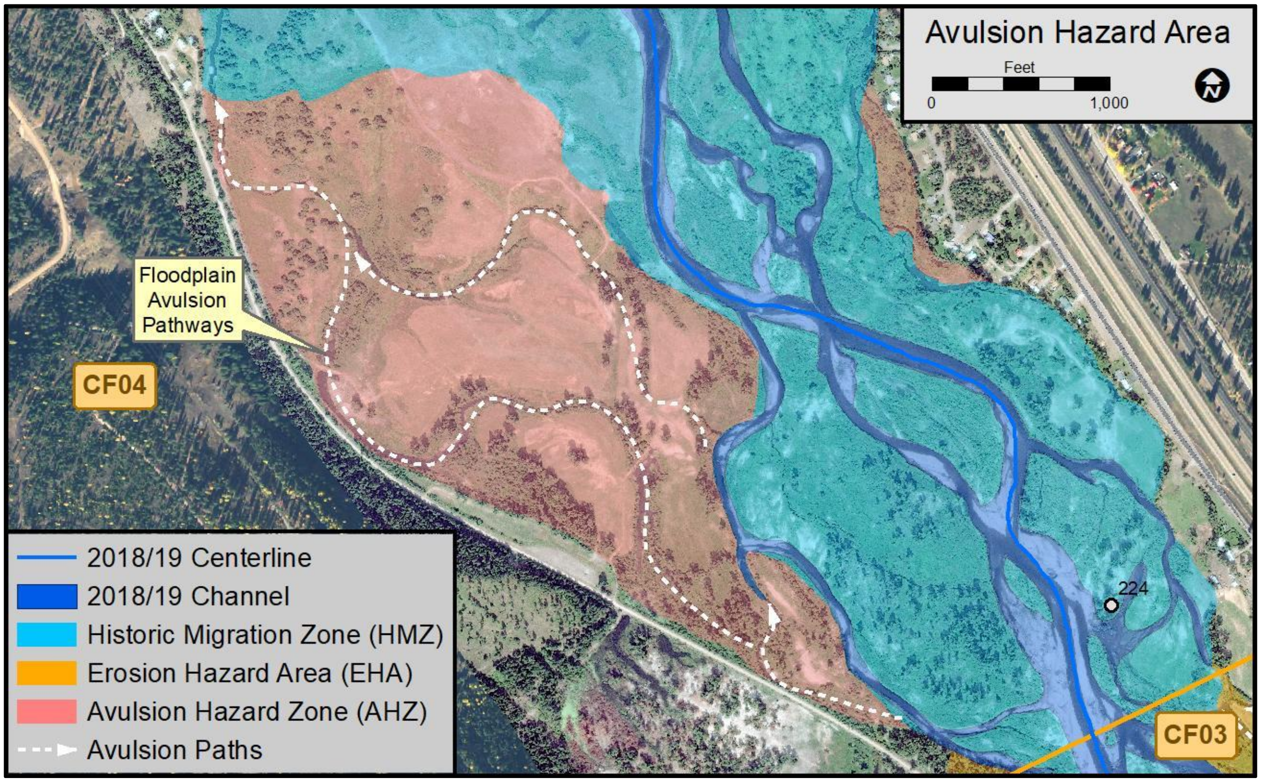

Figure 29. Example avulsion pathways .

4 Results

The Channel Migration Zone (CMZ) developed for the Clark Fork and Bitterroot Rivers is defined as a composite area made up of (1) the existing channel, (2) the historic channel since 1955 (Historic Migration Zone, or HMZ), (3) an Erosion Hazard Area (EHA) that encompasses areas prone to channel erosion over the next 100 years, and (4) areas beyond the EHA/HMZ that pose risks of channel avulsion (Avulsion Hazard Zone or AHZ). Those areas of the CMZ where migration has been restricted are highlighted as Restricted Migration Area (RMA). Lastly, areas bound by geology such as erosion-resistant valley walls were excluded from the CMZ.

4.1 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 3 and Figure 30). On the Clark Fork River, the 68 miles of project length was broken into ten reaches ranging in length from 2.3 miles at the Milltown Dam Restoration site to 9.9 miles through the city of Missoula. The 23 miles of the Bitterroot River was broken into two reaches.

Table 3. Clark Fork and Bitterroot River CMZ mapping project reaches.

Reach	General Location	Upstream RM	Downstream RM	Length (mi)	Description
			CLARK FORK RIVER		
CF01	County Line to Rock Creek	246.3	239	7.3	Beavertail State Park, moderately confined by south valley wall and transportation
CF02	Rock Creek to Allen Creek	239	230	9	Dynamic, avulsions common
CF03	Allen Creek to Milltown Restoration Site	230	224.1	5.9	River closely follows corridor margins
CF04	Milltown Restoration Site to Blackfoot River	224.1	221.8	2.3	Expanded floodplain, reconstructed channel through reservoir footprint
CF05	Blackfoot River to Water Treatment Plant Below Reserve St	221.8	211.9	9.9	Highly confined through Missoula
CF06	Water Treatment Plant Below Reserve St to Bitterroot River	211.9	207	4.9	Kelly Island--- dynamic wide corridor
CF07	Bitterroot River to Kona Ranch Rd Bridge	207	203.8	3.2	Straight with low rates of lateral shift
CF08	Kona Ranch Rd Bridge to Below Council Grove State Park	203.8	201.2	2.6	Unconfined with large bendways
CF09	Below Council Grove State Park to Below Smurfit Stone	201.2	194.5	6.7	Major west valley wall control, Smurfit Stone reach
CF10	Below Smurfit Stone to Petty Creek Rd Bridge	194.5	185.6	8.9	Dynamic, split flow common, rapid migration
			BITTERROOT RIVER		
BR1	County Line to Maclay Ranch Rd Bridge	21.4	15.8	5.6	Dynamic, wide corridor
BR2	Maclay Ranch Rd Bridge to Clark Fork River	15.8	0	15.8	Semi-confined, straight

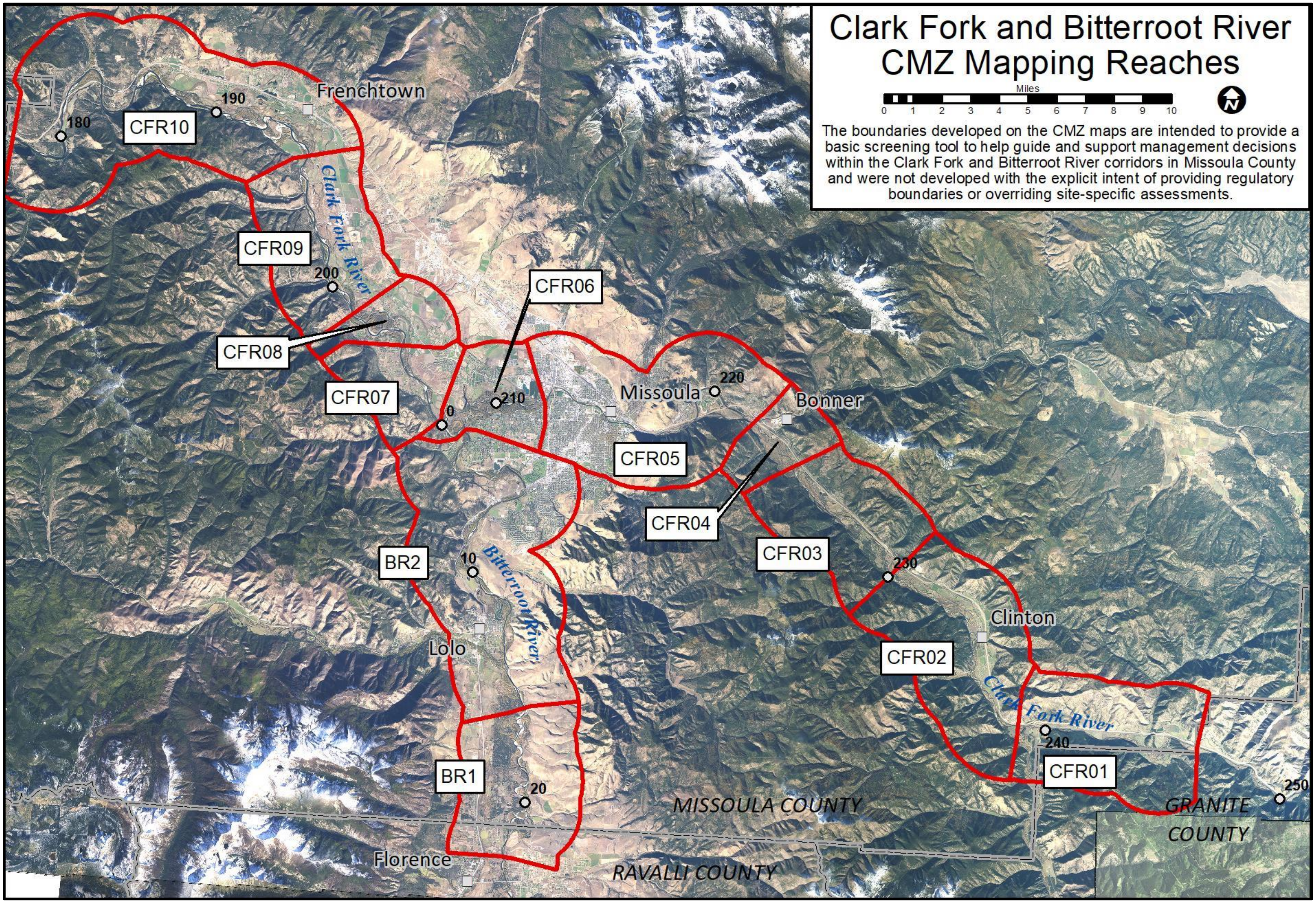

Figure 30. Clark Fork and Bitterroot Rivers CMZ mapping project reaches.

4.2 The Historic Migration Zone (HMZ)

The Historic Migration Zone (HMZ) is created by combining the bankfull channel polygons into a single HMZ polygon. The bankfull channels commonly split and rejoin, creating a mosaic of channel courses with intervening islands, some of which are seasonal. The HMZ footprint includes all channels as well as any area between split flow channels. By including islands, the HMZ captures the entire footprint of the active river corridor from 1955-2019. In some settings where island areas are non-erodible, it may be appropriate to exclude these features from the CMZ. In the case of the Clark Fork and Bitterroot Rivers, however, these areas have been retained in the CMZ since they are made up of young alluvial deposits that are prone to reworking or avulsion and are thus part of the active meander corridor.

Any side channels that have not shown perennial connectivity to the main channel since 1955 were not mapped as active channels and are not included in the HMZ.

For this study, the Historic Migration Zone is comprised of the total area occupied by bankfull channel locations including islands in 1955, 1964 (Bitterroot only), 1972, 1995 (Clark Fork upstream of Milltown), 2005, 2011, 2017, and 2018/19 (Figure 31). The resulting corridor captures 64 years of channel occupation for the length of the Clark Fork/Bitterroot study area.

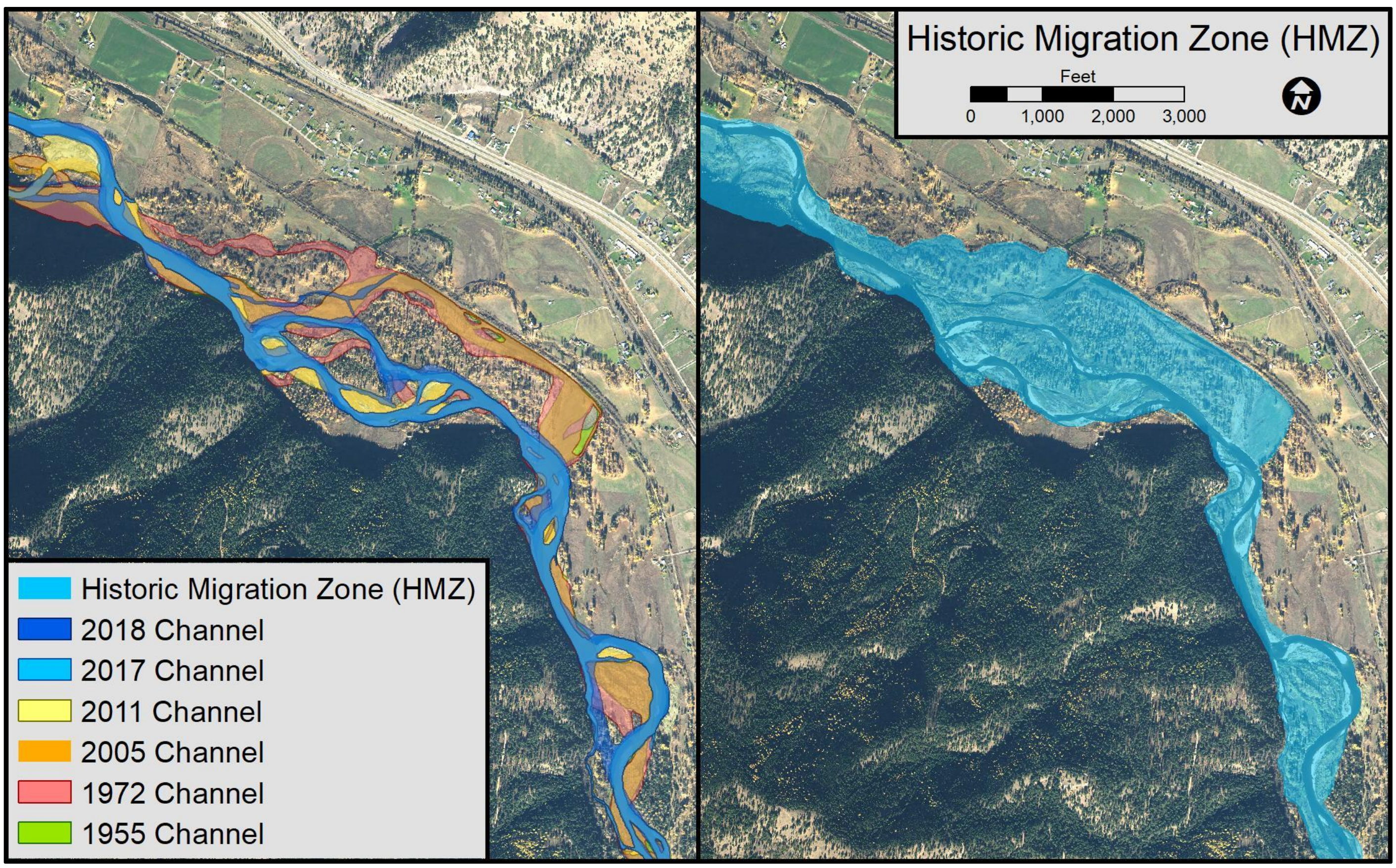

Figure 31. The Historic Migration Zone (HMZ) is the combined footprint of all mapped channel banklines.

4.3 The Erosion Hazard Area (EHA)

The Erosion Hazard Area (EHA) is based on measured migration rates, which are derived from measured migration distances. Migration distances between the 1955 and 2019 banklines were measured where it was clear that the channel movement was progressive lateral movement and not an avulsion. Measurements were collected at a spacing of 100-150 feet along eroding banklines to capture the entire range of migration distances at a given site. The minimum amount of movement captured is 30 feet, as this proved to be an easily measurable distance that is not compromised by the resolution or spatial accuracy of the data. Using this approach, a total of 765 measurements were collected on the Clark Fork River and 148 on the Bitterroot River.

Figure 32 shows the distribution of measurements for each reach. 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 points. The results show that 7 of the 12 reaches have individual areas of markedly high migration rates that show up as outliers on the plot.

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. In some systems where the migration rates cluster and show limited variability, the mean value is used to define the buffer. In the case of the Clark Fork and Bitterroot Rivers, however, the predominance of outliers in most reaches means that an average migration distance is unlikely to effectively capture future migration potential on the river. In these settings we generally consider using a higher, more inclusive migration distance value to capture that potential.

Figure 33 shows the migration distance measurements plotted as average rate of movement (ft/yr) from 1955-2019. The rates over this 64 year period are generally less than 5 feet per year, although in some reaches the migration rates are much higher, with outliers exceeding 20 feet per year.

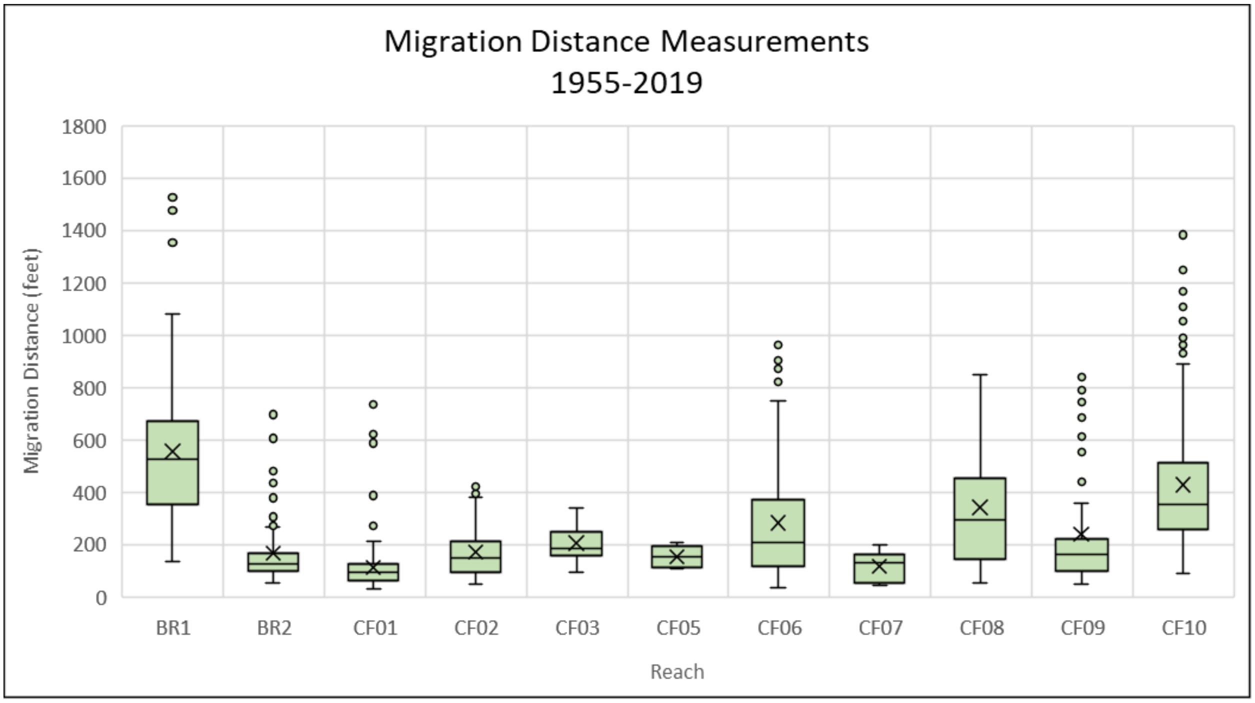

Figure 32. Box and whisker plot showing measured 1955-2019 migration distances by reach - reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X."

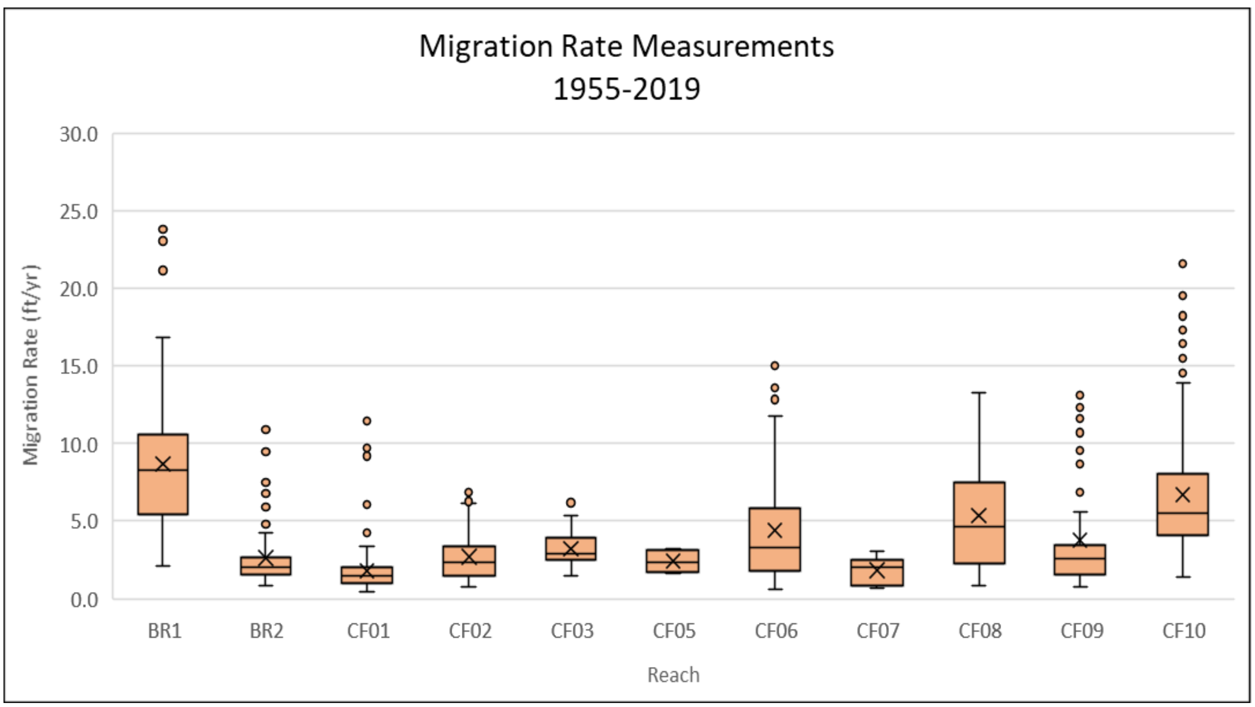

Figure 33. Box and whisker plot showing measured 1955-2019 migration rates by reach - reaches are plotted from upstream (left) to downstream (right). Mean values are denoted by "X."

Because of the broad range in migration rates, there is substantial risk in using the average migration rate in defining erosion hazard areas on these segments of the Clark Fork and Bitterroot Rivers. To that end, a more inclusive statistic, the 75th percentile value, has been used to define the rate for determining erosion buffer width. This provides a reasonably conservative estimate of migration potential over the next century. Table 4 and Figure 34 show the resulting 100-year erosion buffer distance values for each reach. They range from about 200 feet in the upstream most reach on the Clark Fork River (CFR01) to over a thousand feet on the Bitterroot River in Reach BR01. These buffer widths were placed on the landward edge of the 2019 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 4. 75th percentile migration annual rate and 100-year EHA buffer by reach.

Reach	Number of Measurements	Maximum Migration Distance (ft)	75th Percentile Annual Migration Rate (ft/yr)	100- Year Buffer Width (ft)
CF01	134	734	2.0	201
CF02	134	445	3.3	332
CF03	31	398	3.9	388
CF04*	NA	NA	NA	NA
CF05	4	208	3.0	303
CF06	155	983	5.8	580
CF07	26	198	2.5	252
CF08	38	848	7.1	706
CF09	96	854	3.4	344
CF10	147	1397	8.0	800
BR1	74	1550	10.5	1047
BR2	74	697	2.6	262

*CF04 is the Milltown Dam restoration site with a reconstructed channel and no migration measurements.

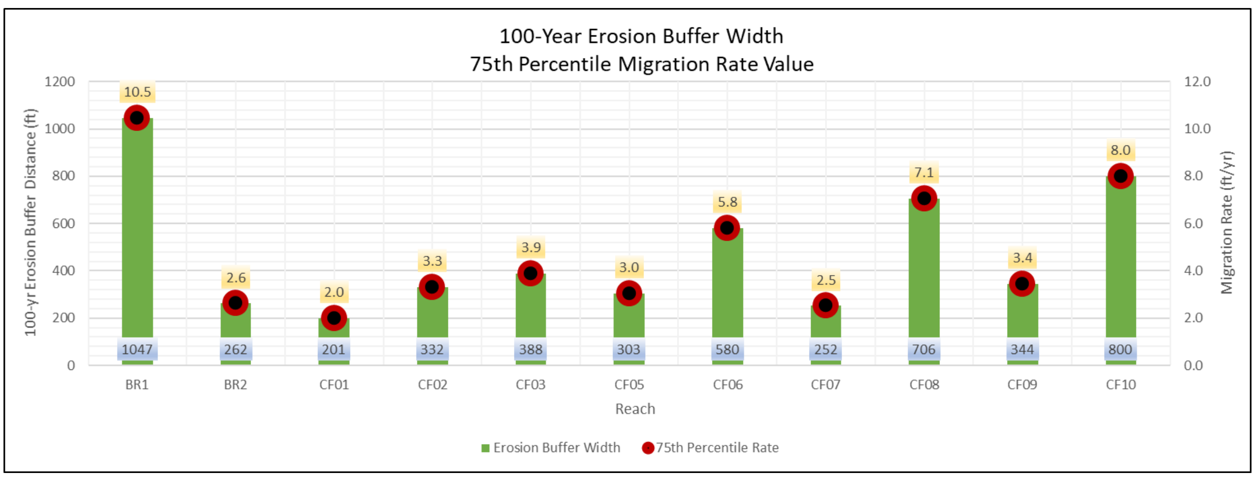

Figure 34. Erosion buffer widths developed for each reach based on 75th percentile migration rate value in each reach- points show migration rate and bars are corresponding buffer width (ft/yr rate multiplied by 100 years).

As the *75th Percentile* migration rate is the statistic used to define the EHA buffer, the results are inherently conservative and some localized channel migration through and beyond the EHA buffer should be anticipated over the next century. Figure 35 shows that in almost every reach, the 100-year erosion buffer is less than the maximum measured migration distance for the reach. Typically, however, these areas of rapid bankline movement are within the Historic Migration Zone and thereby captured in the CMZ.

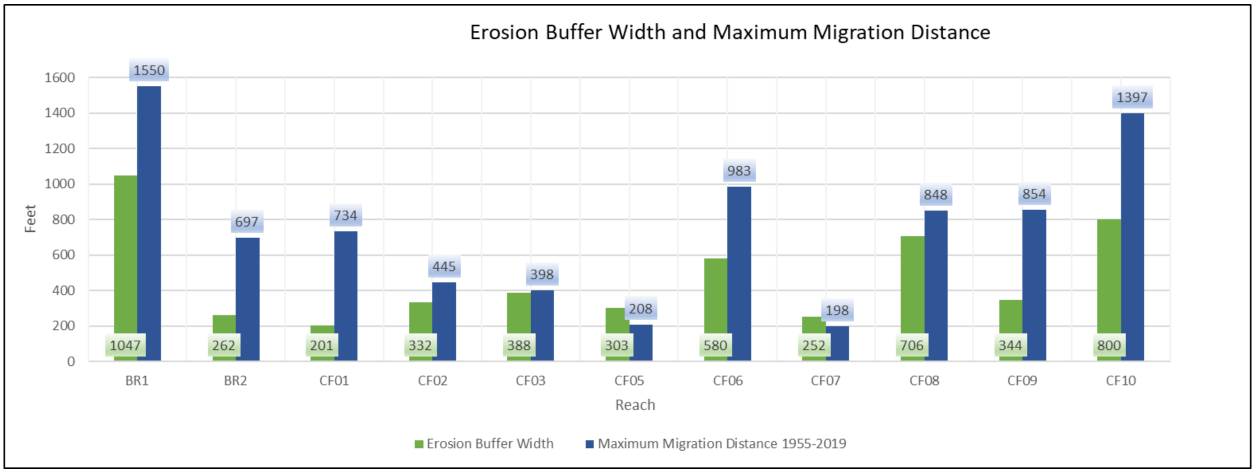

Figure 35. Comparison of Erosion Hazard Buffer width and maximum measured 1955-2019 migration distance.

To consider whether the 75th percentile value will broadly underestimate migration potential over the next century, the buffers were applied to historic banklines to see if the river had migrated through them by 2019. One expects to see some locations where the Historic Migration Zone (footprint of all channels) extends beyond the historic buffer in localized areas of high erosion (e.g., the Tree Farm site), but for the most part, the HMZ should be contained within this historic buffer. An undersized buffer would show extensive regions that have eroded beyond the historic buffer, while too large a buffer would show no areas having eroded beyond the historic buffer. From this review, the 75th percentile buffer performs well.

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).

An example of EHA mapping is shown in Figure 37. If the EHA extends into the Historic Migration Zone, it is masked by the HMZ so that areas of historic channel locations are prioritized in the mapping hierarchy. As a result, the EHA is typically discontinuous along the river.

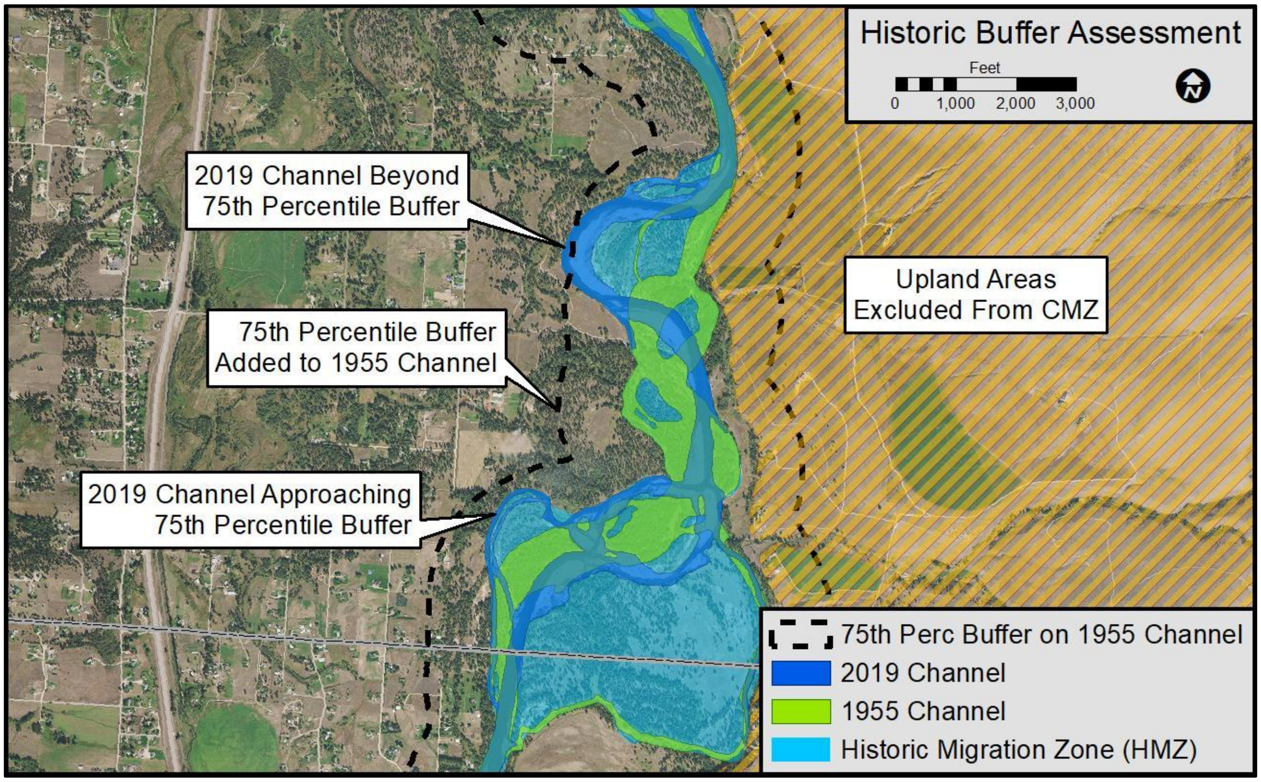

Figure 36. Assessing erosion buffer performance.

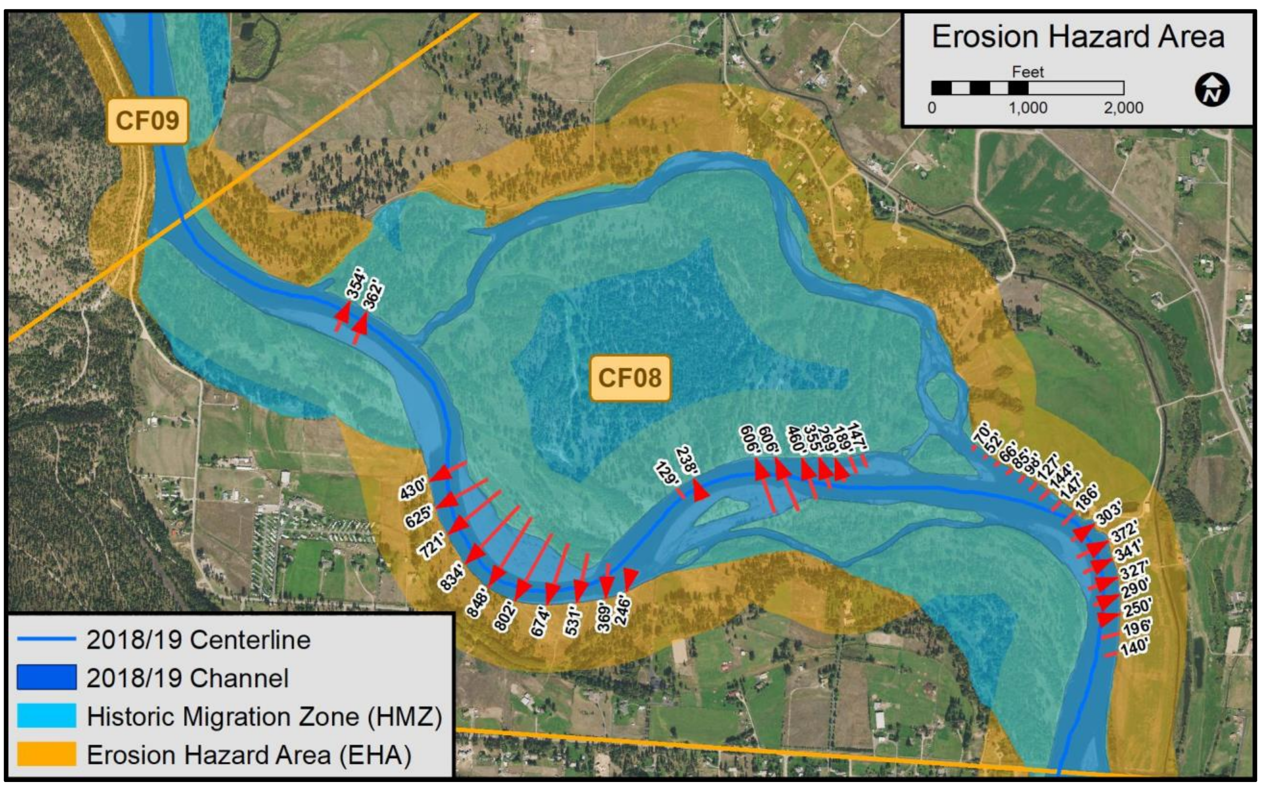

Figure 37. The Erosion Hazard Area (EHA) is a buffer placed on the 2019 banklines based on 100 years of channel migration for the reach.

4.4 The Avulsion Hazard Area (AHZ)

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

At least 19 avulsions happened in the project area since 1955, with most occurring in the Kelly Island area (Reach CF06). Figure 39 shows an example of an avulsion through a subtle floodplain swale in Reach CF02 about two miles downstream from Clinton.

Considering the history of avulsions in the project area, the CMZ boundaries were extended to capture similar areas that show demonstrable potential for avulsions over the next century. These mapped units capture floodplain areas that are beyond the HMZ or EHA but have side channels prone to re-occupation or meander cores prone to cutoff. It is important to recognize, however, that these events could realistically happen anywhere on the river's floodplain, and the CMZ mapping captures only the most demonstrable avulsion-prone areas.

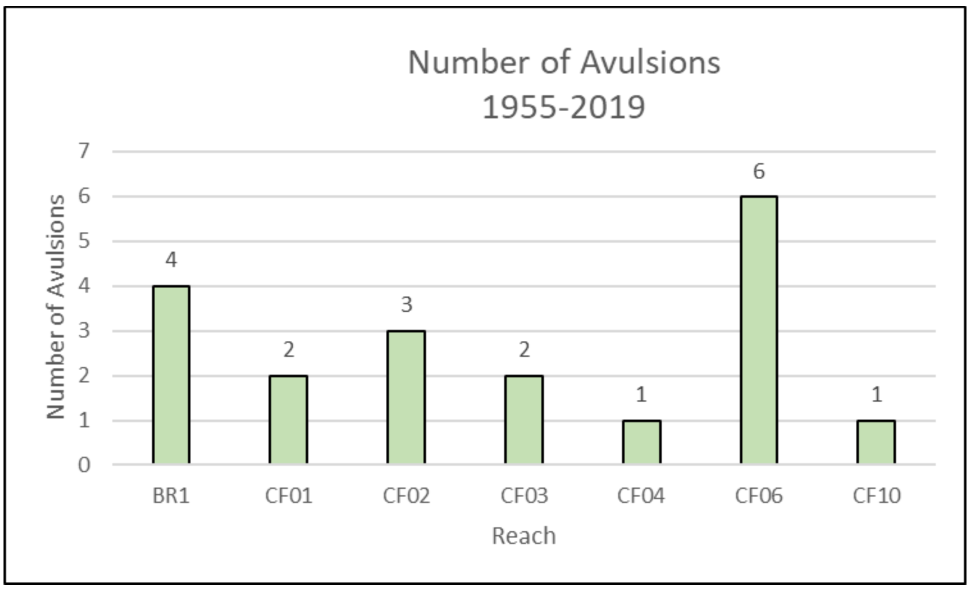

Figure 38. Number of mapped avulsions by reach.

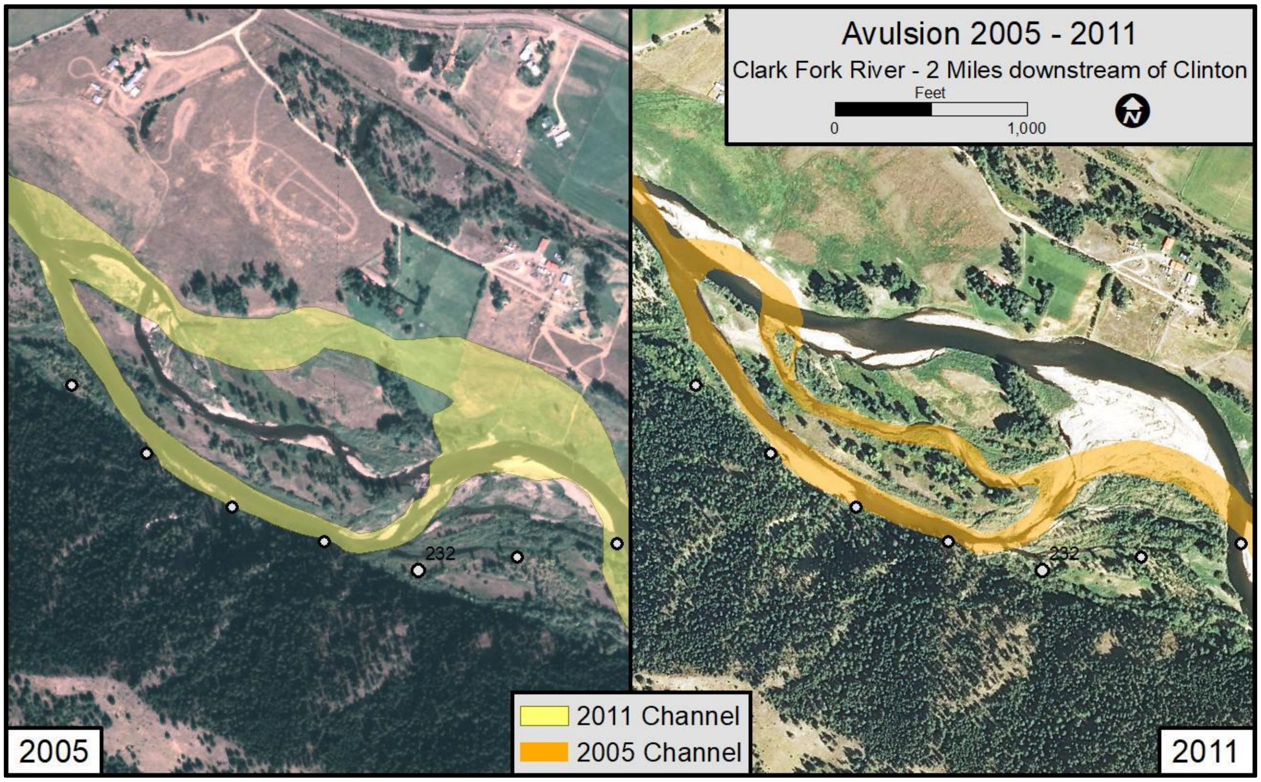

Figure 39. Major avulsion at RM 232 between 2005 (left) and 2011 (right).

4.5 The Restricted Migration Area (RMA)

The restricted migration area largely reflects bank protection associated with a variety of land uses including property protection, bridges, roadways, railroad beds, floodplain, remediation (Milltown), and Smurfit Stone. The primary reason for bank protection varies by reach. For example, in reaches CF01 through CF03 most of the armor is associated with the transportation corridor (roads, railroad, and bridge), while the armor in CF09 is entirely associated with Smurfit Stone. On the Clark Fork below Milltown and on the Bitterroot River, bank armoring is commonly associated with residential properties.

A total of 21 miles of bank armor were mapped on the 91 miles of project length. As this data was compiled from a variety of sources at different times, it is likely a conservative estimate of the amount of armor in the system. Additionally, some mapped armor has been lost due to local channel migration, further complicating any assessment of amount of armor. Figure 41 shows that the extent of armored banks ranges from 6% to 33% of the main channel length. The densest armor is in Reach CF05, where about 34,890 feet or almost 33% of the total bankline is armored to protect the highly-developed City of Missoula core.

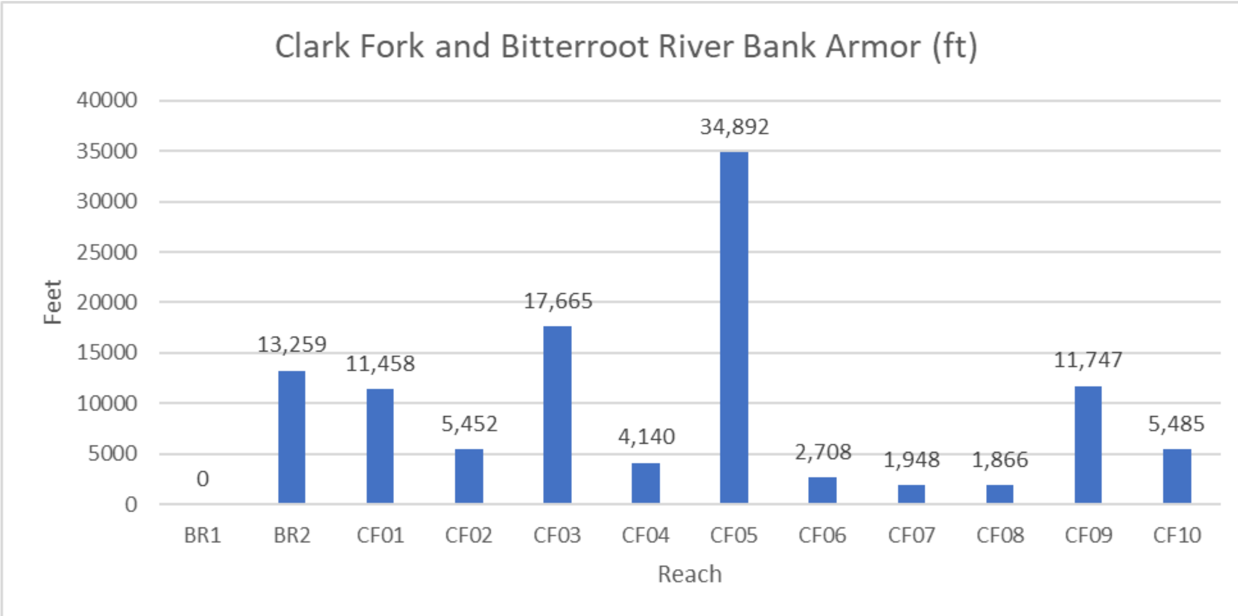

Figure 40. Total length of mapped bank armor on the Clark Fork and Bitterroot Rivers.

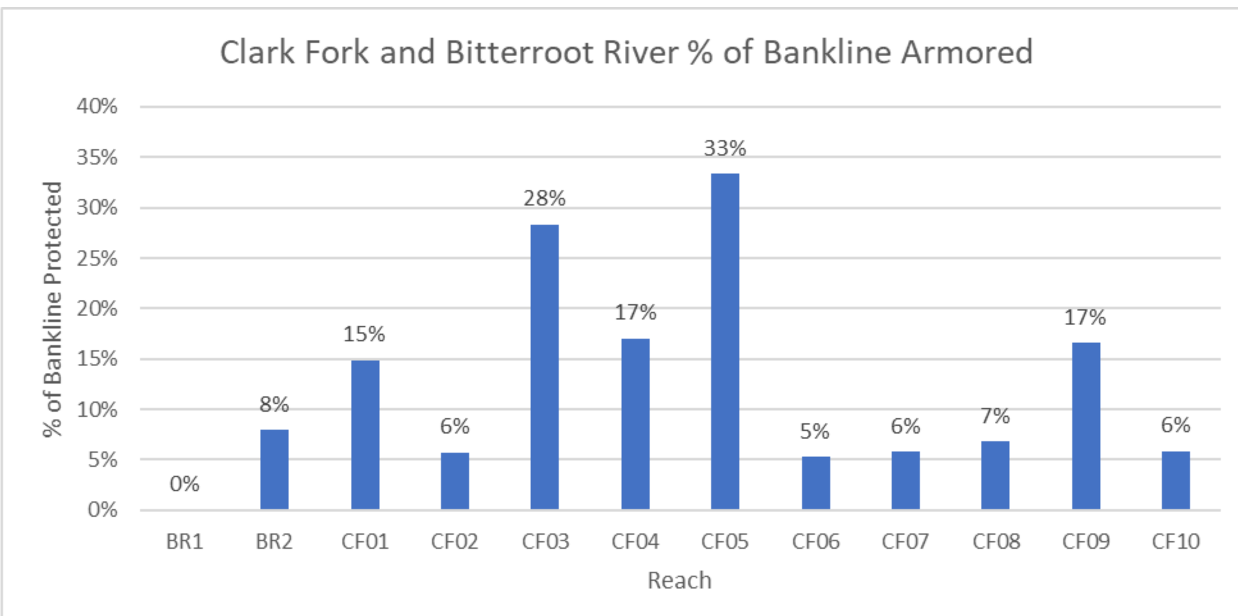

Figure 41. Percentage of bankline with mapped armor by reach.

Figure 42 shows an example of Restricted Migration Areas on the Bitterroot River where it joins the Clark Fork.

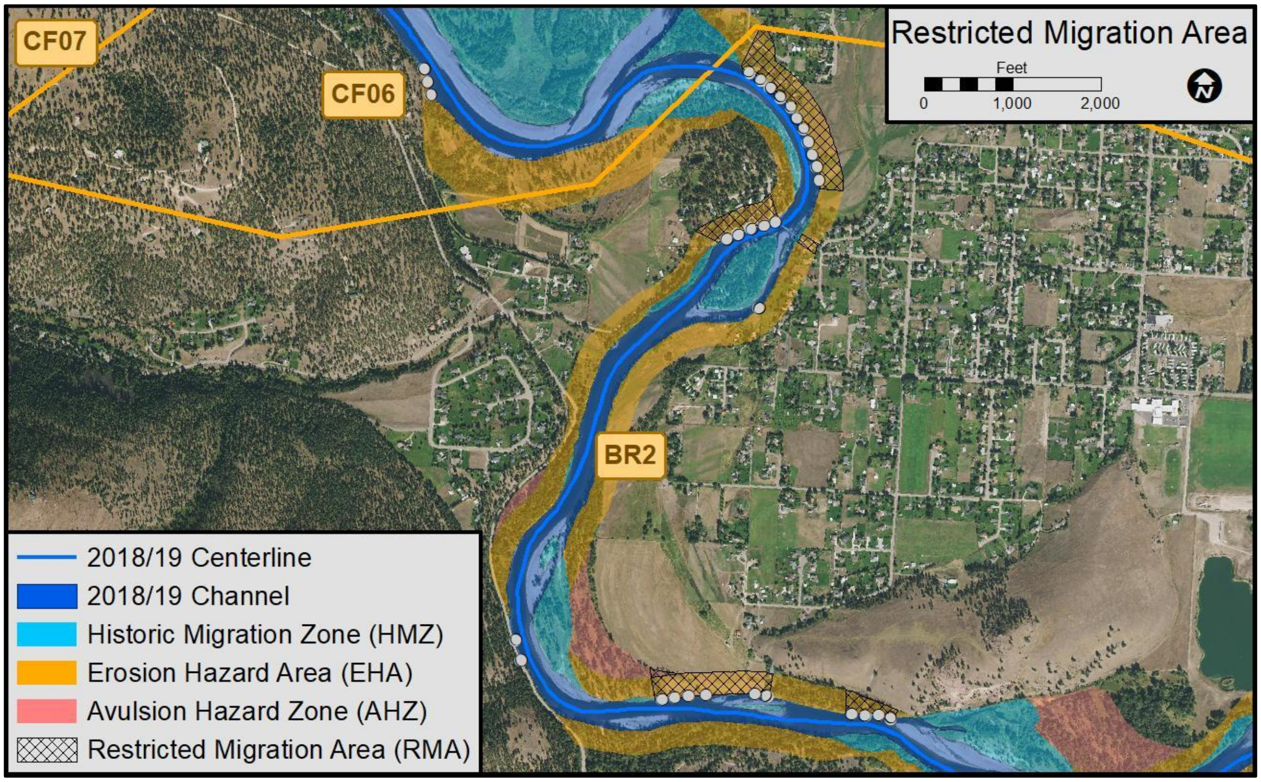

Figure 42. Restricted Migration Areas at the Bitterroot/Clark Fork confluence.

Bank armoring and levees currently restrict access to approximates 1,275 acres of the Channel Migration Zone (Figure 43). This is most evident in reaches CF05 (downtown Missoula) and CF09 (Smurfit Stone).

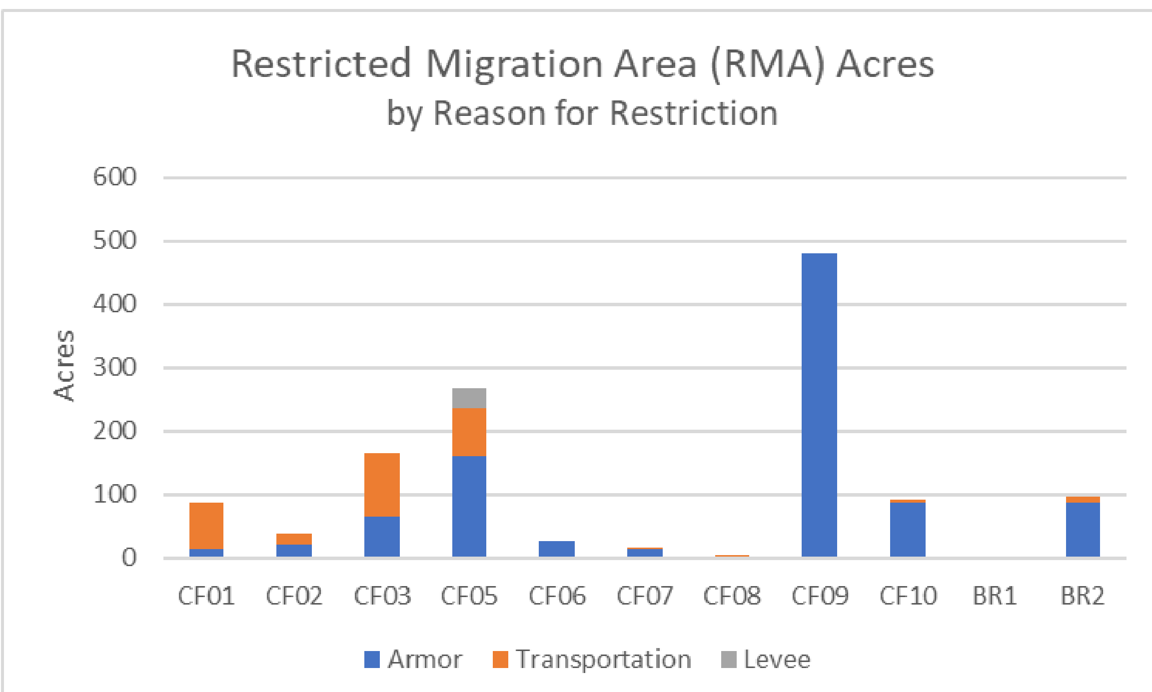

Figure 43. Acres of the CMZ mapped as restricted by reach.

4.6 Composite Map

An example portion of a composite CMZ map at Beavertail Hill is shown Figure 44. Each individual mapping unit developed for the CMZ has its own symbology, so that any area within the overall boundary can be identified in terms of its basis for inclusion. Over the 91 mile project reach, a total of 18,737 acres of land comprises the CMZ, or about 206 acres per mile. The mean width of the CMZ is highly variable depending on the geomorphic setting and hydrology. Upstream areas on the Clark Fork River can be as narrow as 500 feet, while below the Bitterroot confluence it can be over 6,000 feet wide.

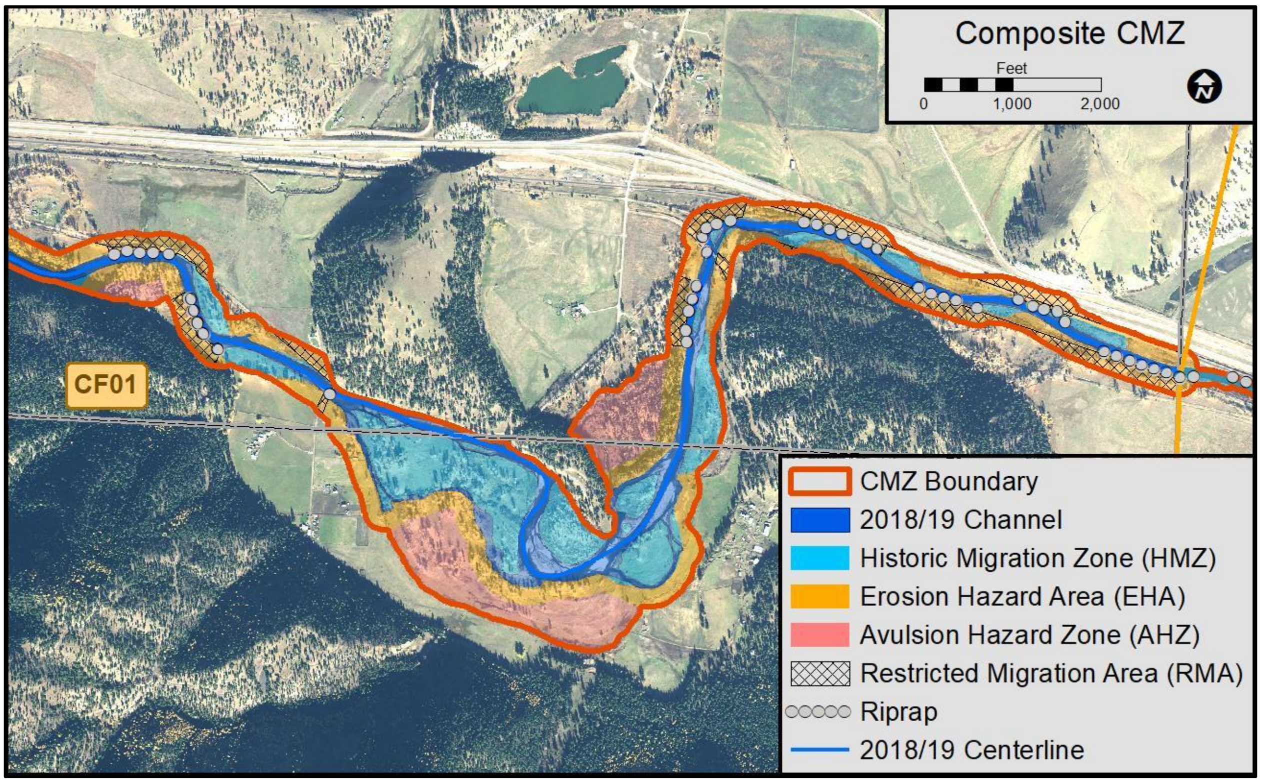

Figure 44. Composite Channel Migration Zone map, Reach CF01 at Beavertail Hill State Park.

4.7 Geologic Controls on Migration Rate

Where the CMZ intersects minimally-erodible valley wall geologic units, the boundaries were clipped to remove these areas from the mapping corridor.

Some CMZ mapping efforts incorporate a Geotechnical Setback on valley walls, which is an area of expanded Erosion Hazard Area (EHA) against geologic units that may be prone to geotechnical failure such as landslides, slumps, or rockslides. Within this project area, there are no mapped active landslides against the river, which suggests that the CMZ will not likely be altered by hillslope failure. Even so, confined channel segments may still be prone to rockslides may impact the river's course. Defining an appropriate setback for these processes is difficult at best and may reflect more stochastic processes than have been used to develop the CMZ. As a result, Geotechnical Setbacks have not been incorporated into the EHA, and incorporating the potential for mass failure on hillslopes was considered beyond the scope of this effort.

In reach CF06 (Kelly Island), an active secondary channel closely follows the edge of a low terrace that has been developed as residential neighborhood. Since older, more geologically mature terrace deposits tend to erode at a slower rate than the modern floodplain, we often develop a separate erosion buffer for these areas. During our period of record, however, the river eroded into only a small portion of this terrace, such that we have only a few measurements available to calculate a separate terrace erosion buffer. As there is significant risk that the main channel will re-occupy this southern-most channel (Section 5.6), it is important to acknowledge its risk of erosion in coming years. Since we lack sufficient measurements into these terrace materials, the Erosion Hazard Area (EHA) for this area uses the same 100-year EHA buffer distance as the rest of the reach (580 feet). This should be considered a conservative yet prudent EHA buffer width. Using the 75th percentile statistic for the measurements that we do have into the terrace would results in an erosion buffer width of approximately 200 feet. This narrower buffer is indicated on the map as a dashed line to reflect a potentially smaller EHA (Figure 45).

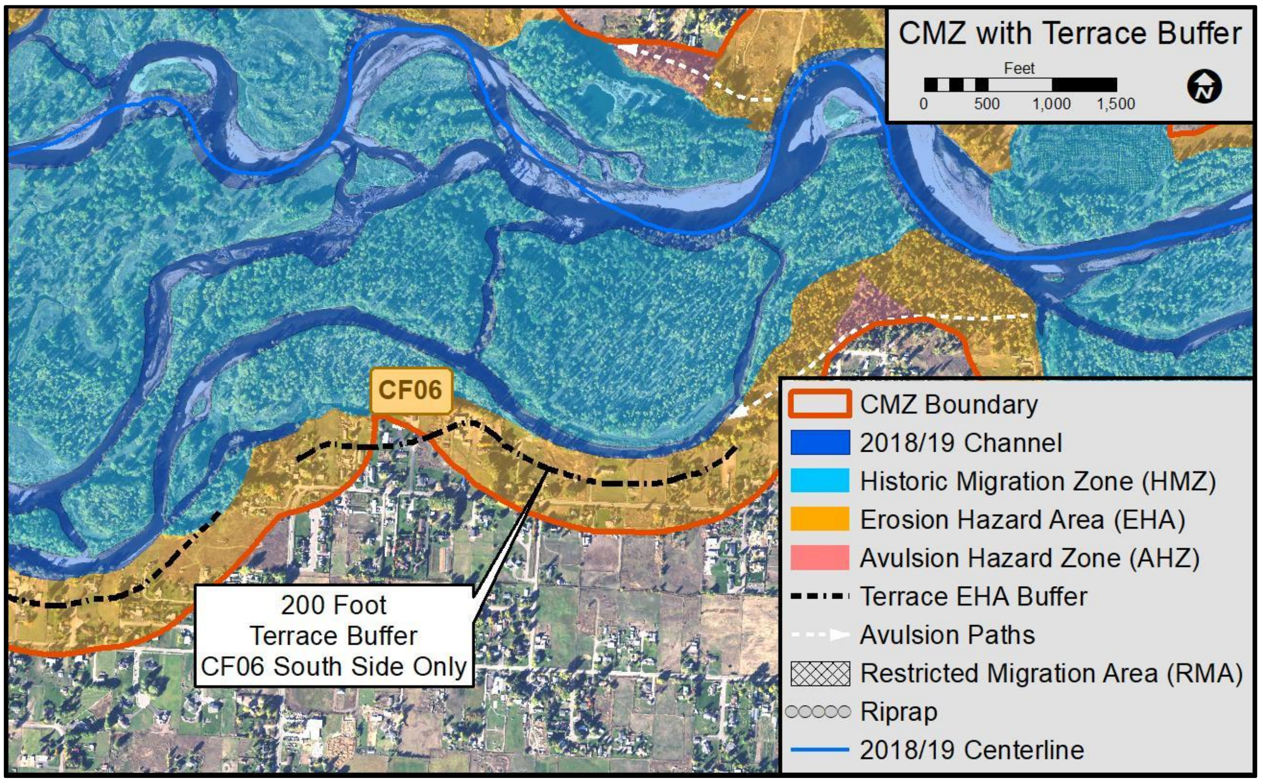

Figure 45. Composite Channel Migration Zone map with CF06 200 foot terrace buffer, Clark Fork River Kelly Island Area.

5 Reach Descriptions

The following sections describe each reach of the Clark Fork and Bitterroot Rivers. The reaches are numbered sequentially from the upstream end of the project. We strongly recommend that the reader refer to the CMZ maps found in Appendix A while reading this section.

Several of the reaches include specific areas of concern identified by Missoula County personnel, where channel migration or flooding are impacting existing infrastructure. These areas are discussed independently at the end of each reach description.

Note: All references to River Miles (RMs) reflect the Fish Wildlife and Parks data layer). River Miles are labeled on the maps in Appendix A. 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 16.4R” refers to the right streambank located 16.4 miles upstream of the river’s mouth.

5.1 Reach CF01 – County Line to Rock Creek

Reach CF01 is 7.3 miles long, extending from the Missoula/Granite County line to the mouth of Rock Creek. A total of 134 migration measurements were made in this reach to capture the amount of lateral migration that occurred between 1955 and 2019. The mean measurement distance was 114 feet, with a maximum migration distance of 734 feet at Beavertail Hill State Park. The erosion buffer width for Reach CF01 is 201 feet.

Figure 46 shows the Relative Elevation Model (REM) generated for Reach CF01. For most of the reach, the river is tightly confined between the valley wall to the south, which is comprised of Precambrian Belt Rocks, and the Interstate to the north Figure 47. The REM shows areas of low, isolated floodplain and abandoned channel swales north of the Interstate. The most dynamic segment of this reach is at Beavertail Hill State Park. Beavertail Hill itself is composed of granitic rocks that form a high spur that juts into the river corridor at a right angle. Just upstream of the spur, the LiDAR data/REM show distinct floodplain channels that consolidate at the base of the bedrock spur, continuing to the southeast along its margin (Figure 48). These channels mark a clear avulsion hazard that has been included in the CMZ footprint (Appendix A).

Just south of the granite spur, a large bendway has migrated over 700 feet southward since 1955 (Figure 49). This bend began to develop after another meander cut off just upstream, leaving an oxbow to the south and directing the main river channel into the rapidly migrating bend. This southward migration, accelerated by the cutoff upstream, has caused the river to migrate into an old channel on the south floodplain that became activated in 2018 as an avulsion (Figure 49). This sequence of events shows how substantially channel locations can change over decades, and how changes in river location can have cascading effects in adjacent areas.

No specific areas of concern were identified in Reach CF01.

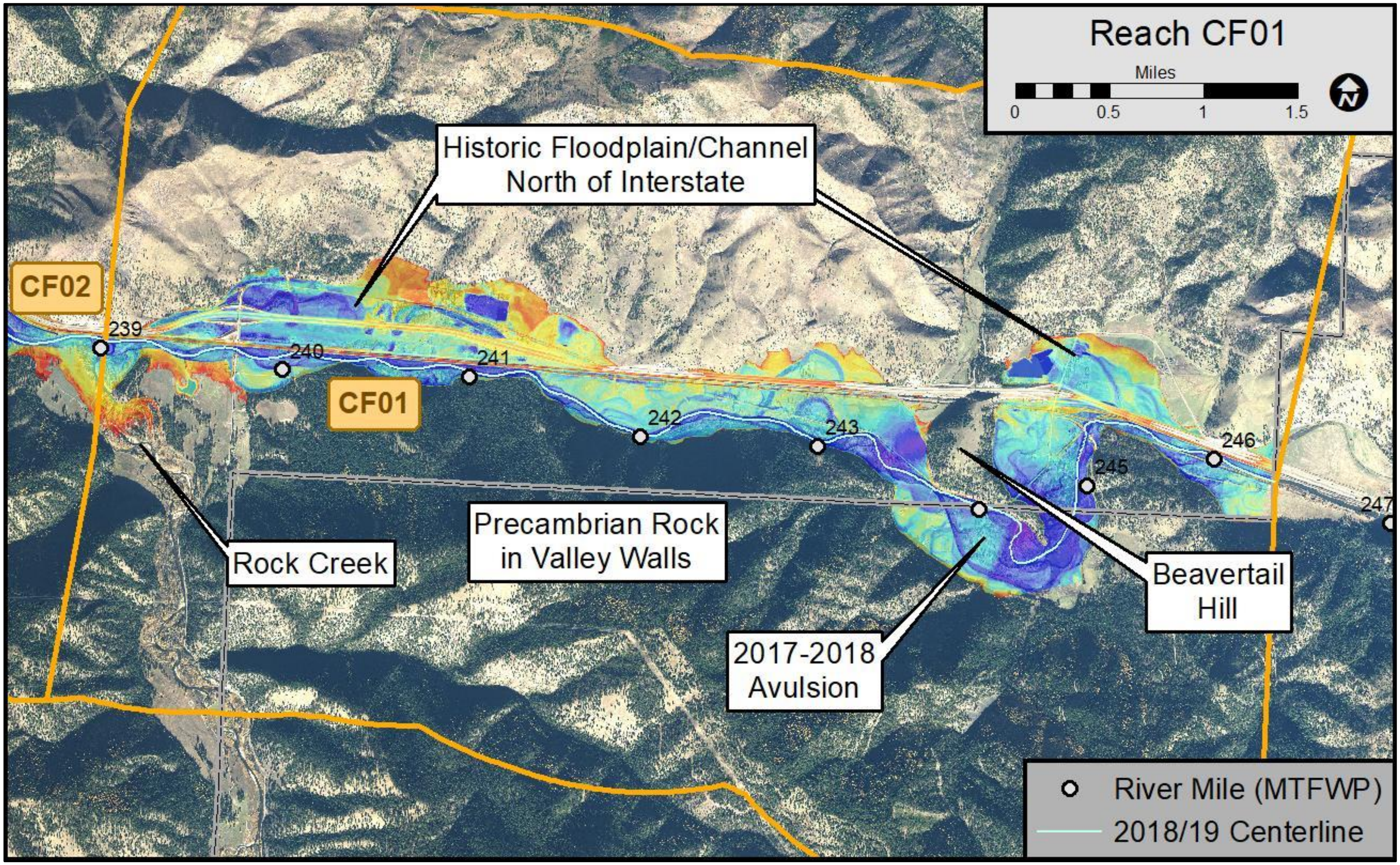

Figure 46. Relative Elevation Model results for Reach CF01; blue colors highlight active and abandoned channels.

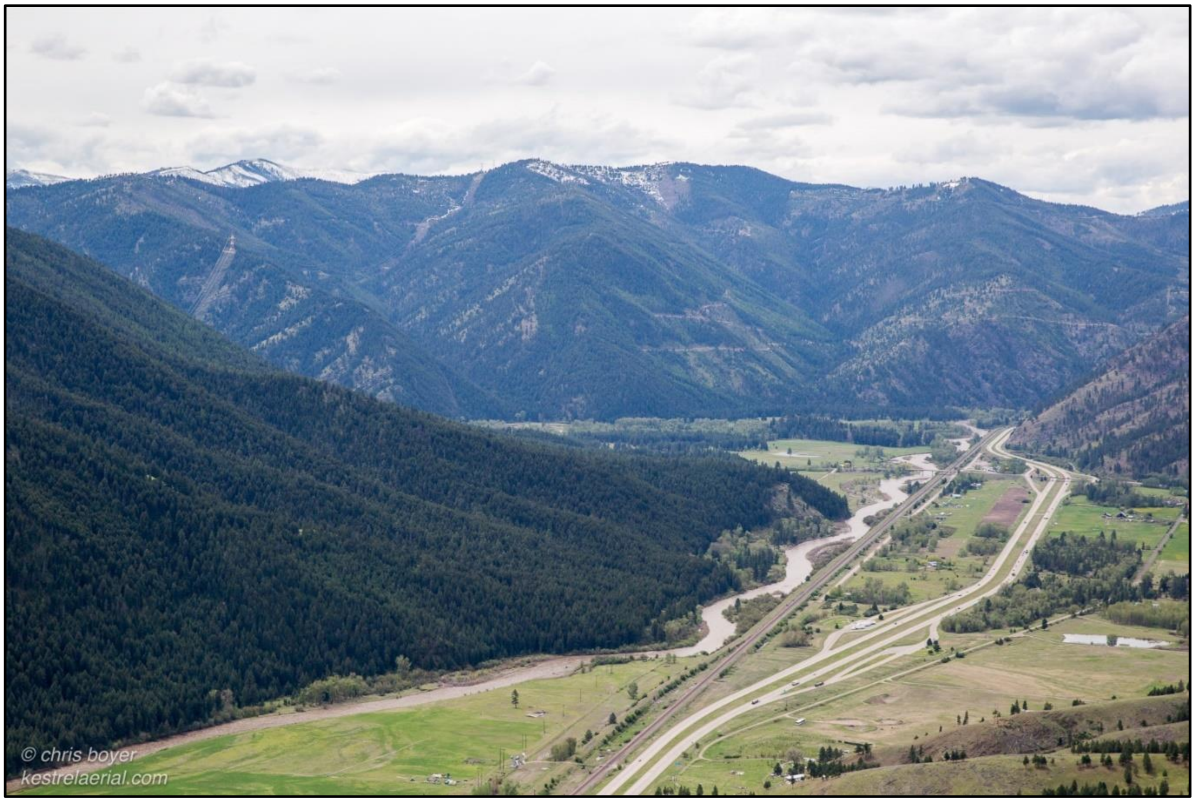

Figure 47. View west of Reach CF01 showing corridor confinement by valley wall and railroad—Rock Creek confluence is in background.

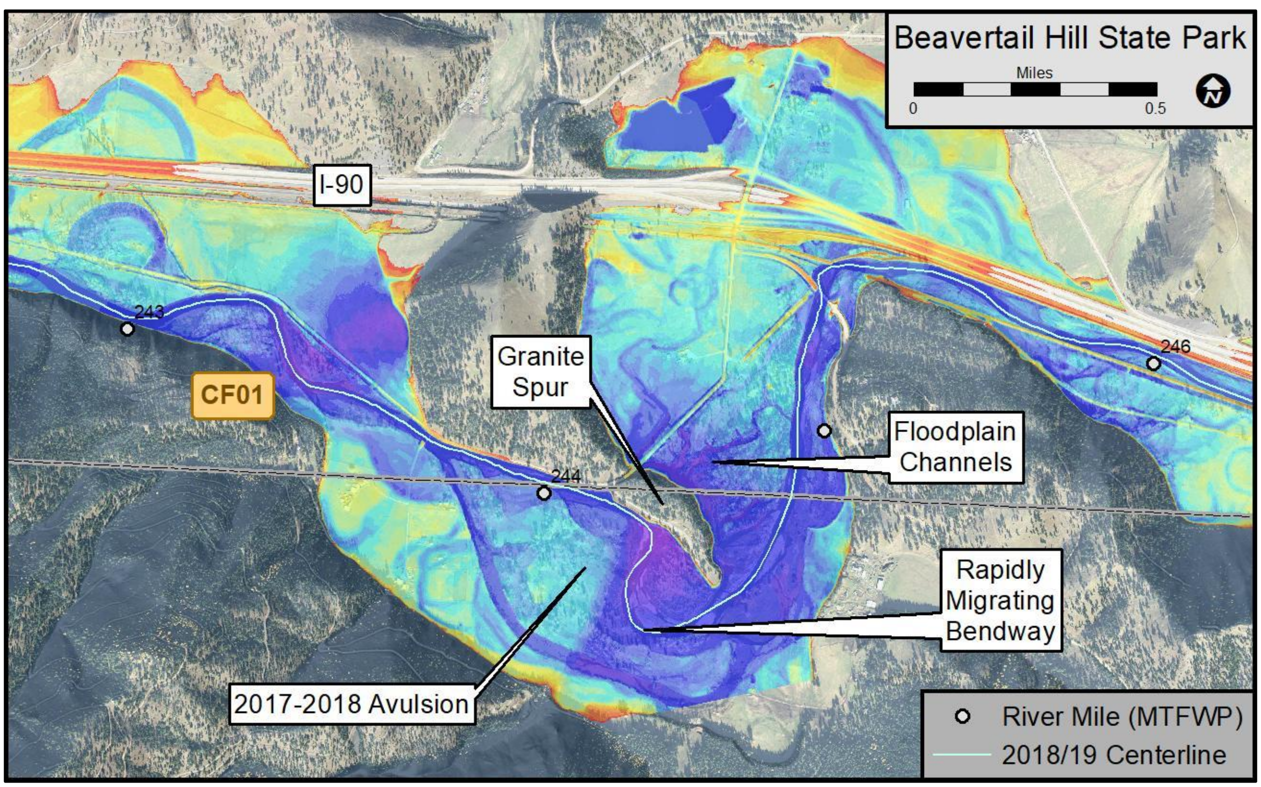

Figure 48. REM map for Beavertail Hill State Park showing major features.

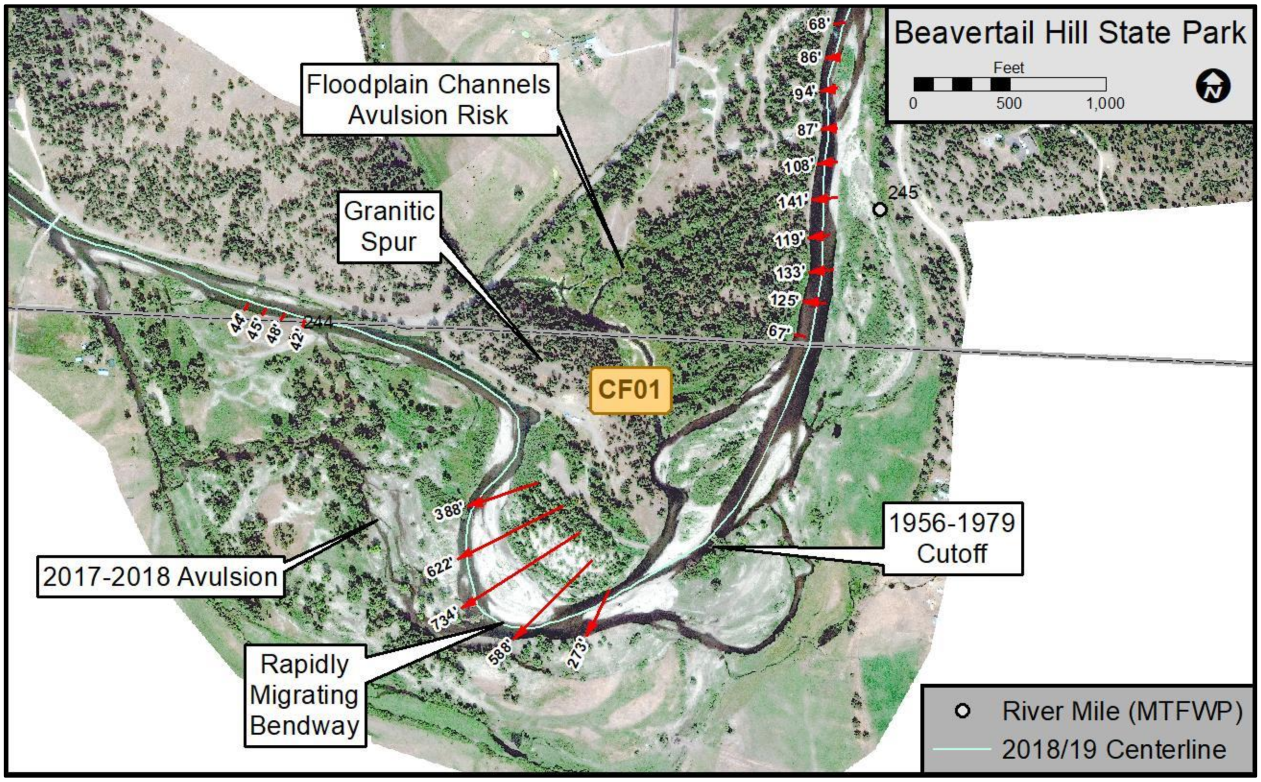

Figure 49. Major features at Beavertail Hill State Park.

5.2 Reach CF02 – Rock Creek to Allen Creek

Reach CF02 is 9 miles long, extending from the mouth of Rock Creek downstream to the mouth of Allen Creek. A total of 134 migration measurements were made in this reach to capture the extent of movement between the 1955 and 2019 banklines. The mean measurement distance was 173 feet, with a maximum migration distance of 445 feet about a mile downstream of the mouth of Rock Creek. The erosion buffer width in Reach CF02 is 332 feet.

Figure 46 shows the Relative Elevation map (REM) generated for Reach CF02. The map shows extensive areas of dark blue that indicate broad complex multi-thread channels that may be prone to reactivation. Split flow is common in the reach, and the CMZ is typically about ½ mile wide, confined between the hillslope and transportion infrastructure. Flooding was extensive in this reach in 2018 as both numerous side channels and floodplain swales were activated (Figure 51). One large meander cut off just west of Clinton when a chute channel through the meander core expanded and captured the whole river, leaving the old channel near Clinton dry at normal flows (Figure 52). Another Reach CF02 avulsion occurred near RM 232 where the river abruptly jumped almost 700 feet northward, carving a new channel in the floodplain and threatening a home (Figure 39).

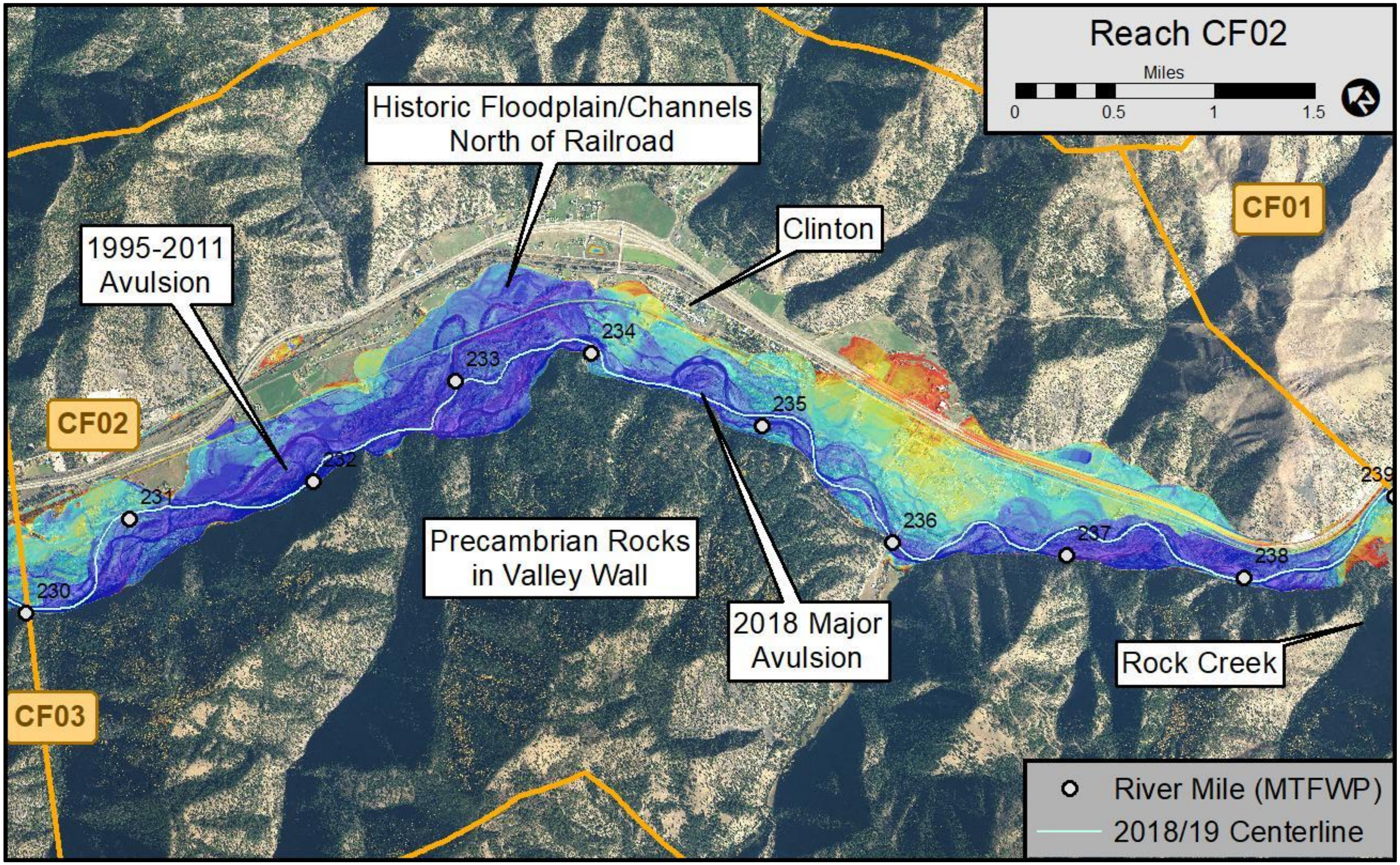

Figure 50. Relative Elevation Model results for Reach CF02; blue colors highlight active and abandoned channels.

Figure 51. View upstream during 2018 flood showing channelized overflow into floodplain swales in foreground, RM 233. The large meander in the upper left portion of photo fully cut off by the end of the flood (avulsion path shown in red).

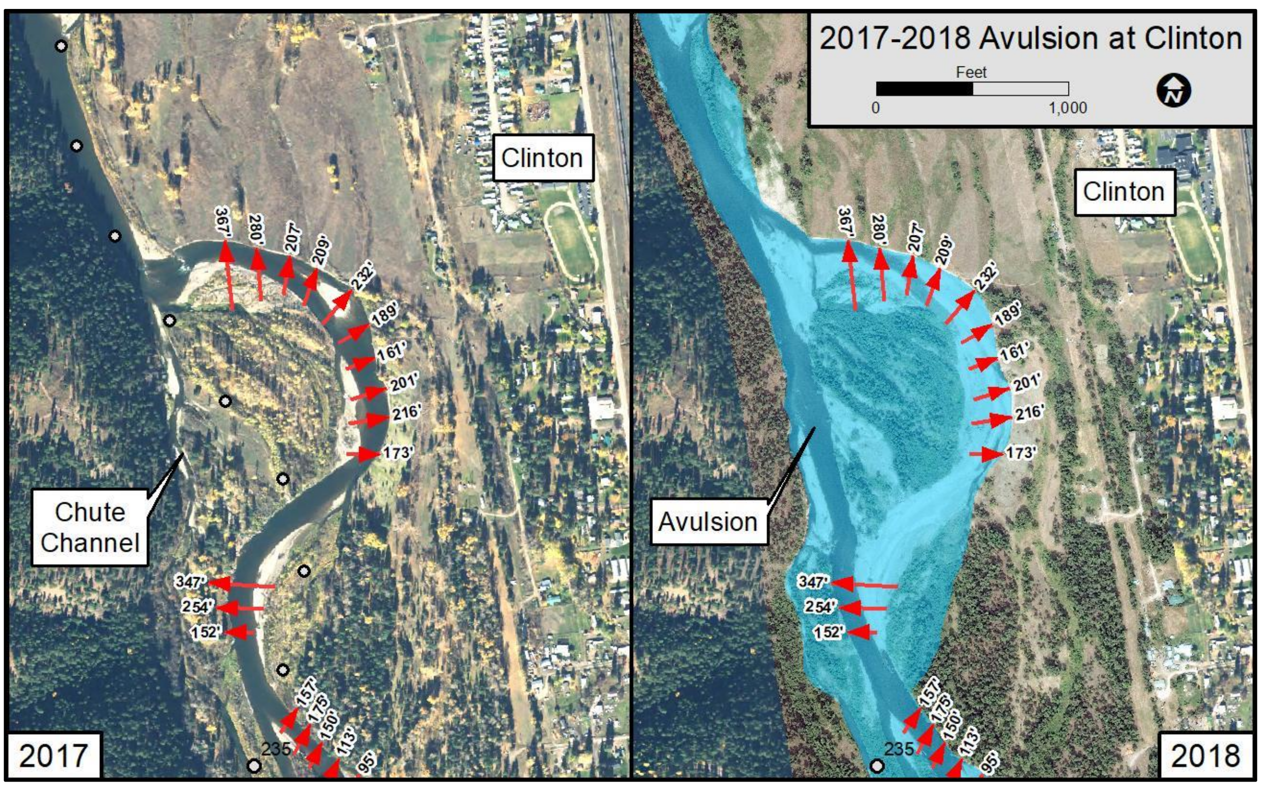

Figure 52. 2017 (left) and 2018 (right) images showing meander cutoff/avulsion through established chute channel at Clinton.

5.2.1 Specific Concern: Left Bank Erosion above Swartz Creek Bridge (RM 236)

The left bank erosion just upstream of the Swartz Creek Bridge is a classic example of channel movement degrading the river's alignment to bridge piers and bridge openings. The bridge is about a mile upstream of Clinton and was built sometime between 1956 and 1961. It is located just downstream of the mouth of Swartz Creek, which enters the river from the west, forming a small alluvial fan against the river (Figure 53). The bridge appears to have replaced another bridge that was about 800 feet upstream; this older bridge was washed out by the early 1970s. The bridge was probably put in this location to tie into the bedrock valley wall just below the Swartz Creek fan.

Imagery from the 1950s and 1960s show the mouth of Swartz Creek, as well as numerous mid-channel bars. These bars were there prior to bridge construction, so their formation is not entirely due to backwatering at the bridge. Rather, this appears to be an inherently depositional area, which is likely due to sediment inputs from Swartz Creek. Since the bridge was put in, additional deposition and vegetation establishment on mid-channel bars has driven about 100 feet of left bank erosion towards the left bridge abutment. This has altered the angle of approach of the river to the bridge, shifting it from a right angle to more of a dogleg. This can be problematic due to increased scour pressure on bridge piers as the river abruptly turns into the opening. An optimal CMZ-related management strategy at bridges is to "taper" the stream corridor to the bridge opening, which often requires bank armoring that flares out upstream of the bridge. This site will likely continue to degrade without action, and it would be appropriate to consider armoring the left bank bridge approach sooner rather than later, or to build out the left bank to improve the angle of approach to the bridge prior to armoring.

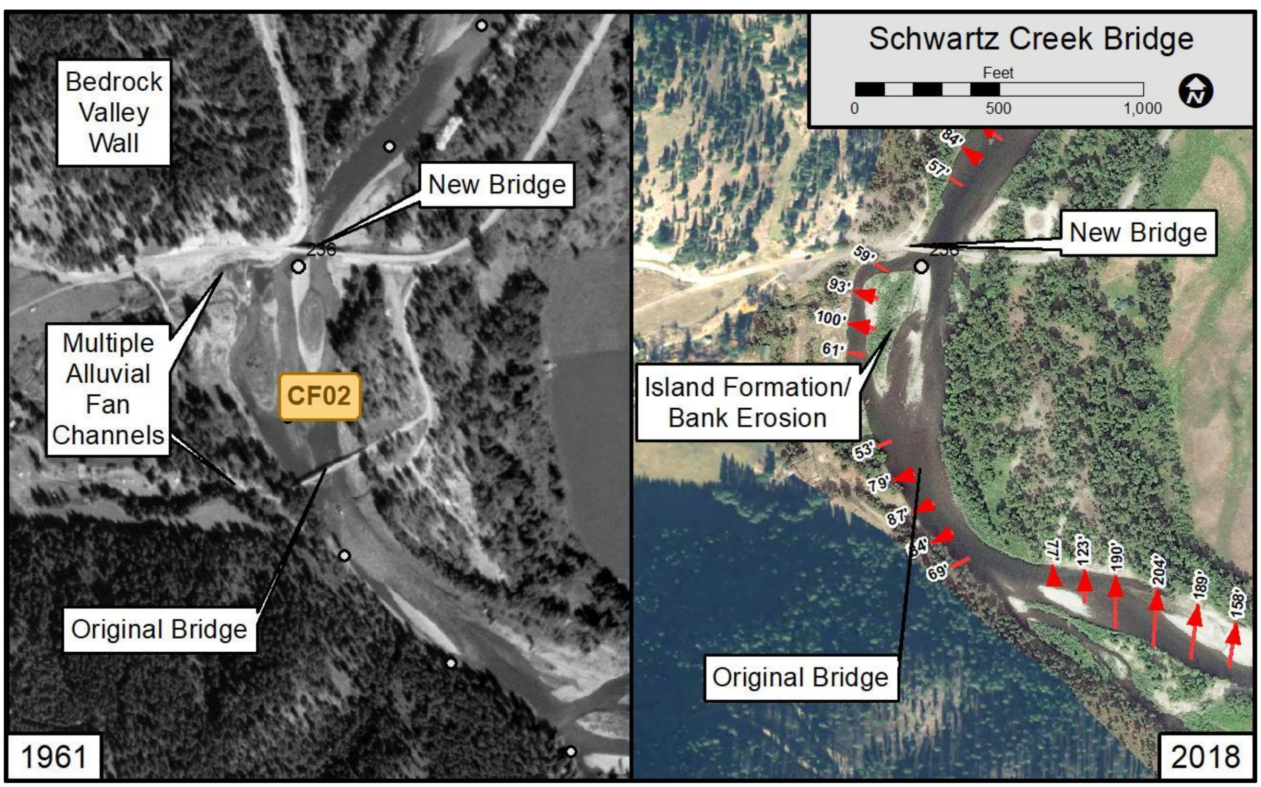

Figure 53. Swartz Creek Bridge in 1961 (top) and 2018 (bottom) showing ~100 feet of left bank erosion just upstream of bridge and loss of right angle approach of Clark Fork River to bridge opening.

5.3 Reach CF03 – Allen Creek to Milltown

Reach CF03 is 5.9 miles long, extending from the mouth of Allen Creek at RM 230 downstream to the upper end of the Milltown Dam Removal/Restoration Project at RM 224.1. A total of 31 migration measurements were made in this reach to capture the extent of movement between the 1955 and 2019 banklines. The mean measurement distance was 206 feet, with a maximum migration distance of 398 feet at RM 226. The erosion buffer width in Reach CF03 is 388 feet.

The Clark Fork River is relatively straight in Reach CF03. Figure 54 shows the Relative Elevation (REM) modeling results for the reach, with the river flowing straight along transportation infrastructure upstream of Turah Bridge. Below the bridge, the river crosses over to the left side of the valley and then closely follows the abandoned Milwaukee Line Railroad embankment. Most of the channel movement in this reach has been concentrated in that crossover area just below Turah Bridge at RM 227.7 (Figure 55). This crossover area is currently developing an avulsion and active headcuts are evident on flood photos (Figure 56). These headcuts will migrate upstream and progressively create a new floodplain channel that has the potential to become increasingly active with time. One other avulsion mapped at RM 225 was characterized by a rapid relocation of about a half mile of river towards the toe of the railroad embankment, which it currently follows closely.

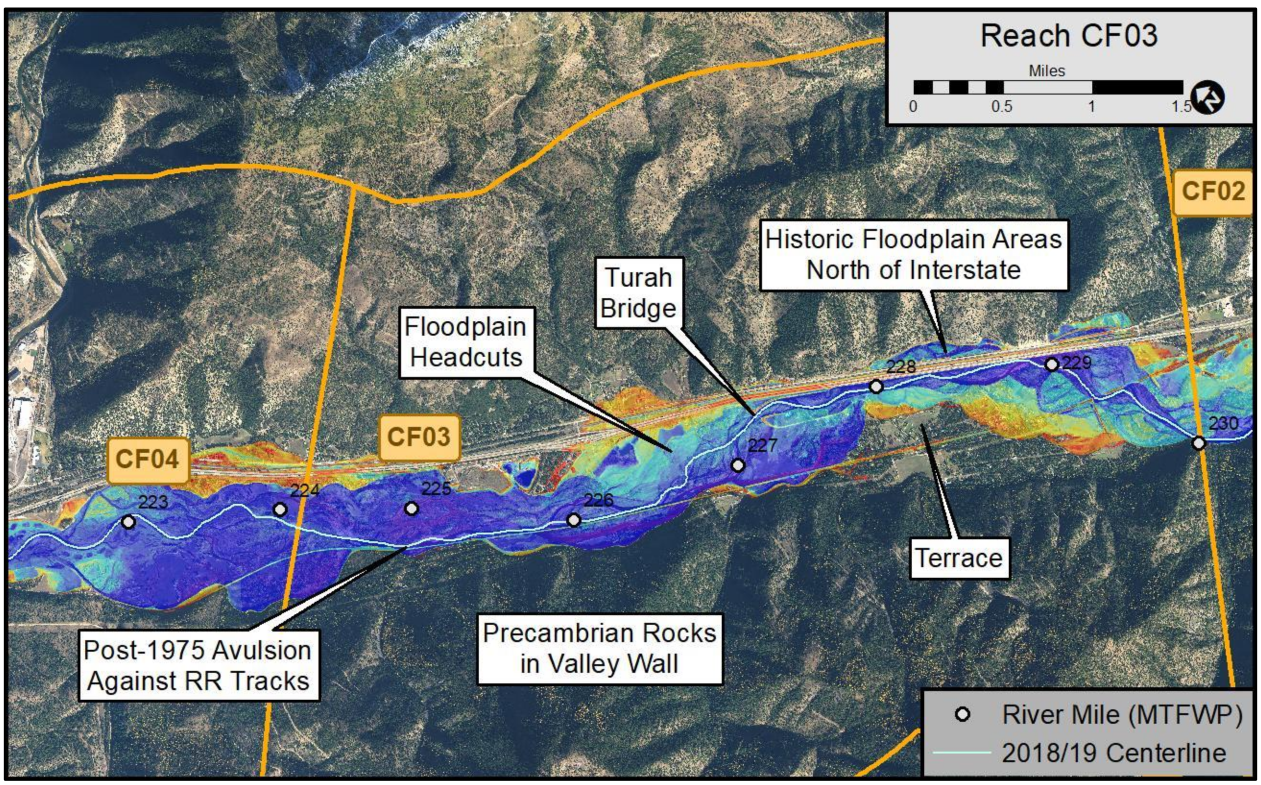

Figure 54. Relative Elevation Model results for Reach CF03; blue colors highlight active and abandoned channels.

Figure 55. View upstream showing river cross from its path closely following the interstate (background) to closely following the rail line (right foreground), RM 227 (May 10, 2018).

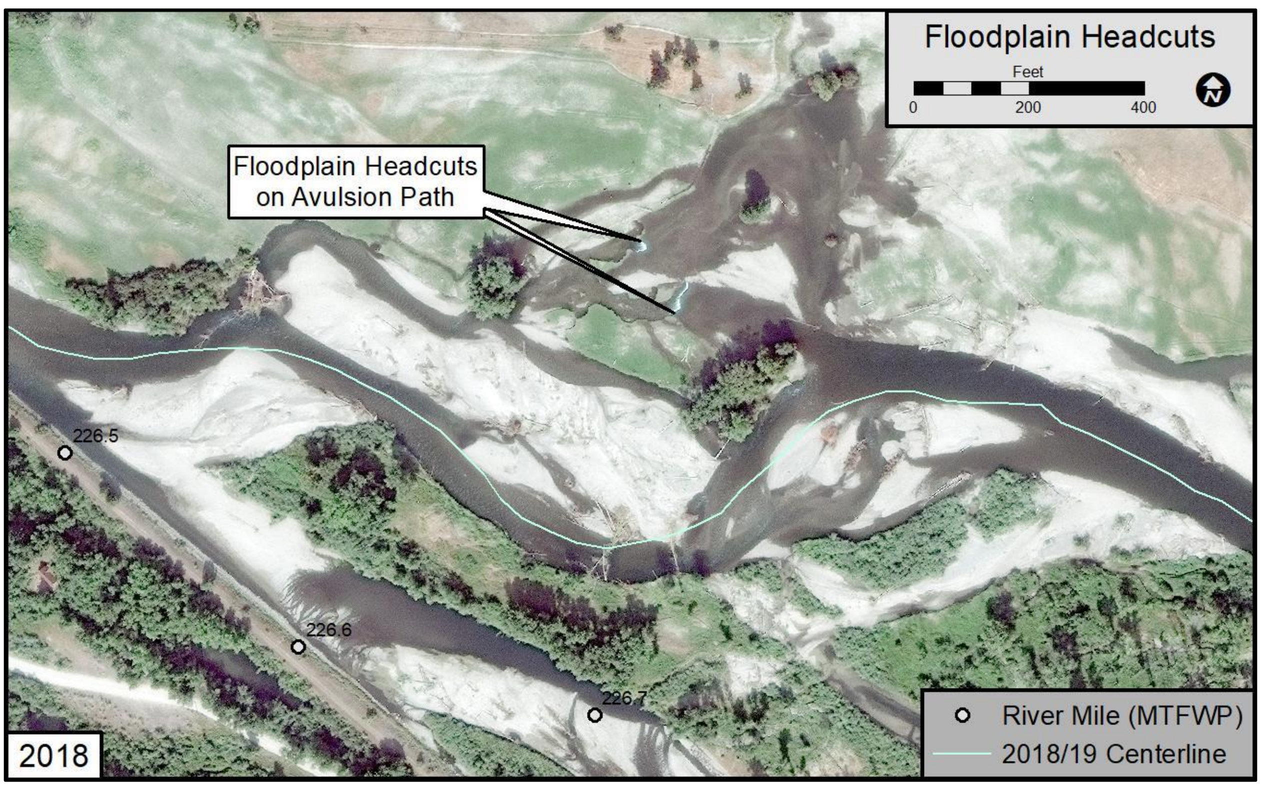

Figure 56. Floodplain headcuts showing an avulsion in process where river crosses valley bottom at RM 227, Reach CF03.

5.3.1.1 Specific Concern: Right bank above old RR Bridge Piers

About 2 miles upstream of Turah Bridge, the river crosses the abandoned Milwaukee Rail Grade through an old railroad bridge crossing. The bridge is gone, but the piers remain in the middle of the river. Just upstream of the bridge, the right bank of the river is armored as it follows the toe of the old embankment, and then makes an abrupt turn through the gap in the embankment (old bridge site). There is active channel migration both upstream and downstream of the crossing. Fortunately, it appears that the river is beginning to "peel away" from the riprapped embankment where it was repaired, which will alleviate the erosive pressure along the embankment toe. In general, however, active channel dynamics in this area will require careful monitoring of the site to maintain the very narrow crossing through the embankment. This demonstrates how river channels can develop deep thalweg lines against riprap that causes them to closely follow armor and not migrate away unless some migration away from the armor begins on the upper end of the site. Additionally, narrow CMZ constrictions caused by infrastructure such as bridges typically require substantial maintenance. When bank armor is used in these areas, it is generally helpful to keep CMZ concepts in mind, to gradually narrow the stream corridor towards the bridge opening rather than creating confined, high angle turns that can create erosion problems. There have also been reports of recent erosion downstream of the crossing on the left bank. It is difficult to say without a field visit as to whether the bridge piers affect downstream bank erosion rates, but they may.

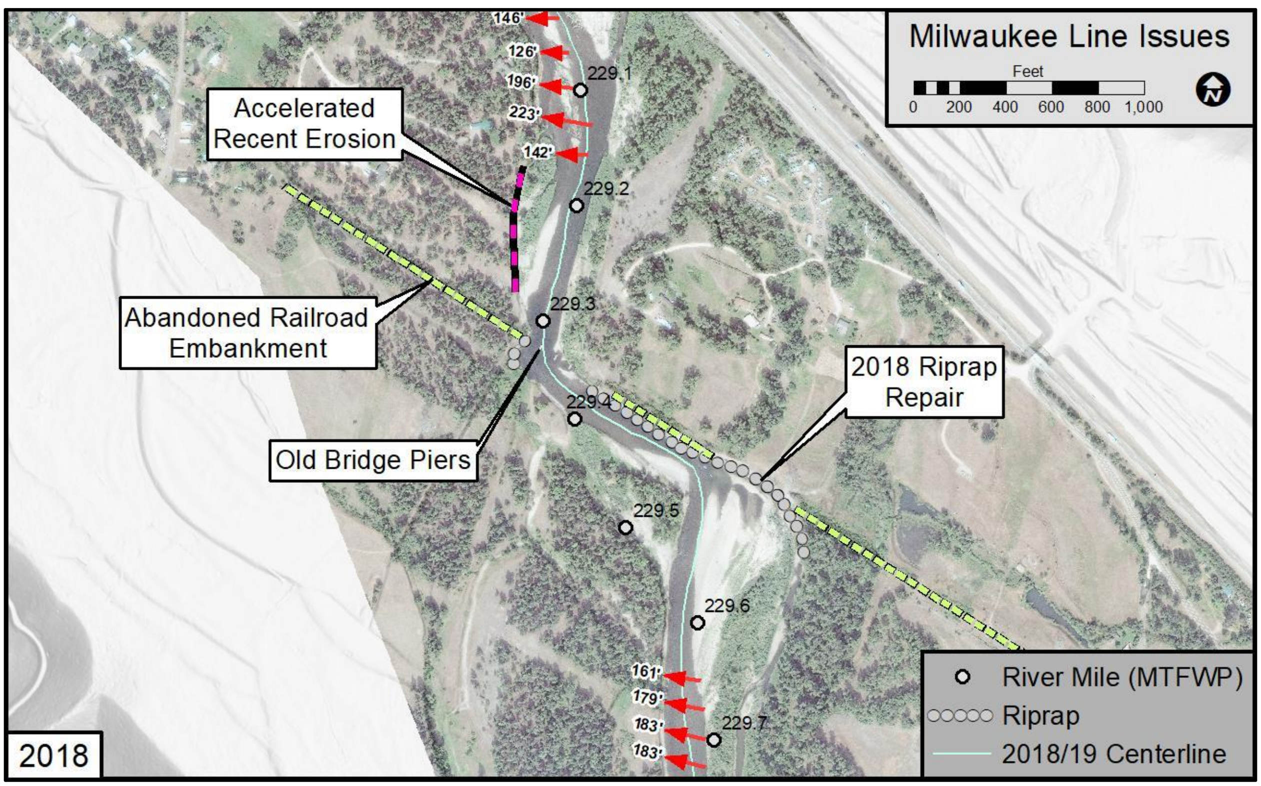

Figure 57. Clark Fork River issues at Milwaukee Line Railroad Embankment, RM 229.3.

5.3.1.2 Specific Concern: Above Turah Rd bridge

Just upstream of Turah Bridge, the Clark Fork River is tightly confined between the Interstate and exurban development. Just upstream of here, about a mile of the Clark Fork River channel was relocated when the Interstate was built (RM 228-229, Figure 54). Much of the Interstate in this area was built on top of 1955 Clark Fork River channel. The Relative Elevation Model (Figure 54) shows the low elevation thread in this area to be very narrow along the channel, with most development (homes, barns, etc.) occurring on low terraces. The historic impacts in this area due to Interstate 90 encroachment into the stream suggests that this section of river may have downcut due to artificial straightening, perching the floodplain slightly and allowing for more development. Unfortunately, however, the channelized river has begun to regain length in this area, and the asymmetry caused by bar deposition is driving bank erosion in the reach. At the specific area of concern, the river has migrated about 50 feet towards a large barn since 2011 (Figure 58). The large open point bar, in combination with a broad sweeping bendway (high radius of curvature) both indicate that continued erosion should be expected, such that the barn will be threatened by both active bank movement on the main channel, as well as enlargement of a side channel that flows right by the barn. Numerous structures in this developed area above Turah Bridge are well within the mapped CMZ boundaries, and some, but not all, are also within the mapped floodplain boundary.

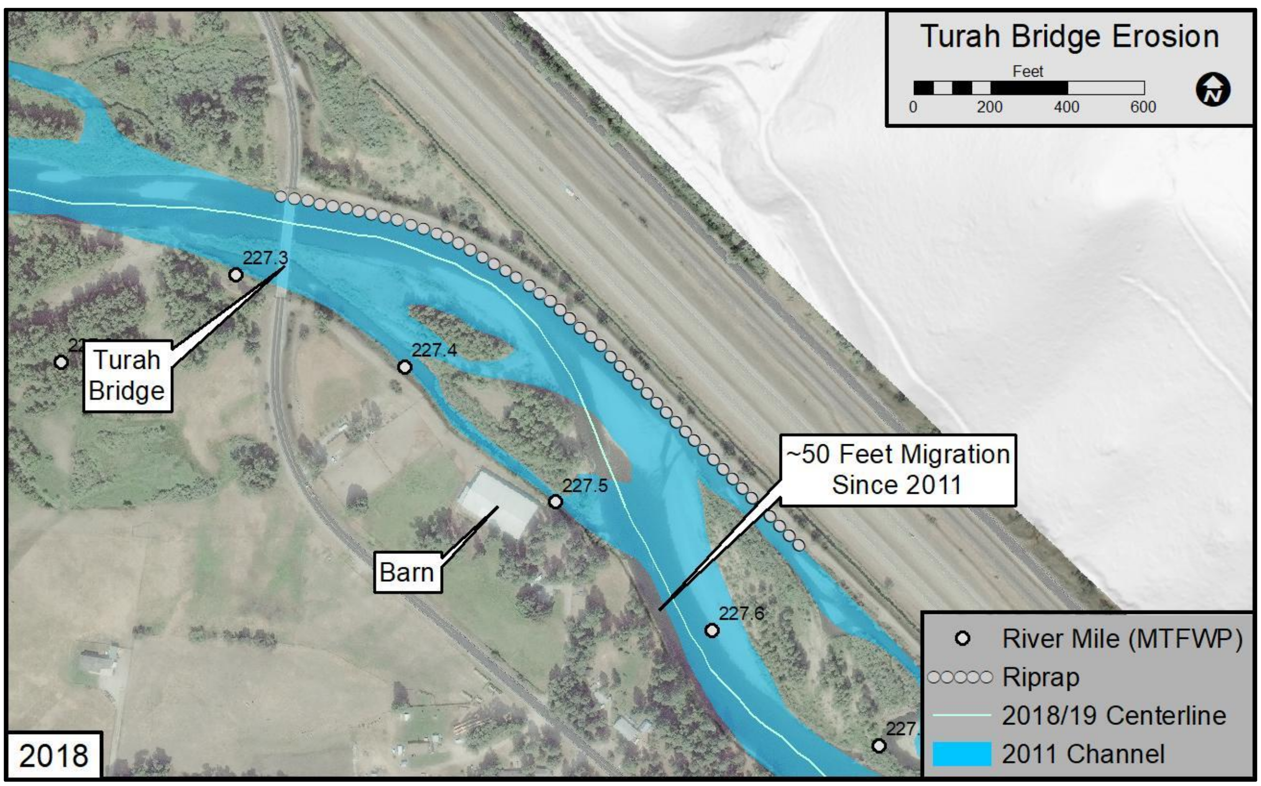

Figure 58. 2018 image of buildings just upstream of Turah Bridge with mapped 2011 banklines showing ~50 feet of migration towards barn in 7 years.

5.4 Reach CF04 – Milltown Reservoir

Reach CF04 is the shortest reach of the project area, encompassing 2.3 miles of the river where it historically flowed through Milltown Reservoir. This section of river occupies the Milltown Reservoir Operable Unit of the Milltown Reservoir/Clark Fork River Superfund Site. Milltown Dam was removed in 2008 and the historic reservoir footprint was restored through extensive channel and floodplain wetland construction (Figure 59). The restoration included nearly three miles of channel restoration and approximately 200 acres of floodplain restoration (River Design Group). One goal of the restoration effort was to create a functional floodplain that was hydrologically connected to the river. Both the Relative Elevation Modeling (REM) (Figure 59) and flood photos (Figure 60) show that this was achieved, especially in the upper portion of the reach where the floodplain is notably wide. During the 2018 flood, Missoula County noted high water adjacent to homes near RM 223.5 on the right floodplain (Connolly Loop), but no structures were threatened at that time. The REM shows these homes to be on a terrace that is perched above the modern floodplain.

Because this is a recently constructed project, no migration vectors were created. Shortly after the project was built, the long duration flood of 2011 caused a constructed meander to cut off; this cutoff was subsequently repaired to meet near-term project objectives on site.

Further discussion of the potential impact of Milltown Dam removal and Reach CF04 restoration on downstream rates of channel change can be found in Chapter 0.

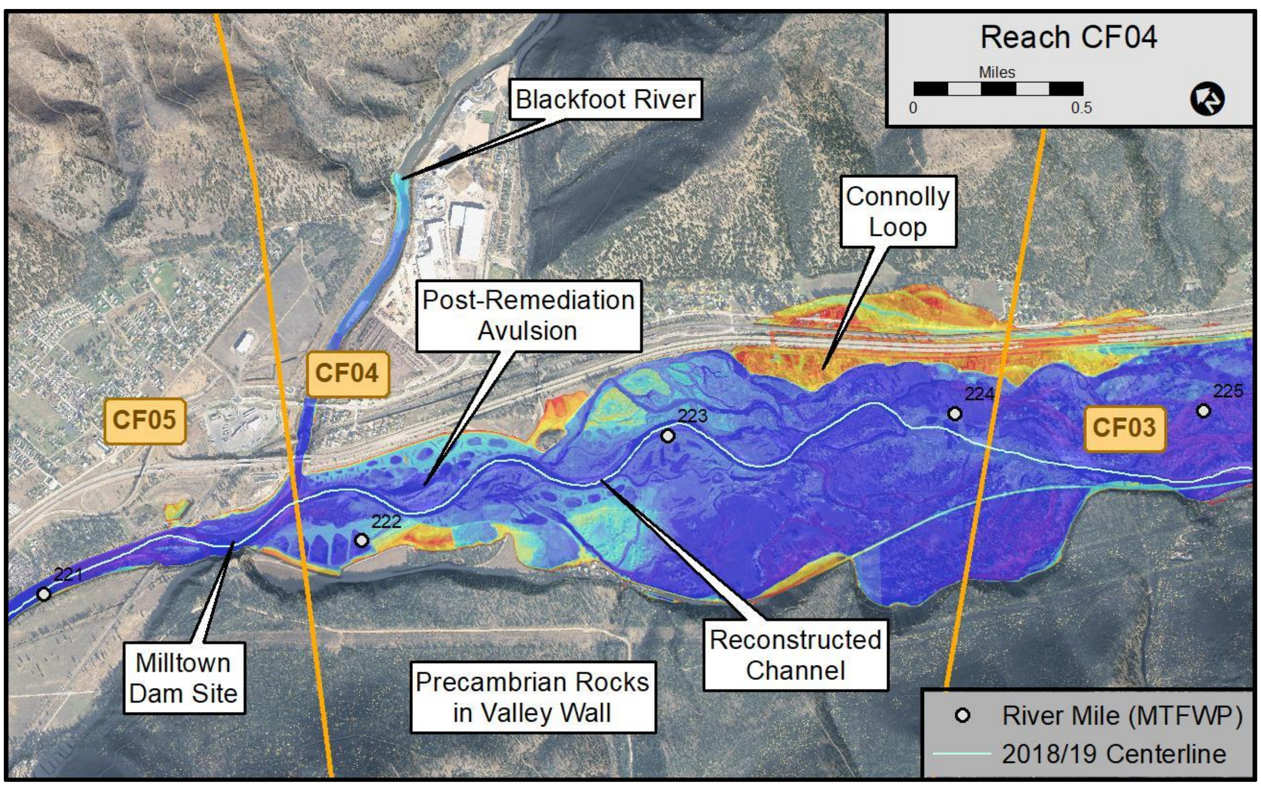

Figure 59. Relative Elevation Model results for Reach CF04; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 60. View downstream through Milltown Dam restoration area showing constructed channel, wetland features, and broad inundation during the 2018 flood event. Connelly Loop feeds the cluster of homes in center-right of photo (May 10, 2018).

5.5 Reach CF05 – Blackfoot River to Wastewater Treatment Plant below Reserve Street

Reach CF05 is 9.9 miles long, extending from the mouth of the Blackfoot River downstream to near Reserve Street on the west side of Missoula (Figure 62). Only four migration measurements were collected in the reach, which is largely confined by either natural geology or constructed erosion control. As a result, the unrestricted CMZ is notably small in this reach. The narrow canyon between East Missoula and Missoula is comprised of Proterozoic Rocks of the Missoula Group. Upstream and downstream of the canyon, the river is bound primarily by older alluvial terraces. Just below North Orange Street at RM 214.5 the Relative Elevation maps show an abrupt expansion of relatively low ground, which correlates well to geologic maps showing the floodplain transitioning from higher, older deposits through the core of downtown to a broad expanse of recent floodplain alluvium below.

Where the river bisects downtown Missoula, an extensive levee system protects the city from flooding (Figure 61). On the north bank from the Madison Street bridge downstream to below the Orange Street Bridge a ~4,000 foot certified levee prevents floodwaters from entering downtown. This levee also cut off a 1955 channel that ran through what is now Caras Park. On the south bank between Orange Street and the railroad bridge a ~1,600 foot uncertified levee separates the river from the McCormick Recreation Site and Currents Aquatic Center.

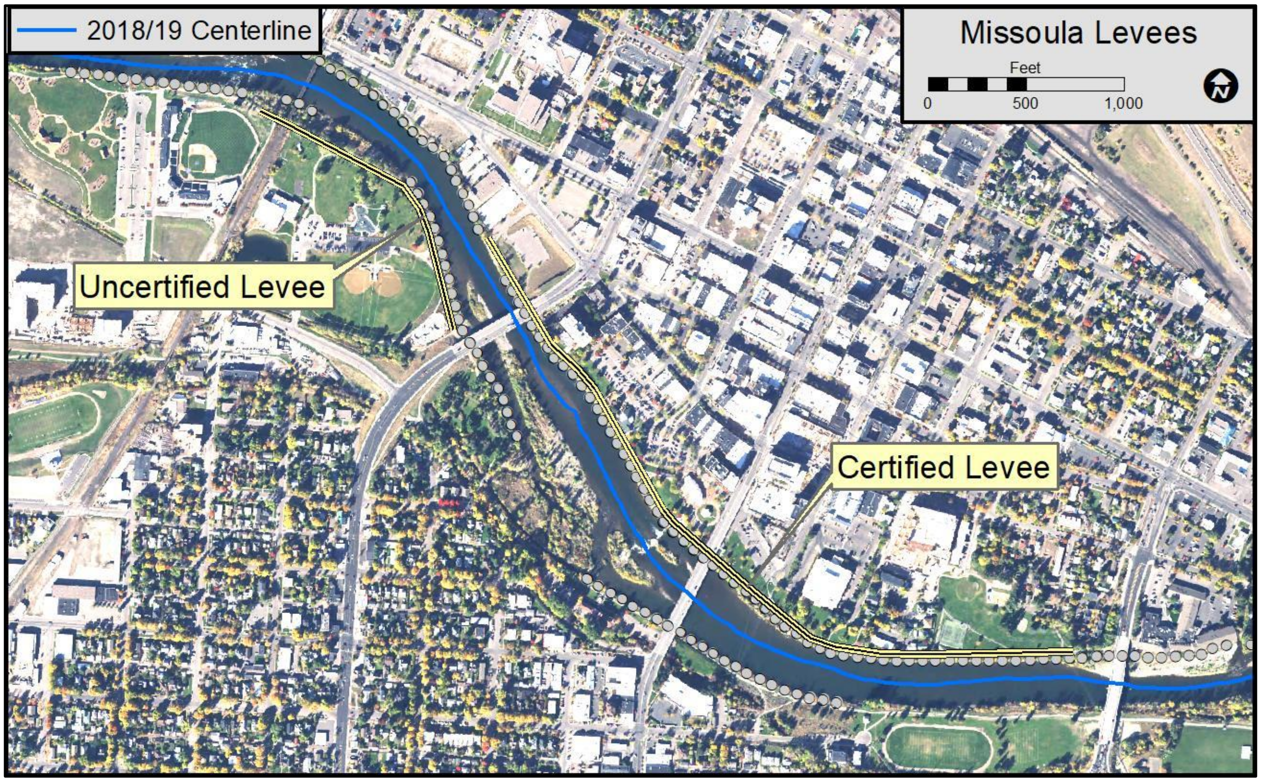

Figure 61. Downtown Missoula levees.

Because of the confinement and poor floodplain access in Reach CF05, there were few reports of 2018 flood issues by Missoula County. Each of these flood impacts reflect highly localized flooding and/or bank erosion. They include the following:

- Local bank erosion across from the golf course into the toe of the Highway 200 embankment (RM 219.7)
- Flooding into back yards off of Deer Creek Bridge at RM 219
- Bank erosion towards the Riverfront Trail at Allegiance field
- Right bank erosion just downstream of Reserve Street that is potentially compromising a power pole on Clark Fork Drive

Some areas of interest in this urbanized reach include Caras Park near The Wilma Theater, which was an active side channel in the 1950s (Figure 63). The 1955 imagery shows a large island downstream of the South Higgins Bridge, and a large diversion structure on the south bank. Since then, the area of channel on the north side of the river has been developed into Caras Park and the river flows primarily through a single thread that is crossed by Brennan's Wave Kayak Park. The grading out of the north channel was complete by 1972. The left bank diversion below is still functional, although it doesn't have a large rock structure feeding it as it did in 1955.

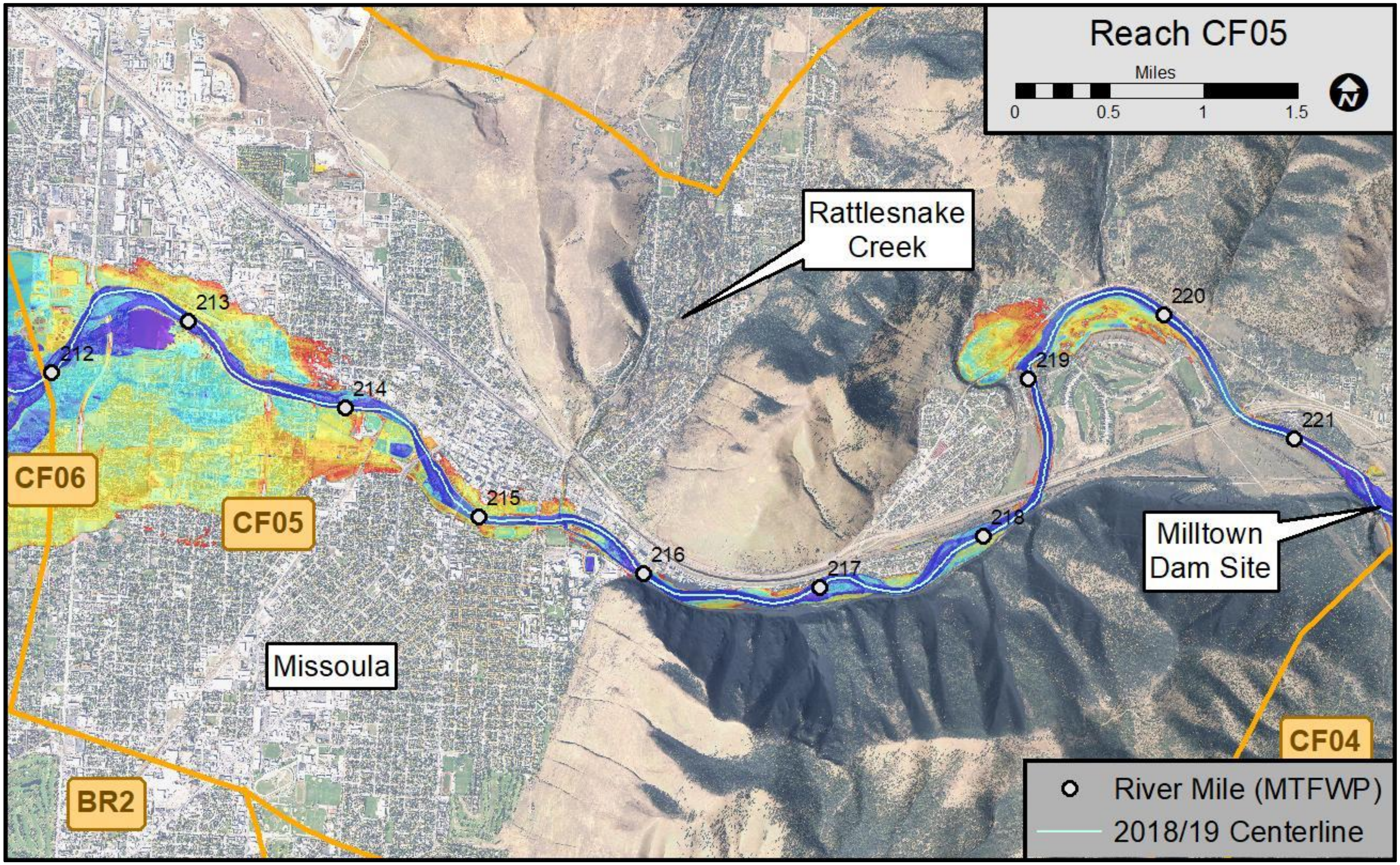

Figure 62. Relative Elevation Model results for Reach CF05; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 63. Comparison of Clark Fork River near Caras Park in 1955 (top) and 2019 (bottom).

5.5.1 Specific Concern-- Secondary channel under Reserve St becoming more active

Another area of interest is the gravel pit just upstream of Reserve Street. Figure 64 shows the progressive development of the pit from a broad area of gravel scalping in 1972 to a single consolidated pit protected by a dike in 2019. The 2019 image also shows a high flow channel that carries water under the Reserve Street Bridge due west of the gravel pit. This channel has enlarged in recent years. The relative elevations for this area as captured by LiDAR data are shown in Figure 65. The channel is clearly an active component of the Clark Fork River flow routing in this area, and the recent enlargement at the head of this channel shows up as wet ground in the 2019 image in Figure 64. The 2019 image also shows continuous riprap on the right bank across from the pit. The right bank of the river is locked into place here, and high water relief through the meander core is a relatively efficient pathway as it is shorter than that of the main channel thread (Figure 66). As such, we would expect this flow split to persist and potentially expand further during channel-forming flood events. The channel is also connected to the western edge of the pit itself, such that any river breach into the pit could rapidly cause a major avulsion at this site.

Figure 64. Gravel pit and high flow channel development at Reserve St Bridge, 1972 (top) and 2019 (bottom).

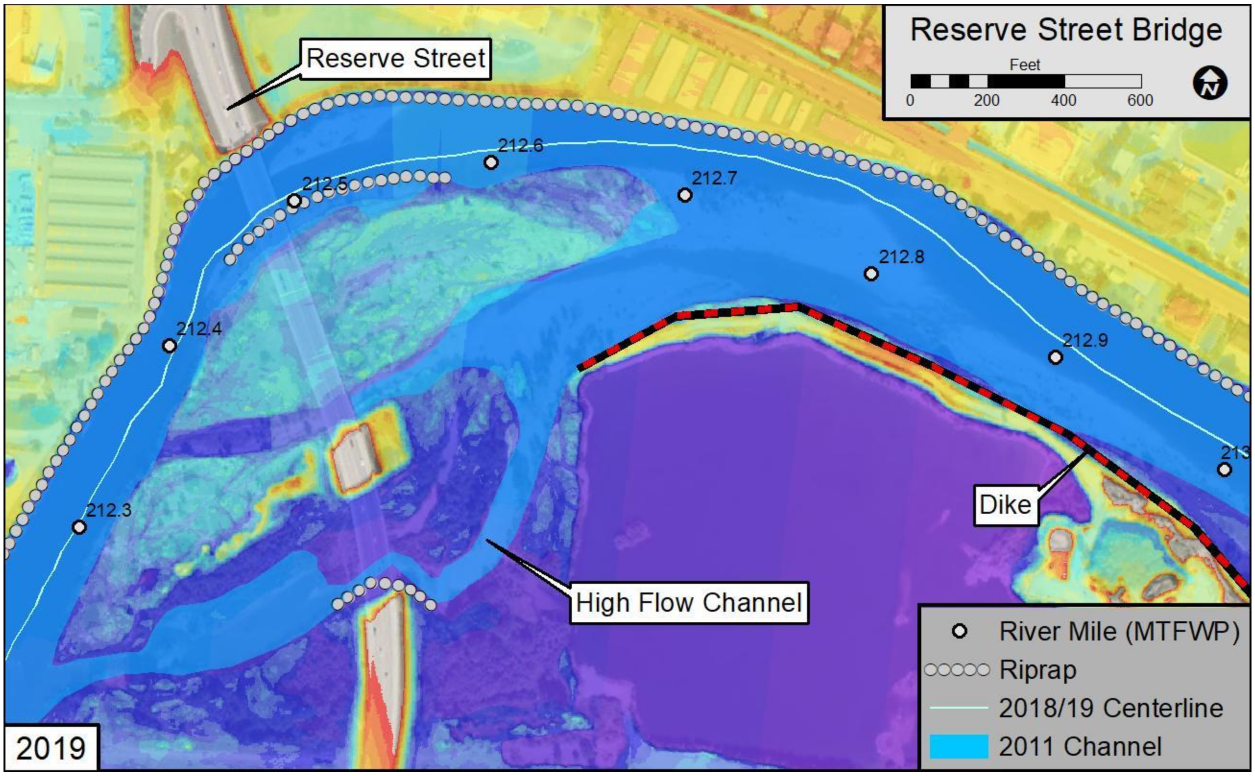

Figure 65. Relative Elevation Map for gravel pit area at Reserve Street Bridge showing side channel connectivity to main river.

Figure 66. View upstream of Reserve St Bridge showing gravel pit and high flow paths under bridge to the right of the main channel (May 10, 2018).

5.6 Reach CF06 – Kelly Island to Bitterroot River

Reach CF06 is 4.9 miles long, encompassing the Kelly Island area. A total of 155 migration measurements were collected in the reach, which is largely unconfined, supporting a wide dynamic river corridor. The mean migration distance in this reach is 283 feet, and the erosion buffer width is 580 feet. The maximum migration distance measured is 983 feet at RM 210.8. The Relative Elevation maps show a wide swath of active and abandoned channels, with low terraces forming the south floodplain margin (Figure 67). In some portions of this reach, at least 6 channels are active at moderate to high flows (Figure 68).

Six avulsions were mapped in Reach CF06, which is the most of any reach in the project area (Figure 38).

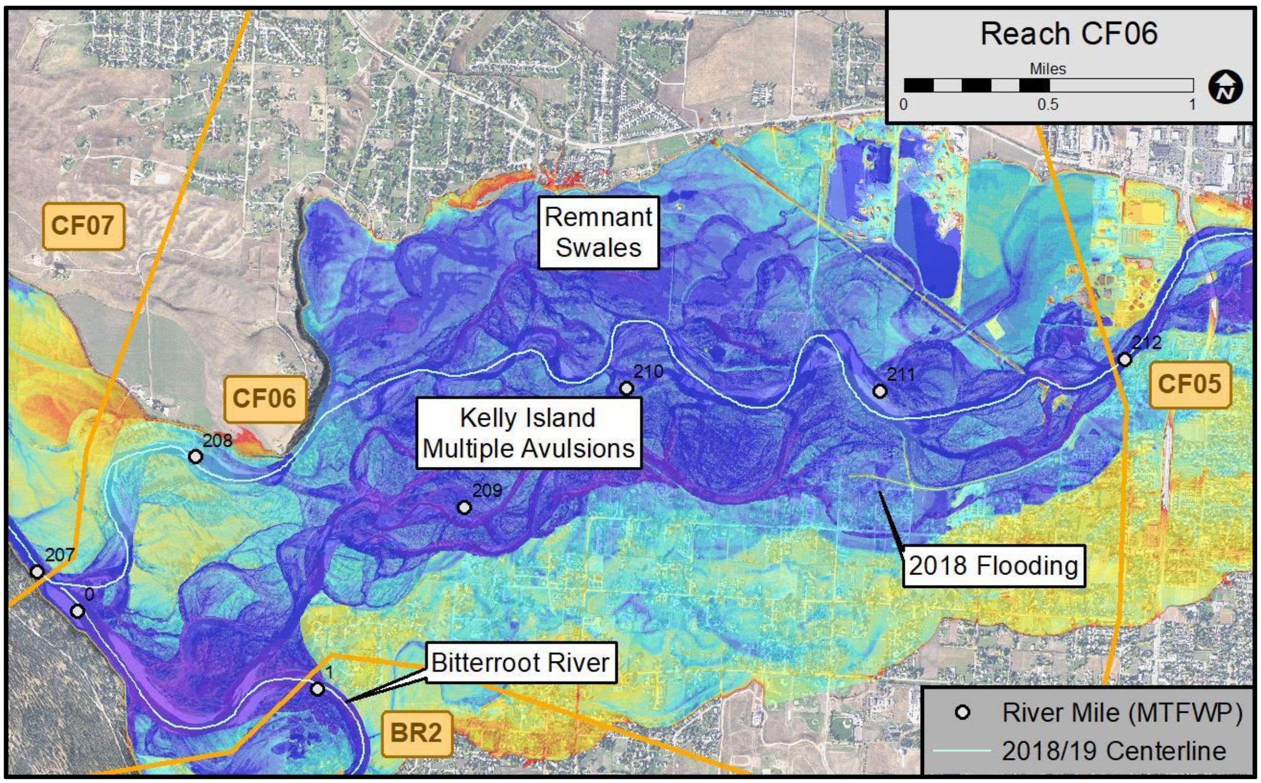

Figure 67. Relative Elevation Model results for Reach CF06; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 68. View upstream of Reach CF06 during the 2018 flood (May 10, 2018).

5.6.1 Specific Concern: Abandoned Railroad Crossing (RM 211.7)

In the uppermost portion of Reach CF06, an abandoned railroad line crosses the river (Figure 69). In the 1972 imagery, the crossing had three bridges over individual Clark Fork River channels, but by the mid-1990s, two of those had been removed or eroded out. Some piers remain in the main northernmost channel. A power line also follows the railroad line, with large utility poles located well within the CMZ boundary. Since the 1950s, the river has been migrating northward upstream of the bridge, but since 2017, that northernmost channel has aggraded such that it is dry under normal flows (Figure 69). This site provides a good example of how problems can arise due to CMZ restrictions by abandoned infrastructure. Currently, the right bank of the main channel is armored where it goes under the power line and through some abandoned bridge piers, and that corner is at risk of flanking. Several power poles appear to be at risk of erosion as they follow the rail bed. Some rock reinforcement of those poles appears to have been placed to protect them (Figure 70).

The positive aspect at this site is that, besides the power line, there appears to be little operating infrastructure at risk. Aggradation in the north channel will potentially reduce some of the right bank erosion and armor flanking potential. That said, the main channel which has shifted southward currently doglegs through the rail grade and the abandoned bridge piers are at a high angle to that already sub-optimal flow path. This site would be worthy of a more detailed evaluation of potential remedies to CMZ discontinuities and potential associated risk.

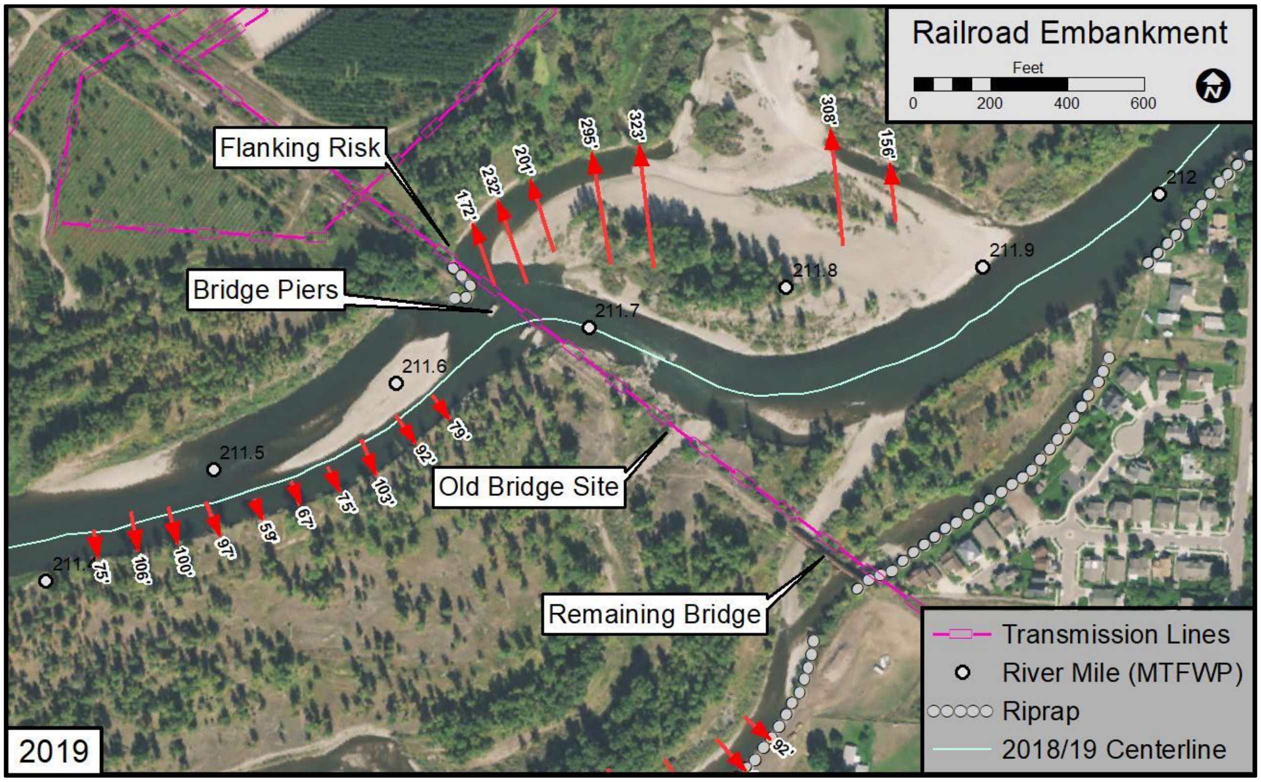

Figure 69. 2019 air photo showing major issues at abandoned railroad crossing, RM 211.6.

Figure 70. View downstream showing flow paths through abandoned rail line crossing; rock-reinforced utility pole is noted by black arrow (May 10, 2018).

5.6.2 Specific Concern: Rapid Migration at Schmidt Road (RM 201.8)

As described previously, the maximum migration 1955-2019 migration distance measured in Reach CF06 was 983 feet at RM 210.8, which is about a mile downstream from the railroad crossing/powerline described above. This site is at the south end of Schmidt Road, where a large bendway has migrated northward at an average rate of 15 feet per year since the 1950s (Figure 71). Another powerline crosses the river just upstream of this bend, and evidently power lines were downed across the river at this site during the 2018 flood. Figure 71 shows the 2011 banklines on the 2019 imagery to capture recent patterns of movement on this bend. As is typical with meander bend evolution, the most rapid movement in recent years has been on the downstream limb of the bend as the bend has translated down-valley. Since 2011, there has been no northward migration on the apex of the bend, but the downstream limb has migrated about 200 feet down valley. This area flooded badly in 2018 and several structures were destroyed (Figure 72).

This bend will probably cut off in coming years, there are several chute channels and a major scour pocket in the core of the meander where the open gravel abuts woody vegetation ("avulsion prone area" in Figure 71). The biggest near-term risk at this site is likely a power pole that is close to the "Power Line" label in Figure 71 where the river has migrated about 100 feet towards the pole since 2011 and now is within about 70 feet of its base. The south end of Schmidt Road is where the trailer home shown in Figure 18 was destroyed by the flood of 2018.

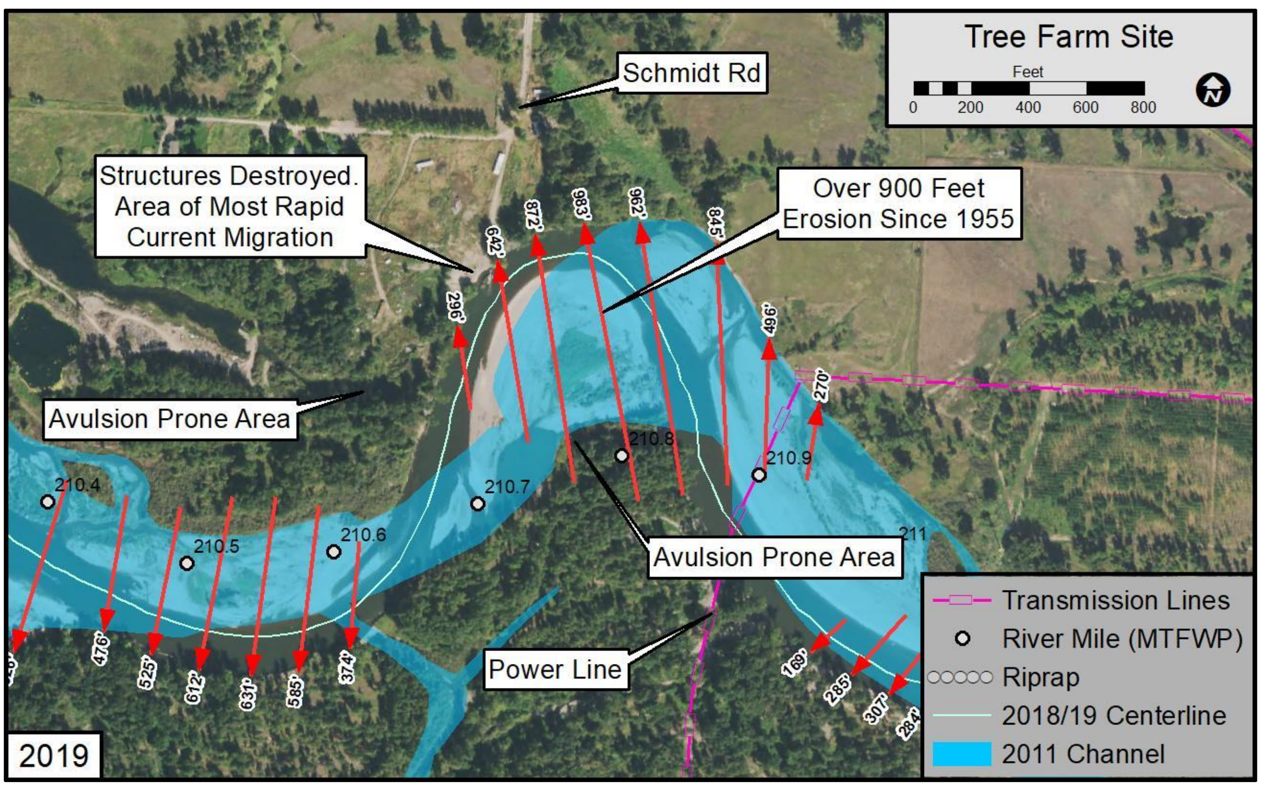

Figure 71. Northward-migrating bendway at RM 210.8 showing down-valley bend translation since 2011 destroyed several structures on the right bank.

Figure 72. Floodwater breakouts point on downstream limb of rapidly migrating bendway, RM 201.8R; structures in foreground were lost during the flood (May 10, 2018).

5.6.1 Specific Concern: Avulsion Risks in Schmidt Road Area

Another concern in the Kelly Island area is the potential for future major potential changes in flow paths in the around Schmidt Road (Figure 73). Channel migration in the area near the south end of Schmidt Road is encroaching into an older channel the has an identified headcut at its upstream end. This headcut is at the upstream end of an old gravel pit that forms a clear avulsion risk. Figure 74 shows a profile through that avulsion route. The headcut is less than 100 feet from the 2019 bankline. Continued westward migration of the channel coupled with eastward upstream migration of the headcut will very likely result in the formation of a new active channel through the old gravel pit. As the headcut is about four feet high, an avulsion at this location could be rapid.

Another avulsion risk is in the southern part of the river corridor, in the area where the utility pole described in Section 5.6.2 is threatened. This is labeled as "Avulsion Path #2" in Figure 73. The REM shows fingers of floodplain channels extending up through the riparian corridor to the utility pole site (black arrow at RM 211 in Figure 73). The LiDAR profile (Figure 75) for this avulsion path shows that as the river continues to migrate westward at RM 211, it will continue to intercept that floodplain swale, which will lower the bank height and allow more water to spill onto the floodplain and into a major partially abandoned channel north of S 3rd West Street. Activation of this channel could seriously threaten developments north of S 3rd West St as channel shifts from being an overflow channel to a primary thread of the Clark Fork River. This channel has been largely abandoned since at least the mid-1990s.

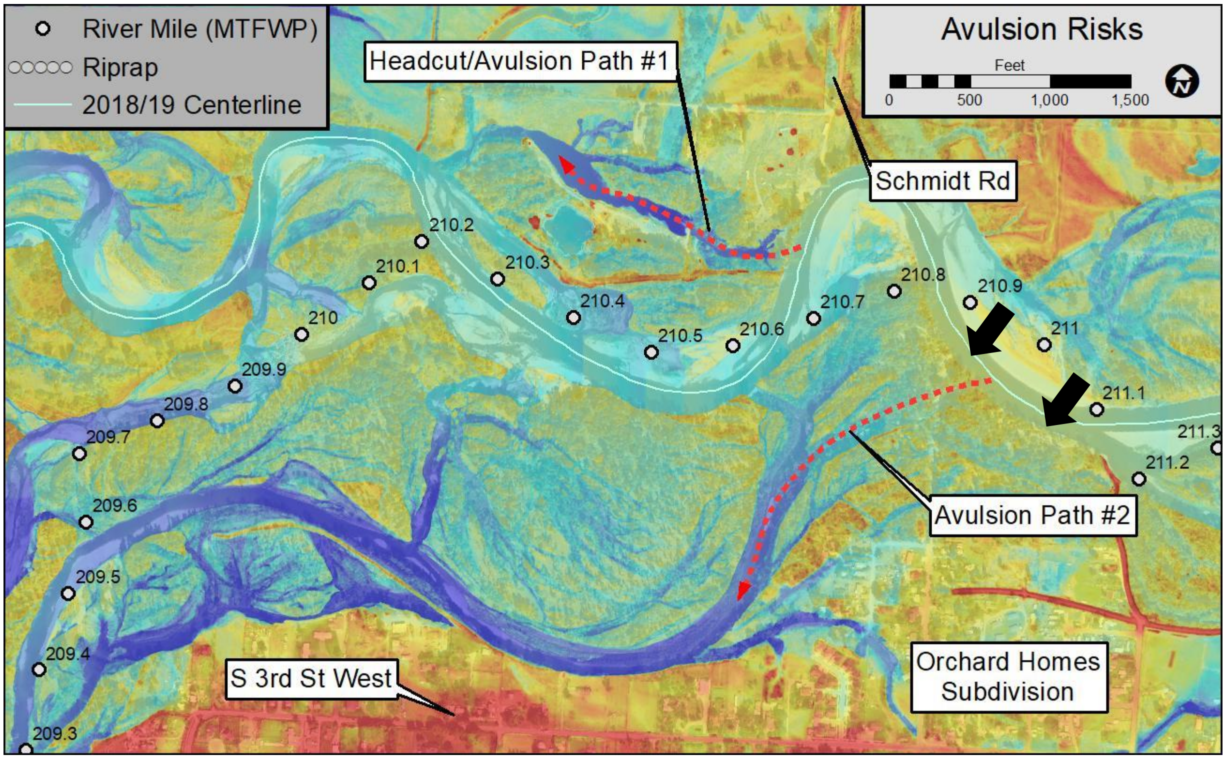

Figure 73. Major avulsion risks in CF06; black arrows show recent migration areas and colored lines follow LiDAR profiles.

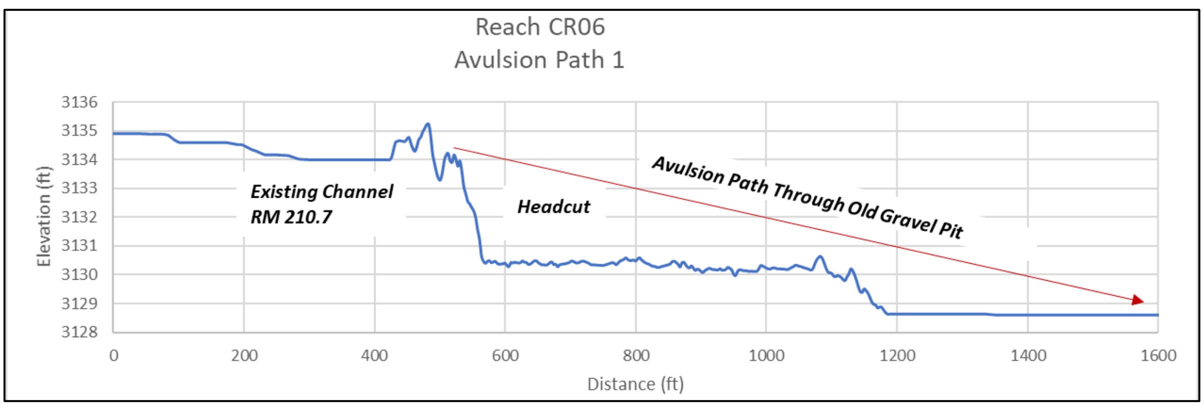

Figure 74. LiDAR profile through Avulsion Path #1 shown in Figure 73.

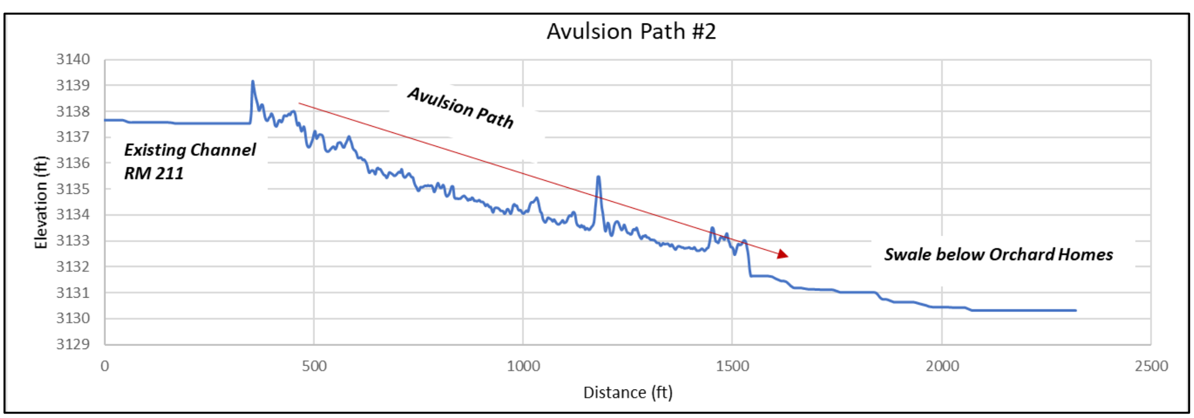

Figure 75. LiDAR profile through Avulsion Path #2 shown in Figure 73.

5.6.2 Specific Concern: Orchard Homes Flooding

Due south of the Schmidt Road erosion area described above, there were major flooding problems on the south floodplain, where the Tower Street/Orchard homes neighborhood was built in low floodplain areas that are dissected by a floodplain swale extending south of South 3rd St West (Figure 76 and Figure 77). These areas are largely out of the modern Channel Migration Zone of the Clark Fork River, which reiterates the concept that flood risk and erosion risk are two different issues. Not surprisingly, high groundwater was described as a contributor to flooding issues in this area.

West of the Orchard Homes neighborhood, the south side of the river corridor is also residential, but a large portion of that development is on a low terrace that is less prone to flooding than the Orchard Homes area.

Figure 76. 2018 flooding of Orchard Homes/Tower Street area-- Reach CF06 (May 10, 2018).

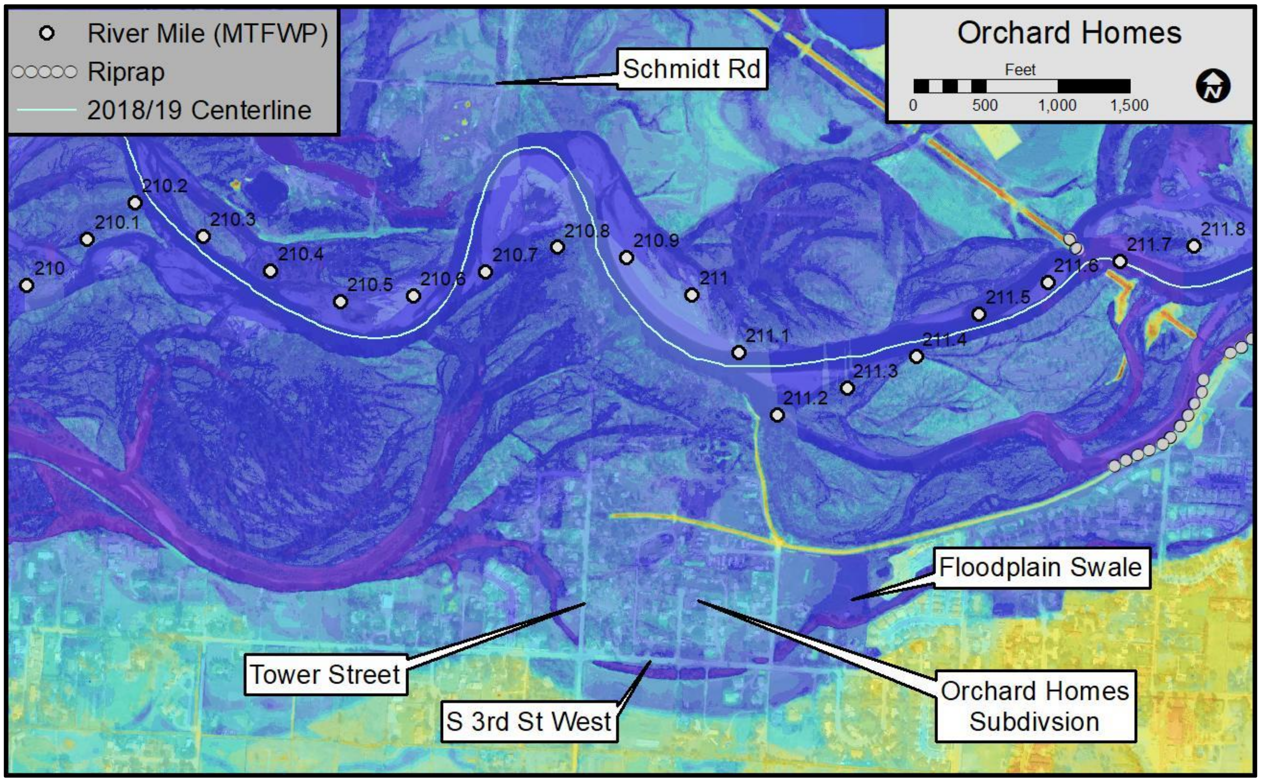

Figure 77. Relative elevation model results showing low topography and historic swales in Orchard Homes subdivision.

5.7 Reach CF07 –Bitterroot River to Kona Ranch Road Bridge

Reach CF07 is 3.2 miles long, extending from the Bitterroot River confluence downstream to Kona Bridge. A total of 26 migration measurements were collected in the reach, which reflects relatively low rates of channel movement. The mean migration distance in this reach is 117 feet, and the erosion buffer width is 252 feet. The maximum migration distance measured is 198 feet at RM 204.7, which is about a mile upstream of Kona Bridge. The Relative Elevation (REM) maps show a fairly narrow active stream corridor in this area, with high bluffs of Glacial Lake Missoula deposits to the north and a low terrace to the south (Figure 78).

Figure 79 shows a 2018 flood photo of the bankline at RM 204.7 where the river has migrated southward on the order of 200 feet since the 1950s. This shows how floodwaters commonly access old river channel features on the floodplain that may be topographically subtle.

There are numerous structures within the CMZ in Reach CF07, including a swimming pool that is about 50 feet from the river. This pool can be seen on the far right side of Figure 79. Just upstream of this swimming pool is the bankline that has shown the most movement in this reach, with about 150 feet of migration since the 1950s. Over the last decade a large mid-channel bar has formed off this bank, likely driving increased erosion on the left bank; between 2017 and 2019 one section of this bank migrated ~50 feet to the south (Figure 80).

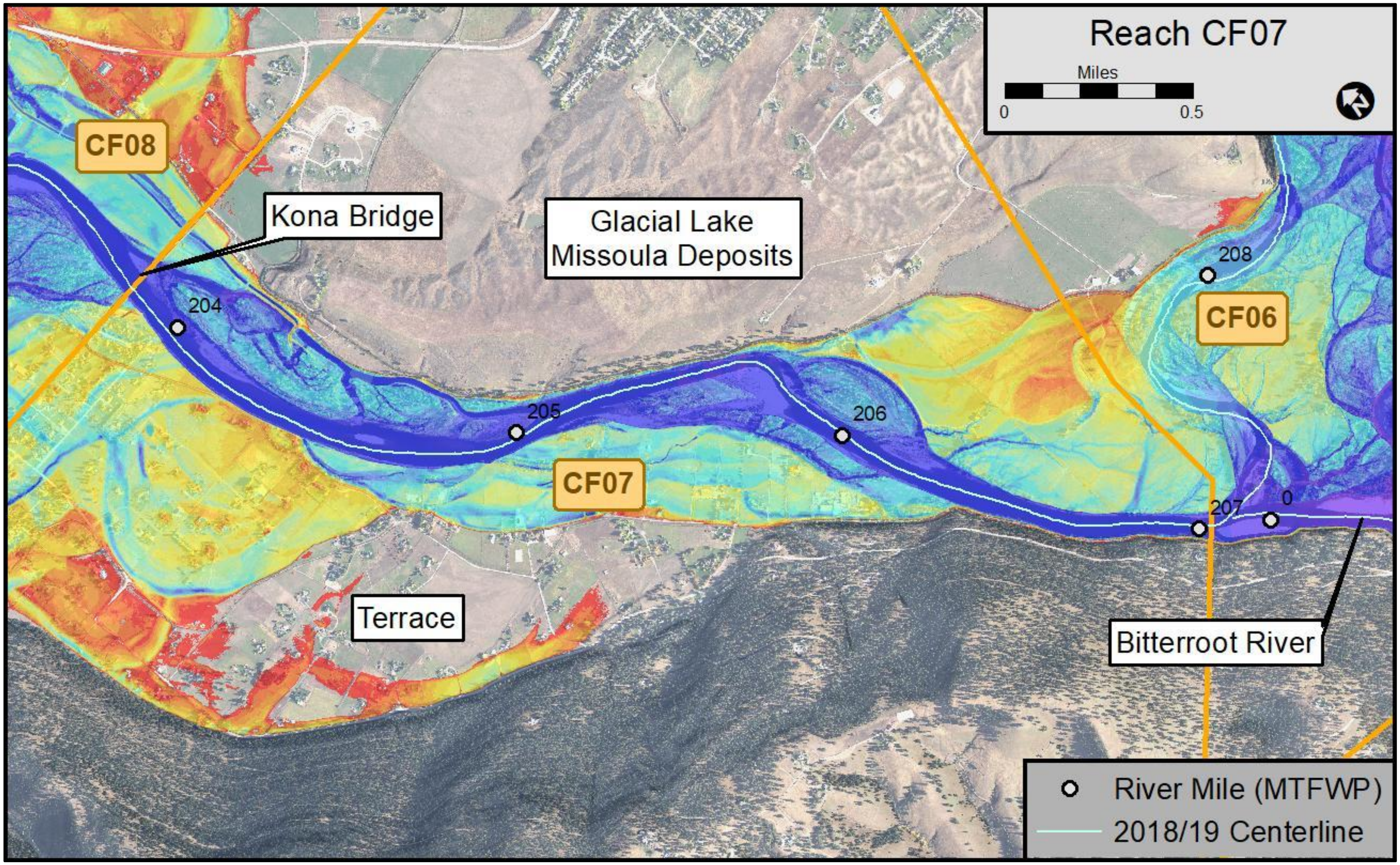

Figure 78. Relative Elevation Model results for Reach CF07; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 79. View south across river showing flooded low terrace swale at RM 204.7 (May 10, 2018).

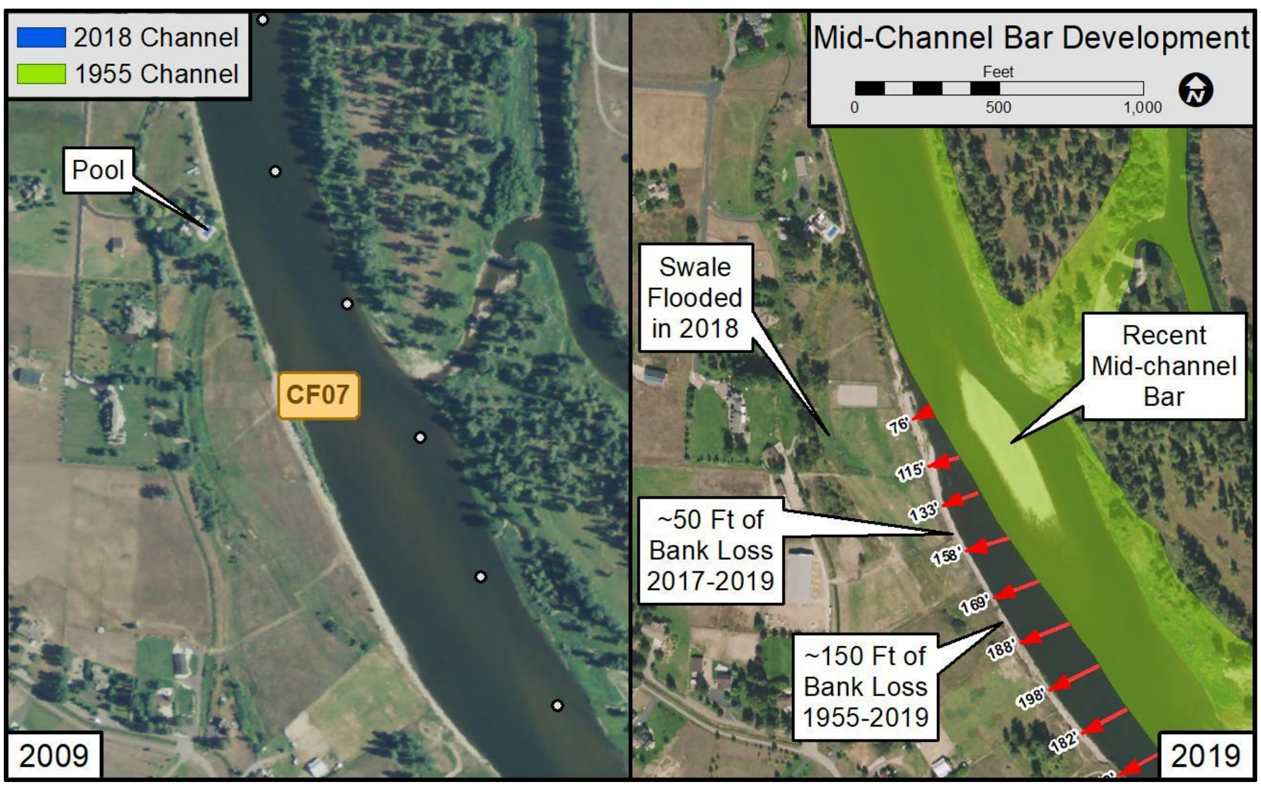

Figure 80. Area of primary bank erosion in Reach CF07 showing newly developed mid-channel bar adding pressure to left bank.

5.8 Reach CF08 – Council Grove State Park

Reach CF08 is 2.6 miles long, extending from Kona Bridge past Council Grove State Park. A total of 38 migration measurements were collected in the reach, most of which were measured on large sweeping meander bends below Kona Bridge. The mean migration distance in this reach is 342 feet, and the erosion buffer width is 706 feet. The maximum migration distance measured is 848 feet at RM 202.2. The Relative Elevation maps show a wide swath of active and abandoned channels through Council Grove State Park, with terraces forming the south floodplain margin (Figure 81).

Just downstream of Kona Bridge, the first large meander bend in Reach CF08 has been an area of high erosive pressure on the right bank for decades. In the 1990s a series of barbs can be seen on the bank extending about 60 feet out into the river (Figure 82). By 2011 the upper barb had eroded out, and the others damaged. By 2019, the original barbs were severely damaged and large scallops had developed along the bank. This bend migrated 370 feet between 1955 and 2019. The scallops deepened by ~30 feet between 2017 and 2019. The home that this bank armor is protecting is well within the Erosion Hazard Area mapped for Reach CF08.

Just downstream of the barbs described above, a prominent side channel known as Warm Slough leaves the river at RM 203 and flows north of Council Grove State Park (Figure 81). This channel was artificially blocked by a large berm in 1972, but the river has progressively eroded out the berm and reactivated the channel. During the 2018 flood there was noted flooding on this channel, with water flowing across Mallard Way and other minor roads. This channel will potentially continue to enlarge and carry additional flow as its entrance is on the outside bank of a large meander, such that the entrance angle to the channel is low and prone to substantial flow capture (Figure 81).

Just downstream, another large bend has migrated ~850 feet across from Council Grove State Park, with over 100 feet of that migration occurring since 2017 (Figure 84).

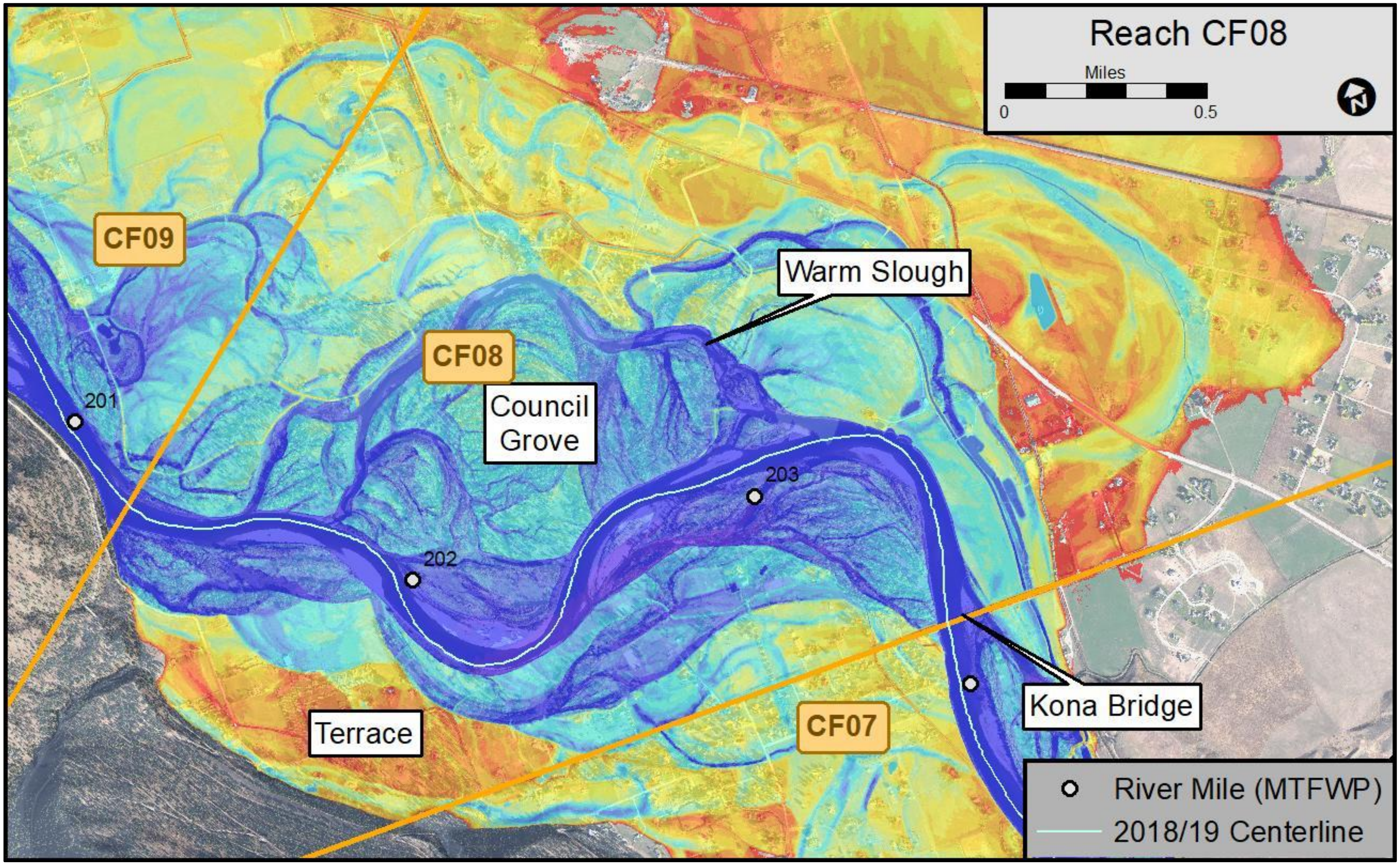

Figure 81. Relative Elevation Model results for Reach CF08; blue colors highlight channels, wetlands, and low floodplain areas.

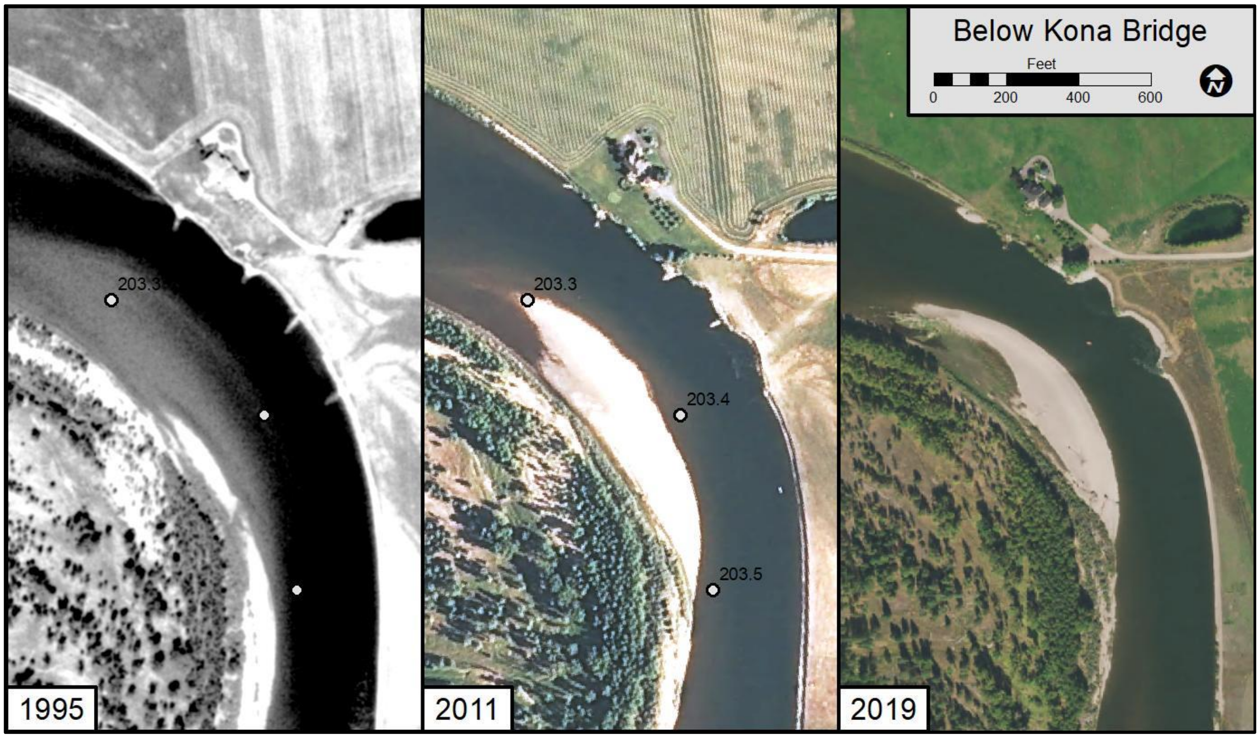

Figure 82. Right bank armoring just below Kona Bridge in 1955, 2011, and 2019.

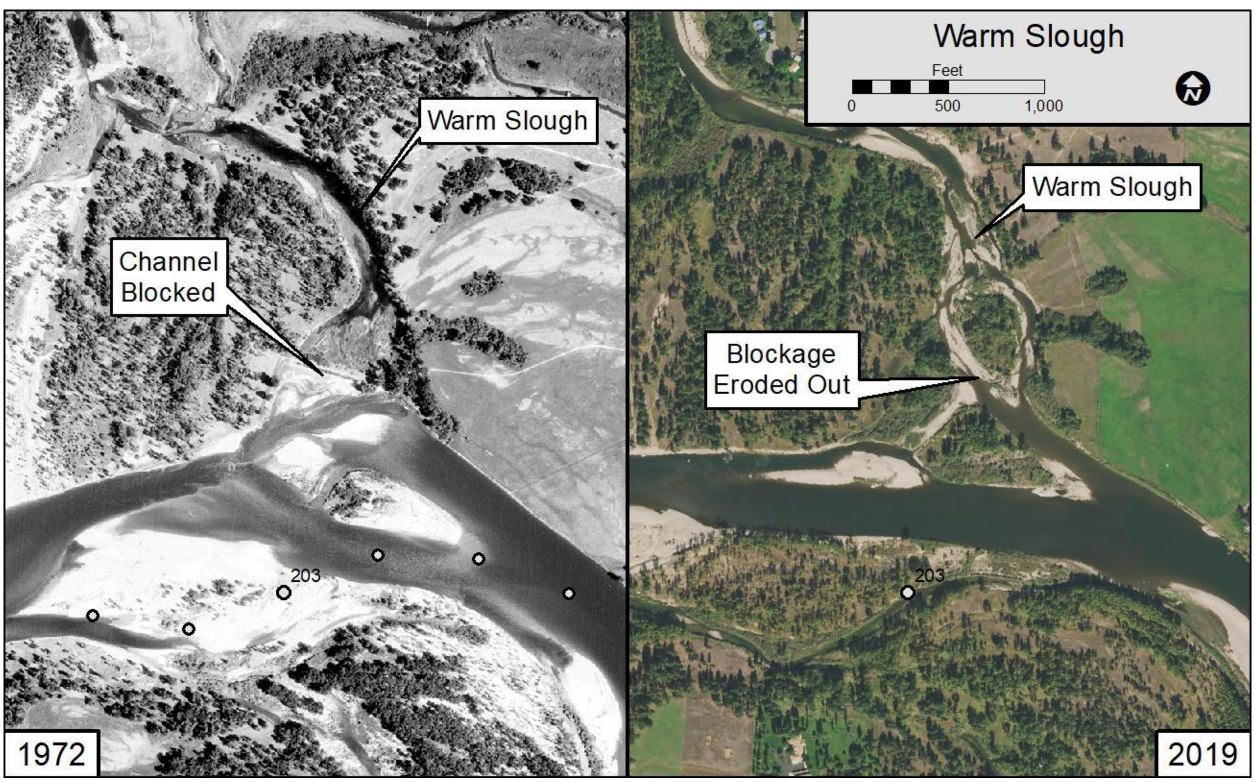

Figure 83. Warm Slough side channel re-activation through constructed blockage at Council Grove State Park, 1972-2019, RM 203.0.

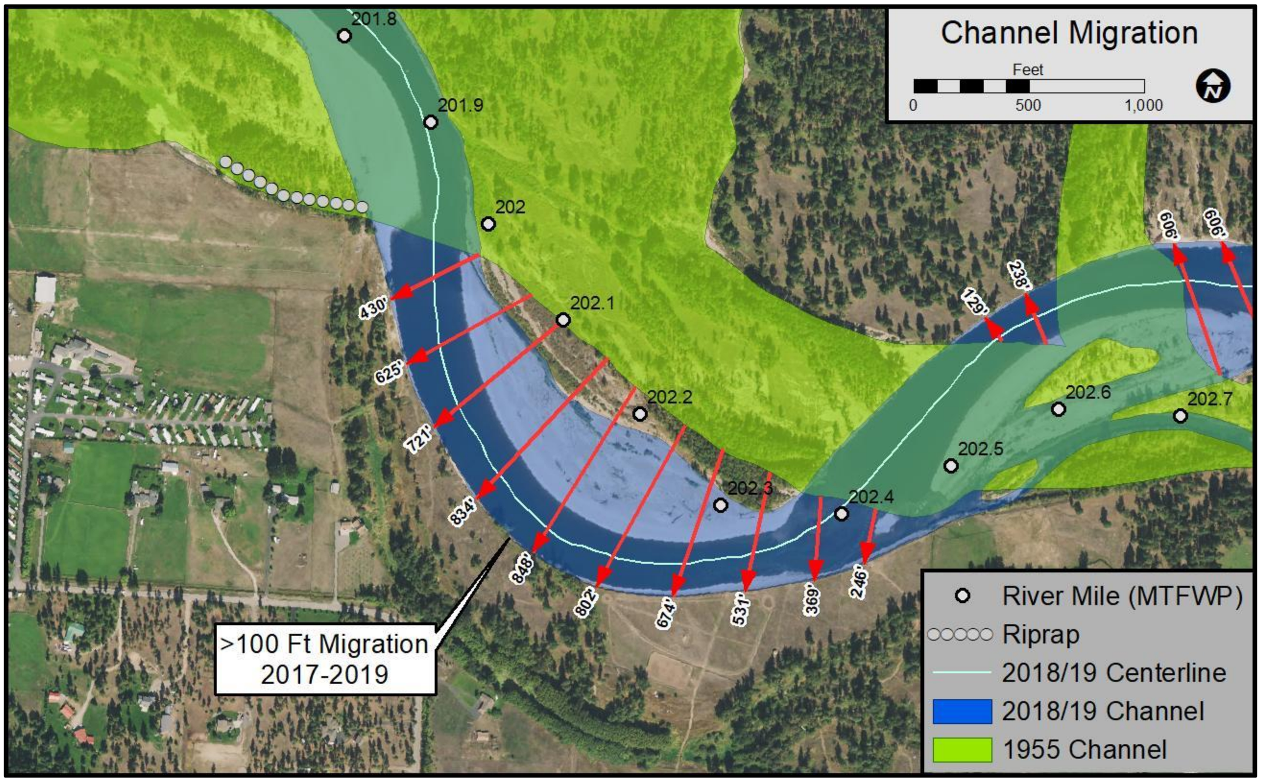

Figure 84. Meander migration at RM 202.2, Reach CF08.

5.9 Reach CF09 – Council Grove State Park to Below Smurfit Stone

Reach CF09 is 6.7 miles long, extending from Council Grove State Park past Smurfit Stone. A total of 96 migration measurements were collected in the reach. The mean migration distance in this reach is 241 feet and the erosion buffer width is 344 feet. The maximum migration distance measured is 854 feet at RM 200.3. The Relative Elevation maps show that this reach closely follows the south valley wall which largely made up of Cambrian dolomite. In the upper portion of the reach, large old river swales are evident on the north floodplain; many of these carried water during the 2018 flood (Figure 85 and Figure 86). The north end of the corridor on river right is confined by the dike system at Smurfit Stone in the lower part of the reach, although swales are similarly evident within the dike system (Figure 85).

In the upper portion of the reach, natural overflow paths appear in part blocked by Harper's Bridge Road (Figure 86), although the road overtopped in 2018, activating swales and flooding residences (Figure 87). Although transportation embankments cross and appear to block these swales, many of them still convey flow during floods and meet criteria as avulsion hazards. This does not imply that there is a high risk of the river completely relocating into one of the swales, but rather that there is potential for their expansion during floods which can lead to an increase in their activation frequency. This is especially the case in the event of any blockage in the river such as an ice jam or series of debris jams.

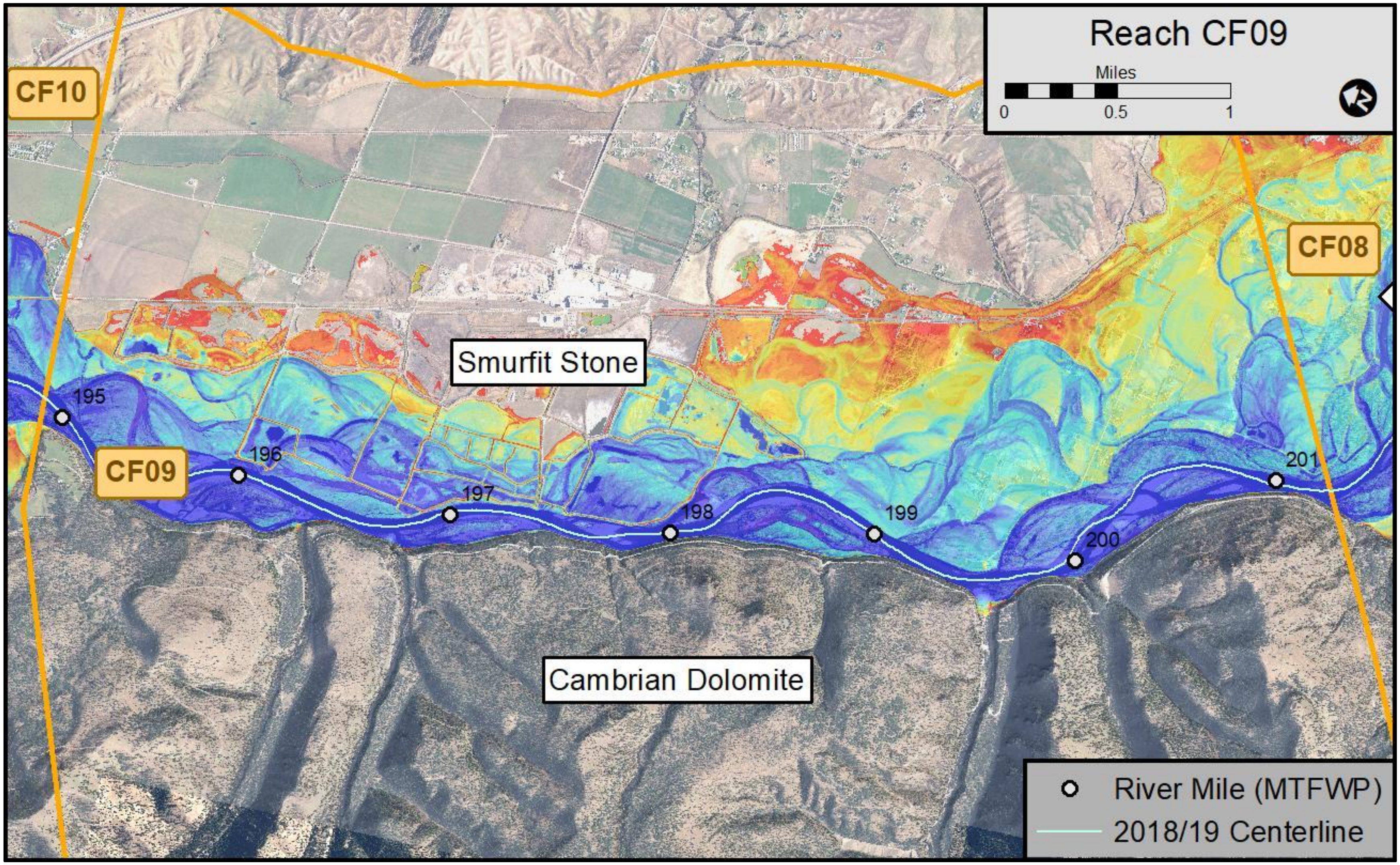

Figure 85. Relative Elevation Model results for Reach CF09; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 86. View downstream of Reach CF09 during 2018 flood; note Harpers Bridge Road acting as a levee in right foreground (May 10, 2018).

Figure 87. Flooding below overtopping section of Harpers Bridge Road; flow direction is left to right. (CAP May 8, 2018)

The dike system at Smurfit Stone is shown in Figure 88. Much of the CMZ in this area is mapped as restricted due to the bank armoring and diking system that limit channel movement into the area. However, this restriction may not be perpetual if the system were to degrade or be intentionally modified. These issues are discussed in more detail in Section 0.

Figure 88. View upstream showing Smurfit Stone dike system that confines river to narrow corridor against the bluffline to right (May 10, 2018).

5.10 Reach CF10 – Below Smurfit Stone to Petty Creek Road Bridge

Reach CF10 is 8.9 miles long, extending from below Smurfit Stone to the Petty Creek Road Bridge. A total of 147 migration measurements were collected in the reach. The mean migration distance in this reach is 428 feet, and the erosion buffer width is 800 feet. The maximum migration distance measured is 1397 feet at RM 193.3. The Relative Elevation maps show that the upper few miles of this reach are characterized by a series of swales and surrounding low ground. At RM 192 the river begins to flow along the south valley wall, with a broad complex of swales evident on the north floodplain (Figure 89). These swales were extensively flooded in 2018 (Figure 90).

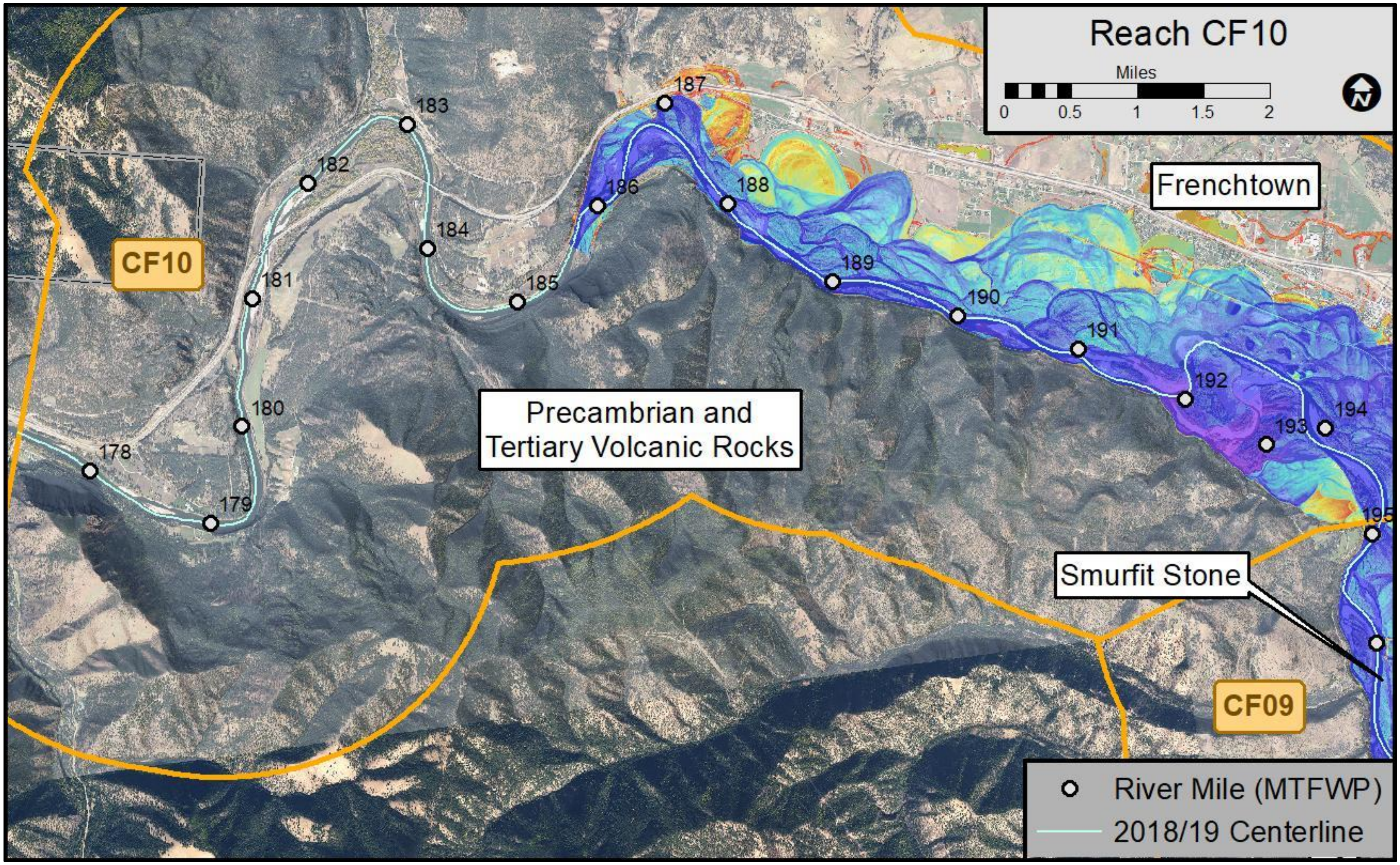

Figure 89. Relative Elevation Model results for Reach CF10; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 90. View downstream of the upper portion of Reach CF10 showing floodwaters accessing floodplain swales (CAP May 8, 2018).

One of the most dynamic areas in the entire project area is RM 192-193, where both rapid migration and wholesale avulsions dominate river process. Figure 91 shows a major avulsion event that occurred when a bendway migrated into an old swale that, by 2019, had captured the whole river. Evolution of that new channel has included a large bendway on the lower end of the avulsion path that is again close to avulsion into another swale/ditch. There are currently headcuts formed on the floodplain that mark an increased likelihood of another major avulsion here (Figure 92). Figure 93 shows the river overtopping into the avulsion path in 2018. Although the bend developed a large chute cutoff in 2018, managers should anticipate re-occupation of the meander bend apex as the river continues to adjust post-flood.

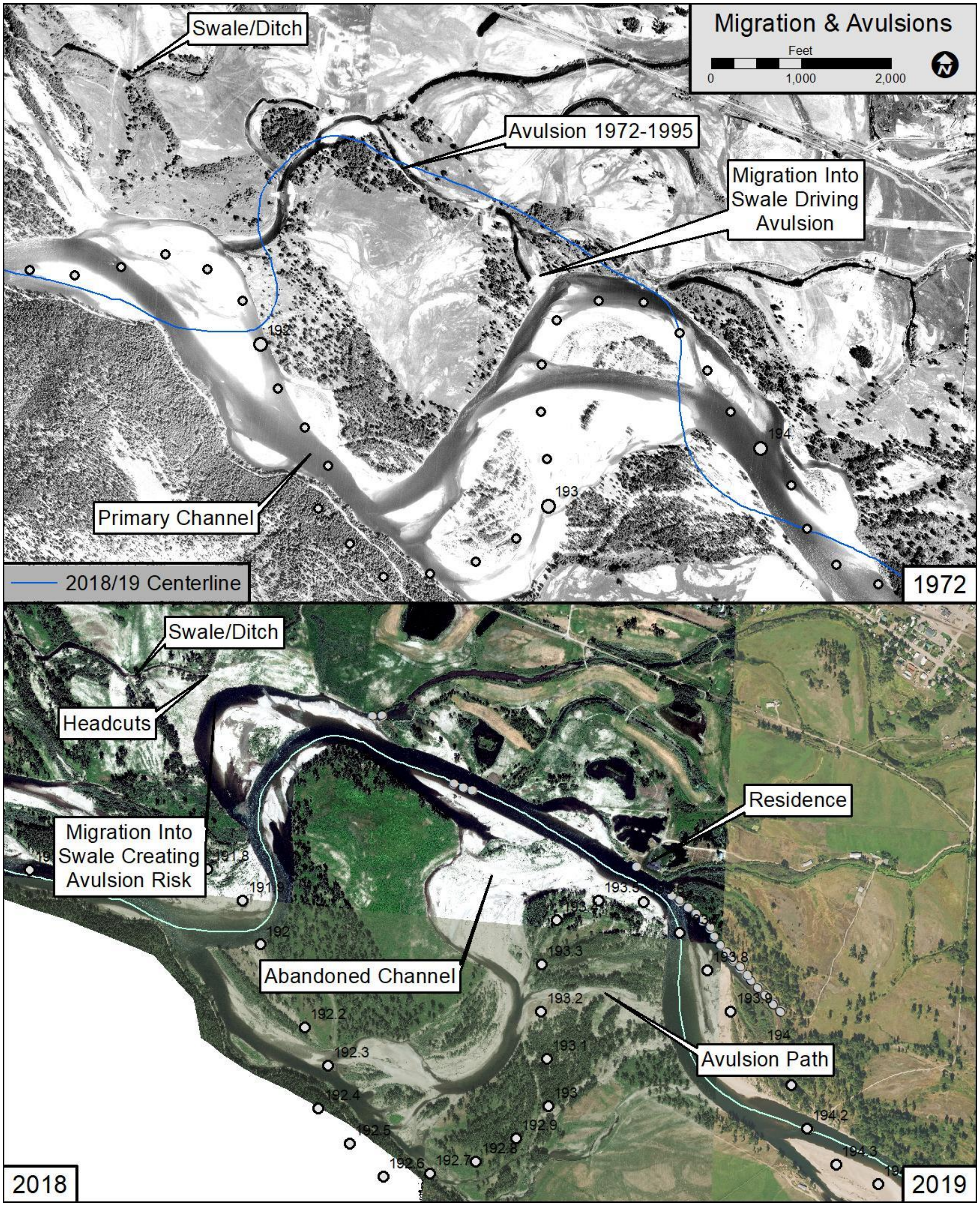

Figure 91. Major avulsion into floodplain swale at RM 193; recent migration and headcut formation has created threat of another avulsion downstream.

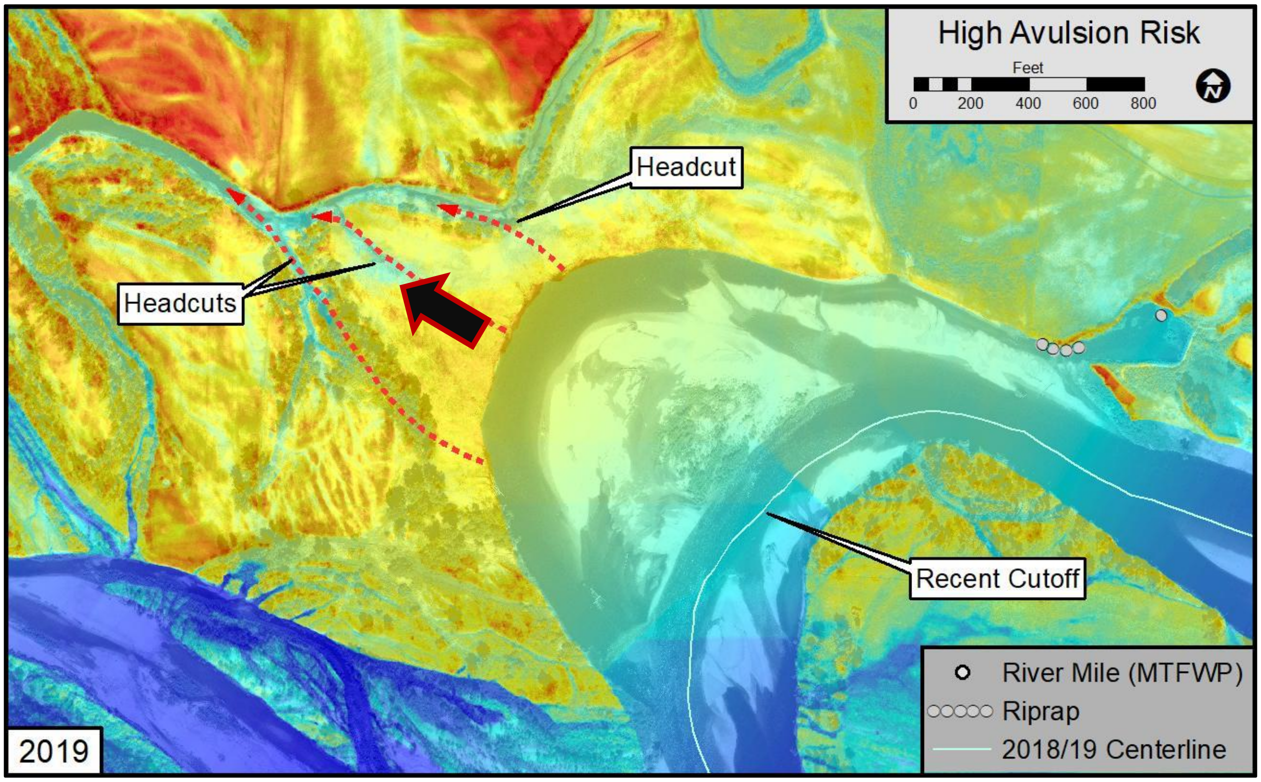

Figure 92. High avulsion risk at RM 193 as river migrates towards a large swale/ditch; headcuts appear to have formed in 2018. Arrow shows likely avulsion path.

Figure 93. View upstream at RM 192 showing high risk avulsion route (red arrow) (CAP May 8, 2018).

5.11 Reach BR1 – County Line to Maclay Ranch Road

Reach BR1 is 5.6 miles long, extending from the Ravalli/Missoula County Line just downstream of Florence to Maclay Ranch Road Bridge. A total of 74 migration measurements were collected in the reach. The mean migration distance in this reach is 556 feet, and the erosion buffer width is 1047 feet. The maximum migration distance measured is 1550 feet at RM 19.4. The Relative Elevation maps show that this reach flows through a broad low corridor that is over a mile wide, confined by Highway 93 to the west and the valley wall to the east (Figure 94). The valley wall on the east side is comprised primarily of Tertiary-aged alluvial fan deposits that overly much older Proterozoic rocks. This reach is characterized by major sites of channel migration, where 1955-2019 average annal rates of movement are commonly over 5 feet per year, and a wide riparian corridor which has resulted in extensive large wood recruitment. Four avulsions have been mapped in the reach at RM 16.2, RM 17.98, RM 20.5, and RM 21.0. All these avulsions occurred prior to 2005.

In general, this appears to be a largely unconfined and dynamic section of the Bitterroot River that, by virtue of its lack of bank armor, supports a vibrant successional riparian corridor. There are no bridges in Reach BR1. Side channels and wetland swales are common, and stacks of large wood are common on open gravel bars and at the heads of flow splits (Figure 96). The CMZ in Reach BR1 is typically ½ to 1 mile wide. There has been some residential development in the EHA in the upper portion of the reach along Ellison Lane, but most of the CMZ is undeveloped. There were no areas of special concern identified in this reach.

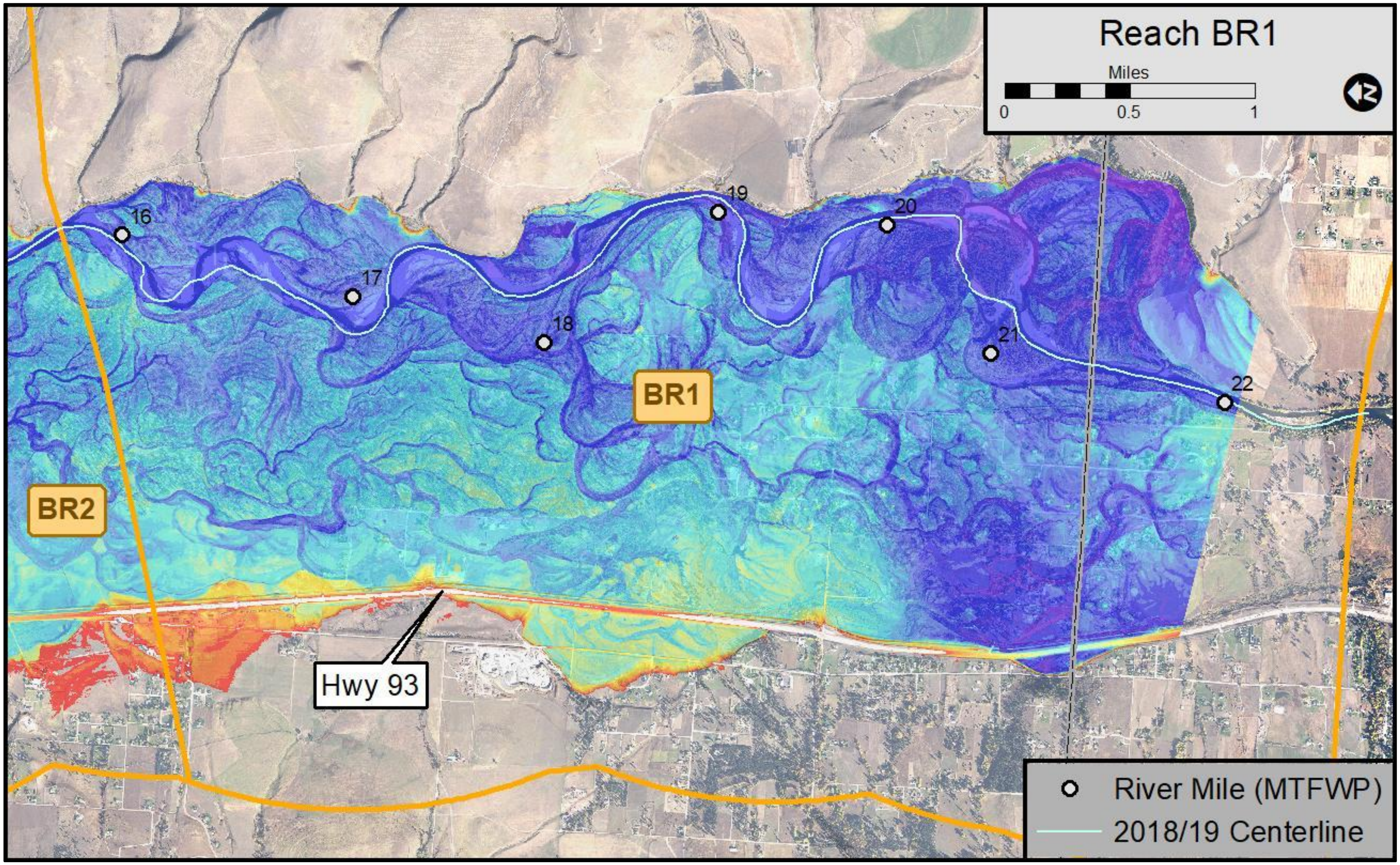

Figure 94. Relative Elevation Model results for Reach BR1; blue colors highlight channels, wetlands, and low floodplain areas.

Figure 95. View upstream during 2018 flood showing islands at RM 20.9. Note riparian succession on island in foreground that shows bands of cottonwoods establishing in direction of channel migration from center of photo to lower left of photo (Civil Air Patrol May 8, 2018).

Figure 96. Google Earth image showing large woody debris jams that are common in Reach BR1.

5.12 Reach BR2 –Maclay Ranch Road to Clark Fork River

Reach BR1 is 15.8 miles long, extending from Maclay Ranch Road Bridge to its confluence with the Clark Fork River. A total of 74 migration measurements were collected in the reach. The mean migration distance in this reach is 167 feet and the erosion buffer width is 262 feet. The maximum migration distance measured is 697 feet at RM 3.5. The Relative Elevation maps show that this reach flows through a relatively narrow valley bottom that includes several valley wall constrictions. Lolo Creek enters the river just upstream of the town of Lolo. Valley wall units range from Proterozoic bedrock to Tertiary alluvial fans and much younger Glacial Lake Missoula deposits and river terraces.

Migration rates in Reach BR2 are markedly lower than those upstream, as the river follows the valley wall through much of the reach. In the uppermost 2 miles of the reach, the corridor is wide although the migration rates are moderate as the active channel is closely bound by the valley wall. Since the 1950s, however, the river has been slowly peeling away from the valley wall towards a series of swales on the floodplain, many of which create avulsion risks west of the current river course (Figure 97). Lowermost Lolo Creek is also at risk of capture by the river. The lowermost 3,800 feet of Lolo Creek avulsed into a new channel between 1972 and 1995.

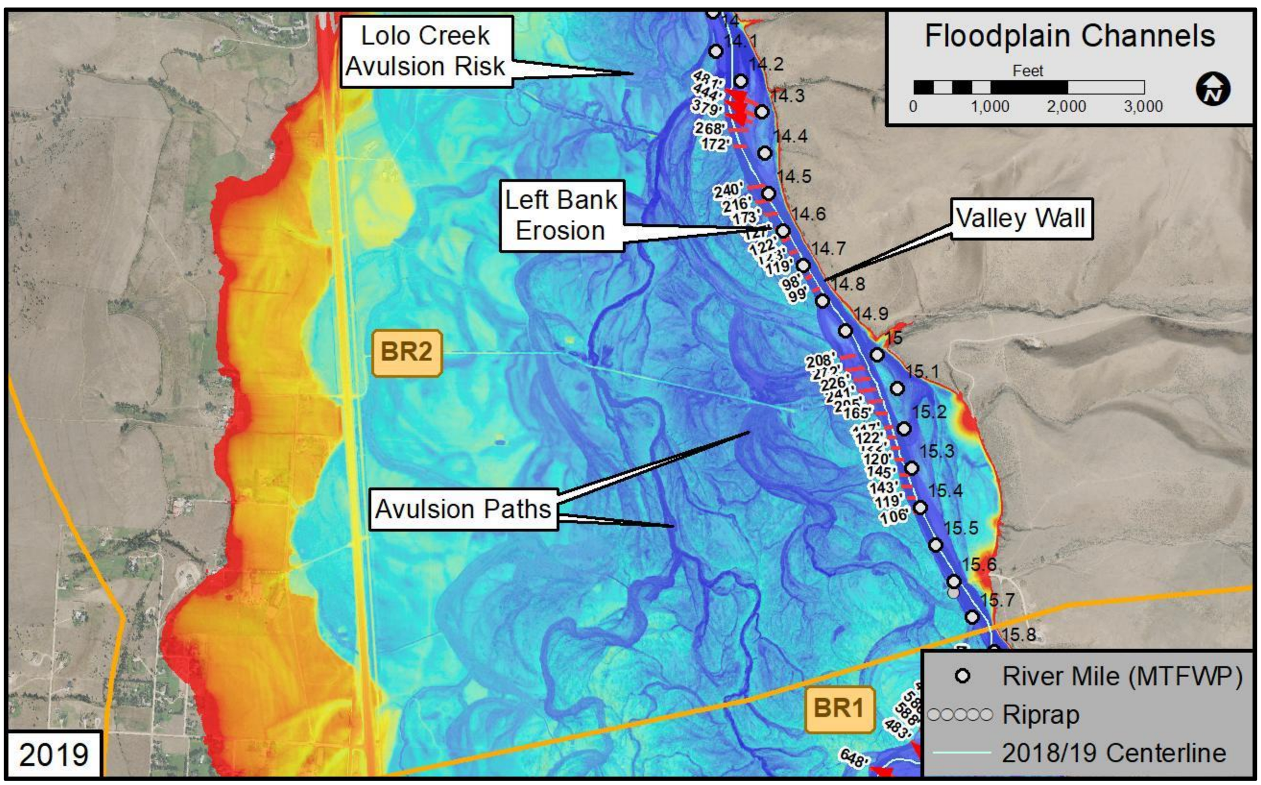

Figure 97. Relative Elevation model of upper Reach BR1 showing straight channel along valley wall and complex channel network on left floodplain. The river is slowly migrating away from the valley wall towards the floodplain swales.

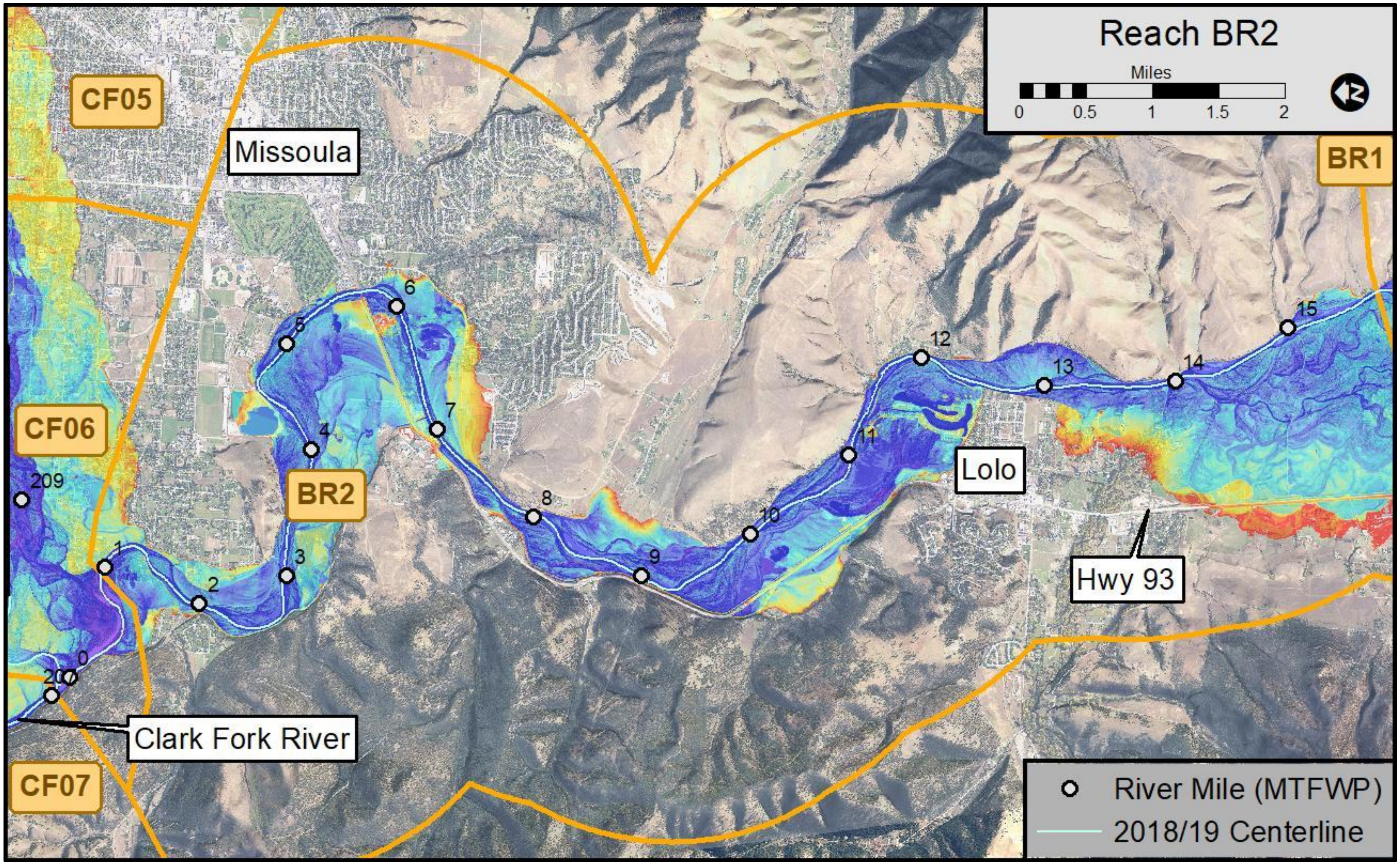

Figure 98. Relative Elevation Model results for Reach BR2; blue colors highlight channels, wetlands, and low floodplain areas.

5.12.1 Specific Concern: Flooding issues below Lolo and around the Wastewater Treatment Plant

One area identified by Missoula County as a concern is the area around the Lolo Wastewater Treatment Plant. In 2018 the fields due west of the water treatment plant flooded, but the plant itself remained dry inside retaining walls. A Relative Elevation map of the area shows a large, abandoned swale extending directly under and west of the plant (Figure 99). This swale is about 330 feet wide and 1.2 miles long; it is clearly an old primary thread of the Bitterroot River that was abandoned by at least the 1950s. Figure 99 also shows left bank erosion at the lower end of the swale; this bank has migrated about 160 feet towards the swale outlet since the 1950s (Figure 100). The outlet is vegetated, but just upstream is a large, abandoned gravel pit pond. Continued migration in this area has the potential to breach the pond although this will take decades if typical migration rates are sustained. In 2018, overflows at this migrating bank traveled down high flow channels on the west floodplain and created distinct headcuts which will promote channel deepening on the floodplain. A plot of the cross section drawn in Figure 99 shows that the elevations of the river, the swale, and a series of floodplain channels are all similar and thus their continued connectivity via flood flows and/or groundwater should be expected (Figure 101).

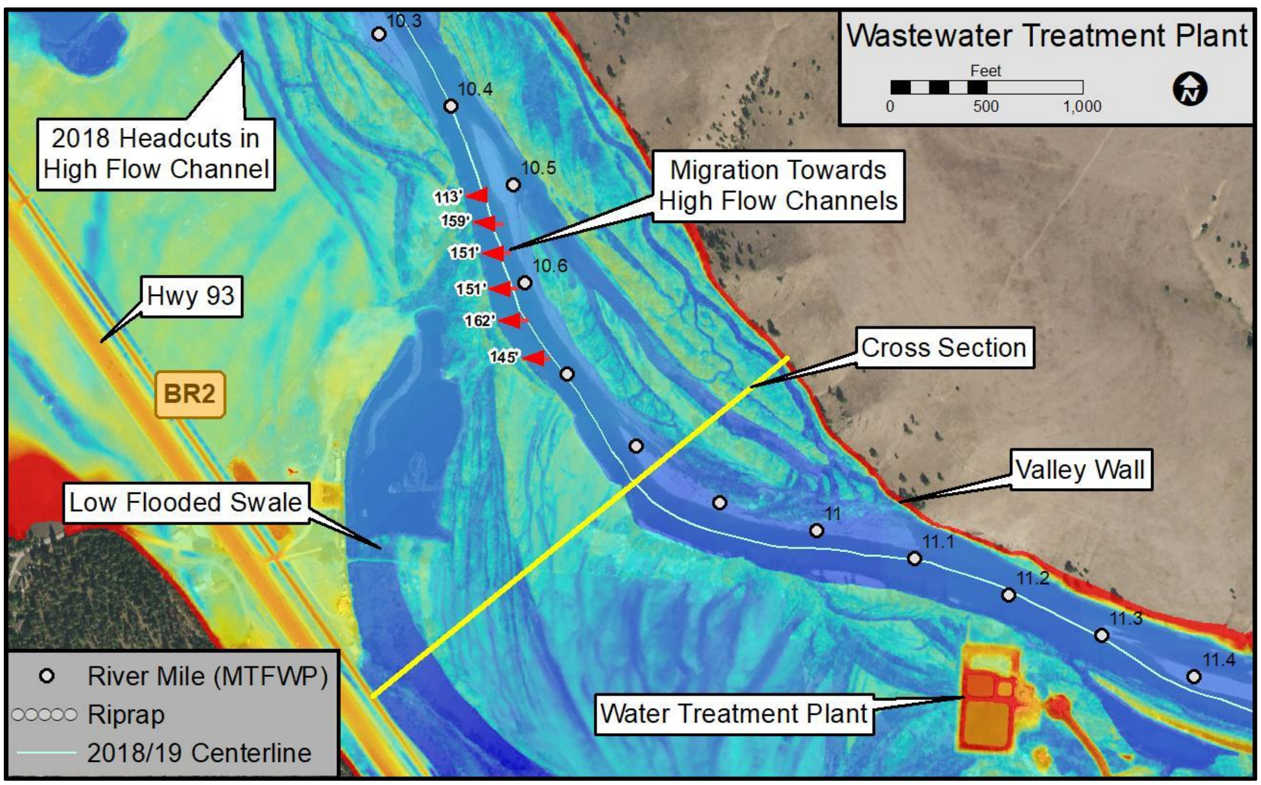

Figure 99. REM below Water treatment plant showing low swale and channels head cutting in 2018. Cross Section shown in Figure 101 is marked by yellow line.

Figure 100. View upstream showing lower end of flooded swale below water treatment plant; migrating bank follows the vegetated strip between swale and river (CAP May 8, 2018).

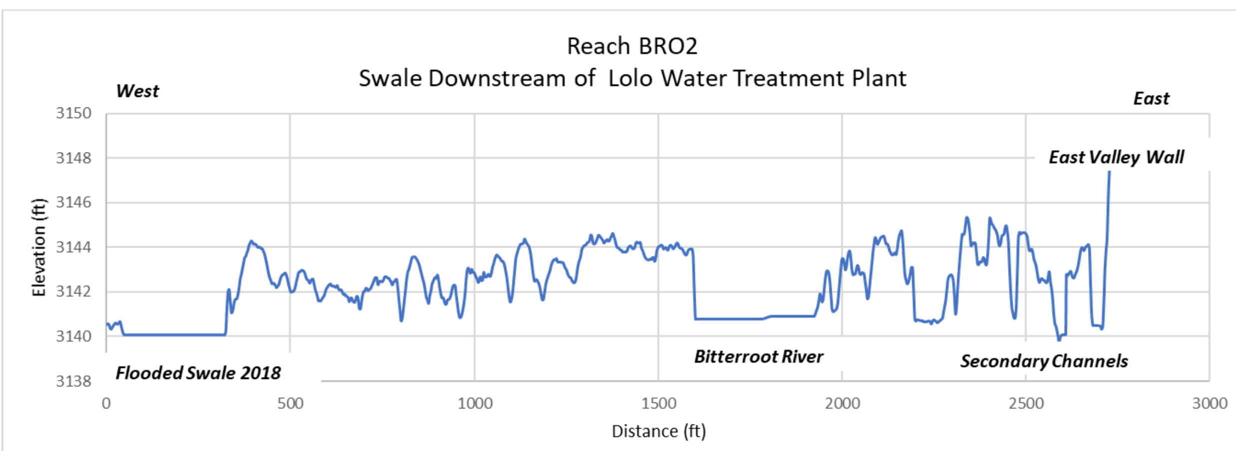

Figure 101. Cross section at RM 10.8 on Bitterroot River showing relative elevations of Bitterroot River (water surface) and floodplain channels; view is downstream.

5.12.1.1 Potential Conversion of Gravel Pit at RM 4.5 into a Recreation Area

At RM 4.5, there is a large gravel pit on the right (north) floodplain that has been reclaimed in recent years. There has been some discussion regarding the potential to turn this area into publicly-accessible open space. Figure 102 shows relative elevations and channel migration patterns in this area. Just upstream of the pit, the right bank has been slowly migrating northward into a terrace since the 1950s (1.4 feet per year on average). A power line crosses the river at this eroding bankline (Figure 103). Just downstream there is about 430 feet of right bank riprap protecting the gravel pit area. Probably the biggest risk in this area regarding channel migration is the potential for the river flanking the armor at the power line. When rivers erode behind armor, unusually rapid rates of bank erosion can occur due to the hydraulic eddies formed at the flanking site. Further downstream the river is currently migrating southward away from the reclaimed pit. This area fortunately has a wide swath of riparian area on the south side of the river that is dissected by swales/high flow channels that will help alleviate flooding pressure at the gravel pit, which sits on relatively high ground.

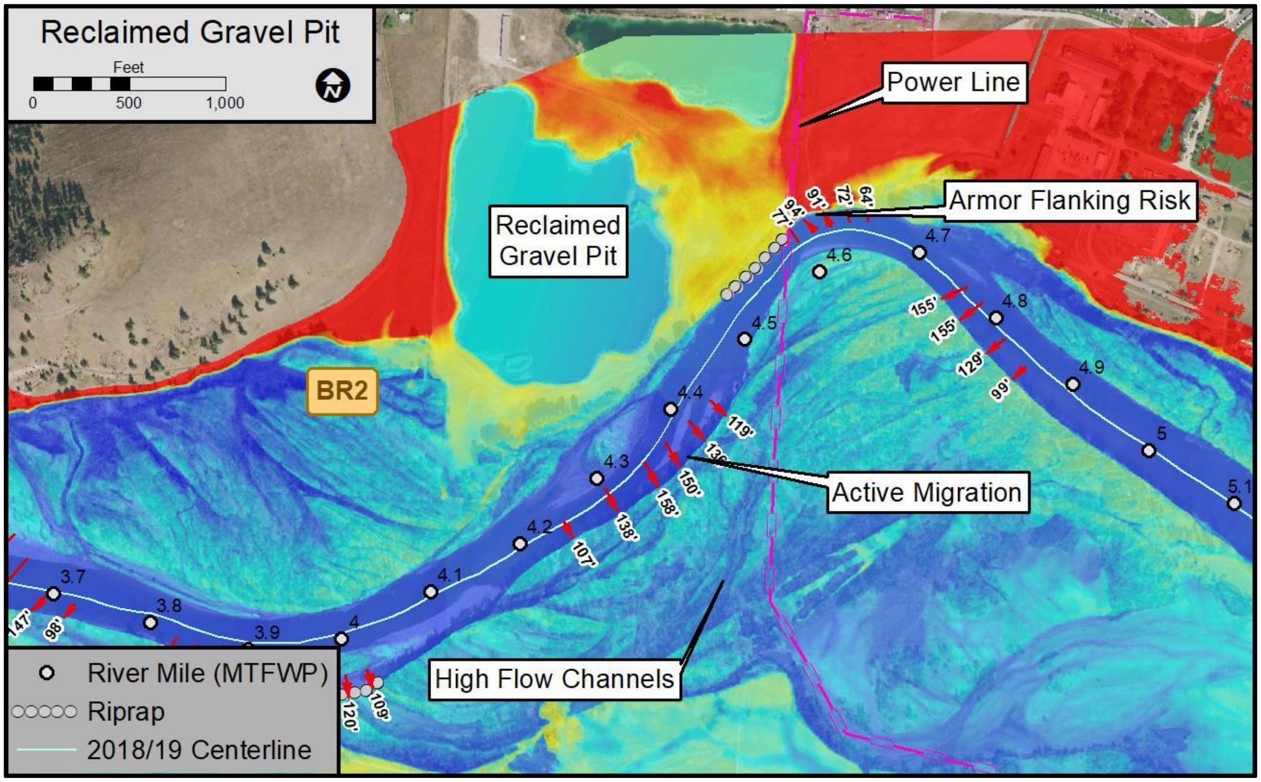

Figure 102. REM showing bank armor and channel migration patterns in vicinity of reclaimed gravel pit at RM 4.5.

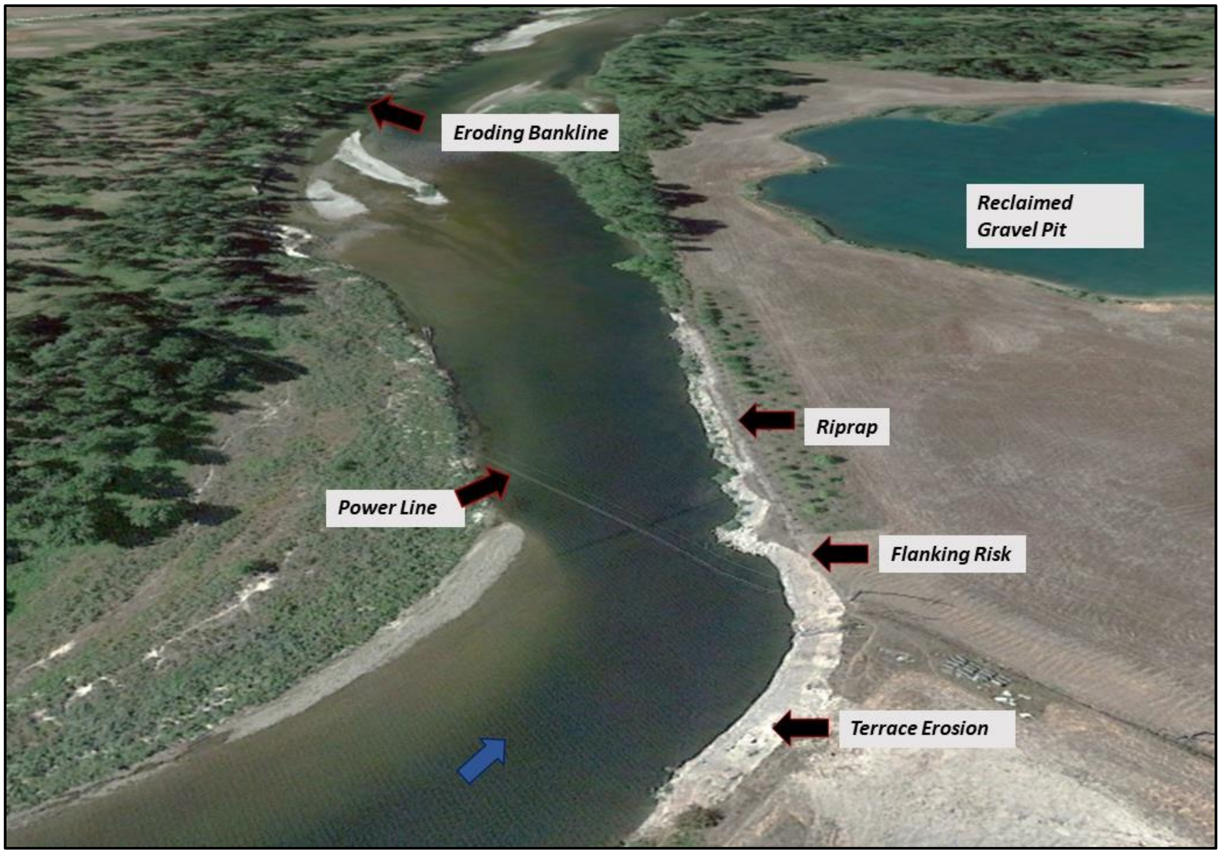

Figure 103. Google Earth oblique image showing major features at RM 4.4; view is downstream.

6 Discussion—Milltown Dam and Smurfit Stone

The following section contains an expanded discussion of specific issues on the river related to the potential influences of Milltown Dam removal on channel dynamics and CMZ complexities at Smurfit Stone near Frenchtown.

6.1 Milltown Dam Removal

This area of the Clark Fork River corridor just upstream of Bonner (Reach CF04) was the focus of a massive dam removal/restoration project between 2003 and 2012. It was 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 104 and Figure 105). The system was reconstructed as a deformable, dynamic river/floodplain, so that the CMZ is minimally restricted in this reach. The overall 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). Upon completion, it was the first time in a century that the Blackfoot and Clark Fork Rivers flowed freely to Missoula.

Aerial view of remediation and restoration activities at the site, 2009.

Figure 104. View upstream of Milltown Dam site during active remediation. Blackfoot River joins the Clark Fork on the left side of image (EPA).

Figure 105. View downstream showing Milltown Dam Removal and Restoration Site shortly after project completion (River Design Group)

The removal of Milltown Dam began in 2008 with a powerhouse breach and continued for several years with the removal of the rest of the dam, as well as sediment removal and floodplain /channel reconstruction upstream. Because the dam disrupted sediment and flow patterns on the river, there have been some questions as to how the river has responded downstream.

Major and others (2017) describe the geomorphic responses of river systems to dam removal using twenty examples from around the United States, one of which is Milltown. In general, the downstream impacts of dam removal tend to include channel aggradation, changes in channel gradient, width, and bed texture, pool infilling, and bar formation. These changes can be transient or persistent. Most sediment accumulation tends to occur in flat reaches. Although Major and others (2017) do not describe increased rates of channel migration downstream of a dam removal project, bar formation and sediment loading are contributing factors to bank erosion and so there is some potential that Milltown Dam removal has affected rates of channel migration downstream. In this paper, Milltown Reservoir is estimated to have held 5.5 million cubic meters of sediment (described as primarily sand), of which about 40% was removed prior to the dam breach as part of the Superfund cleanup. These authors note that the large volume pulse of sediment released at Milltown travelled at least 7-12 miles downstream.

Wilcox (2009) described how the 2008 removal of the dam resulted in base-level lowering of 9 meters (29 feet) at the dam site. This means the bed of the channel below the dam was 29 feet below the bed of the reservoir upstream, creating a steep drop in the river over the dam site (Figure 106). Subsequent erosion introduced a pulse of reservoir sediment to the river. In the first two years following dam breaching, Wilcox (2009) estimated that several hundred thousand cubic meters of sediment were eroded from reservoir segments on both the Clark Fork and Blackfoot Rivers. As flows were high during the first two years following dam breaching, sediment was also delivered to the reservoir site from upstream, making it difficult to calculate the volume of sediment actually derived from the reservoir. Wilcox (2009) indicated that downstream geomorphic adjustments to reservoir-derived sediment delivery was much higher in the first year relative to the second year following dam removal, when easily-transportable fine sediment was sent downstream. The downstream response included side channel deposition on the order of three feet deep in side channels of the Kelly Island area. Fine sediment also settled into the voids of existing gravel deposits. One question raised by Wilcox (2009) was whether dam removal had resulted in short term changes in geomorphic conditions, or "threshold-crossing shifts to new ecogeomorphic conditions."

Figure 106. Large headcut formed as Milltown Dam was breached on March 28, 2008 showing base level lowering that drove channel downcutting upstream and accelerated sediment delivery below (extracted from a youtube video by American Whitewater).

In a subsequent meeting presentation, Brinkerhoff and Wilcox (2010) described how significant sediment accumulation was observed in the multi-thread reach between Reserve Street and the Bitterroot River confluence (Reach CF06 in this report). Evans and Wilcox (2013) studied the Kelly Island area and showed that extensive fine sediment infiltration into gravels was occurring following dam removal.

To assess the impacts from the Milltown Dam removal, we intersected the migration vectors with the mapped banklines to assign shorter-term migration rates at each erosion site. It is somewhat complicated since the banklines do not precisely bracket pre- and post-dam conditions, so the data were summarized as follows:

1. ***Pre-dam removal:*** 1955-1972 and 1972-2005
2. ***During and shortly after dam removal (the dam was breached in March 2008)***: 2005-2011
3. ***Post-dam removal:*** 2011-2017
4. ***Recent floods:*** 2017-2018 and 2017-2019

The results of the segmented migration vector analysis are shown in Figure 107. The data show that the average pre-dam annual migration rates are less than 10 feet per year both upstream and downstream of Milltown Dam. The "during dam removal" shows rates increasing, however they increase both upstream and downstream of the dam. This timeframe includes the two moderately high water years immediately post removal (2008 and 2009) as well as the ~10-year flood of 2011. In contrast, the post-2017 timeframe that includes the 2018 flood has been characterized by much faster average annual rates of channel movement. Most importantly, perhaps, is that recent increases in migration rates occurred both upstream and downstream of Milltown Dam.

These data suggest that the 2018 flood, which was the largest upstream of Missoula since 1908, drove large scale changes both above and below Milltown. Upstream of Milltown in Reaches CF01 through CF03 (County Line to Milltown), average rates were similar with migration sites averaging about 50 feet of movement during the flood year. The timeframe extends from fall 2017 to late summer 2018, and the 2018 flood peaked on May 11, 2018. Downstream, the highest rates of change from 2017-2019 are consistently in Reach CF10 near Frenchtown. This area has experienced recent avulsions and rapid subsequent adjustment. The rapid rates of change here may indicate that this is more of a "response reach" to Milltown Dam removal than the Kelly Island area, where most research has been focused.

When considering the rapid migration rates documented upstream of Milltown dam in the 2017-2019 timeframe, it is important to recognize that the mean annual discharge upstream of the Blackfoot River confluence is about 1,800 cfs at Turah. In contrast, the mean annual flow below the Bitterroot River confluence is almost triple that at about 5,400 cfs. So relative to mean annual flow, the river upstream of Milltown has been especially active in recent years. This area has also seen large avulsions such as that shown in Figure 39. It appears that this section of the Clark Fork River upstream of Milltown is inherently more prone to flood-induced changes relative to downstream. This may be due to lower inherent resiliency on the floodplain (e.g. poor riparian integrity on the floodplain and banks), but it also may be due to the broad effect of historic alterations associated with transportation corridor development that in many places relocated, straightened, or confined the river.

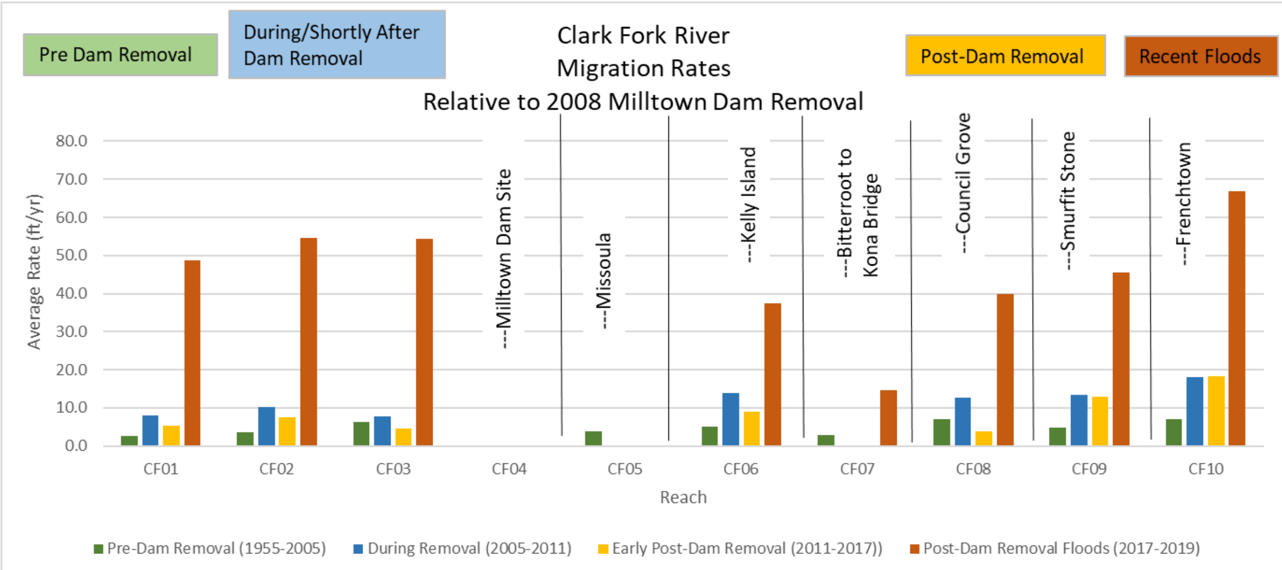

Figure 107. Pre- and post-Milltown Dam removal mean migration rates, Clark Fork River.

6.2 Smurfit Stone

The Smurfit-Stone Mill is in the lower end of project reach CF09, approximately three miles south (upstream) of Frenchtown, Montana. It was operated from late 1957 through early 2010 as a large integrated pulp and paper mill. Whereas the core industrial footprint of the site covers approximately 100 acres, there are over 900 acres of unlined ponds that were used to store wastewater effluent and sludge (URS, 2011). Some of the wastewater ponds initially used to store wastewater were drained and converted to store solid wastes produced by the mill. Currently, about half of the ponds contain freshwater emergent wetlands (URS, 2011). The entire site has about four miles of river frontage (Figure 108 and Figure 110). Several areas described as sludge ponds, aeration basins, and treated water ponds extend into the historic floodplain of the Clark Fork River. Some of these features, mainly treated wastewater storage ponds, encroach into the active stream corridor of the 1930s and 1950s (Figure 108).

Whereas most of the site was developed prior to 1963, the northern ponds (Ponds 12, 13, 13a, 16, and 18), were constructed between 1963 and 1978.

Between 1958 and 1984, pond wastewater was discharged directly to the Clark Fork River during high flows. After 1984, discharges to the river were year round if river flows exceeded 1900 cfs (URS, 2011). Raw wood materials including sawdust, woodchips, and rejected timber were delivered to the mill site by truck and rail; there was no log driving down the Clark Fork River in support of the mill.

In 2016 we were asked to consider the relationship of the Smurfit Stone site to the Clark Fork River Channel Migration Zone (Boyd and Thatcher, 2016). The primary findings of that evaluation showed that hundreds of acres of the natural CMZ of the Clark Fork River are now occupied by Smurfit-Stone facilities, mainly treated wastewater storage ponds, and that the active river corridor has been narrowed by over 40% through much of the site (Boyd and Thatcher, 2016).

Figure 109 shows the Relative Elevation Modeling (REM) results as well as the CMZ map for the Smurfit Stone site. Much of the mill site occupies the Historic Migration Zone where, in the 1950s, floodplain channels were continuous and active. These older channels are still visible as swales in the treatment ponds in the REM, and they stand out due to ponding in the 2018 flood photo (Figure 110).

6.2.1 Berm Failure Mechanisms

The Smurfit Stone Mill site is currently under much discussion regarding inspection needs, remediation approaches, and restoration opportunities. One issue that repeatedly arises is the interaction between the river and the ponds, especially with respect to risk of berm breaches.

The processes that are considered highly applicable to berm failure risk at Smurfit Stone include the following (RDG, 2016):

- Surface Erosion: Flowing water along the dike face
- Sliding: Pressure force from high water on one side pushes the dike
- Under-seepage: Seepage through porous levee foundation materials causes piping under the levee
- Internal Erosion: Seepage through an internal void causes piping through the levee

Regarding the CMZ, there are two main risk issues at this site. One is channel migration into the berm, and the second is avulsion risk through the ponds. Erosion of the berm due to channel migration is a surface erosion process. The other processes considered to highly be applicable at this site (sliding, under-seepage and internal erosion) relate to avulsion potential on the floodplain.

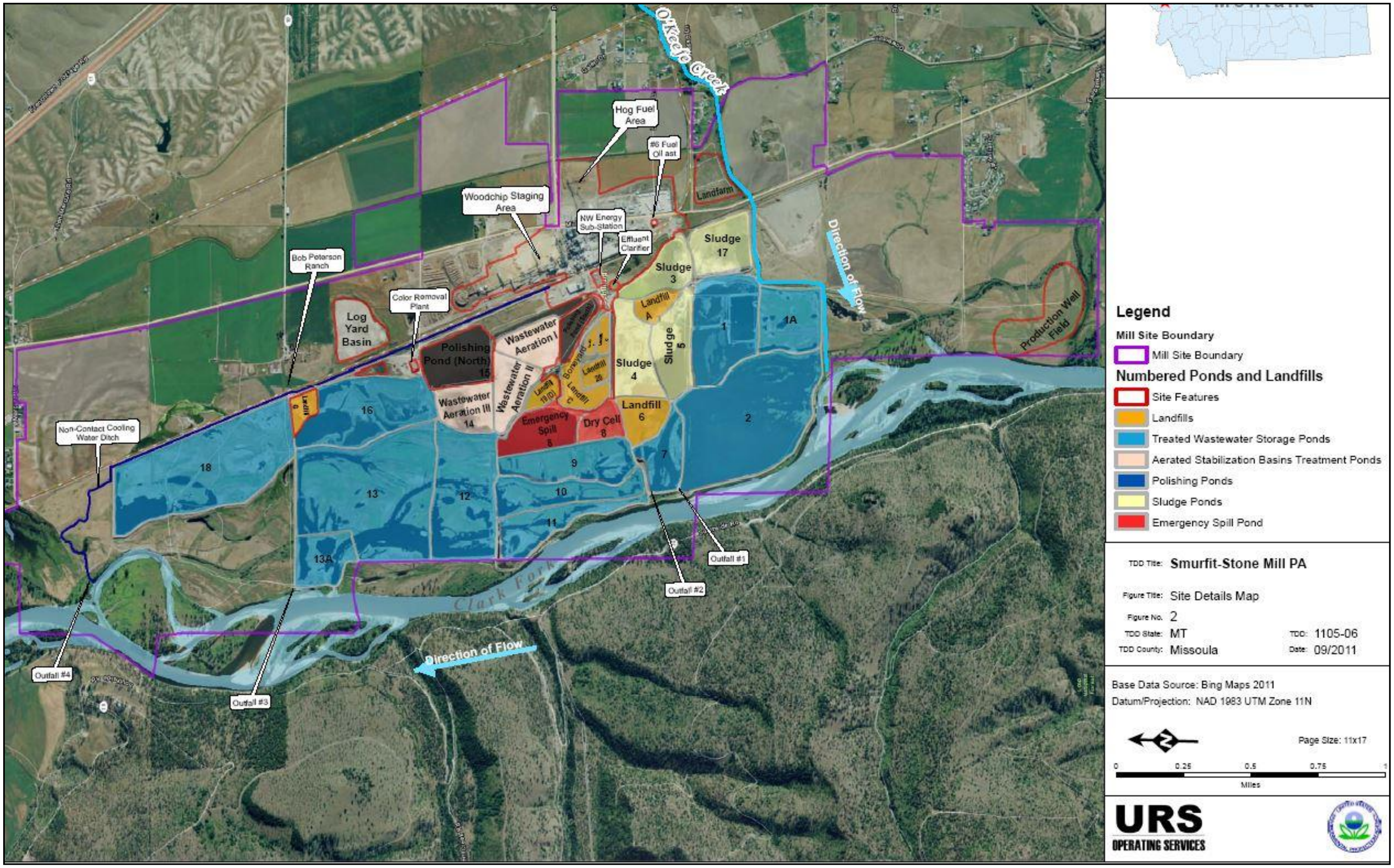

Figure 108. Generalized map of Smurfit-Stone site facilities; river flow direction is right to left (URS).

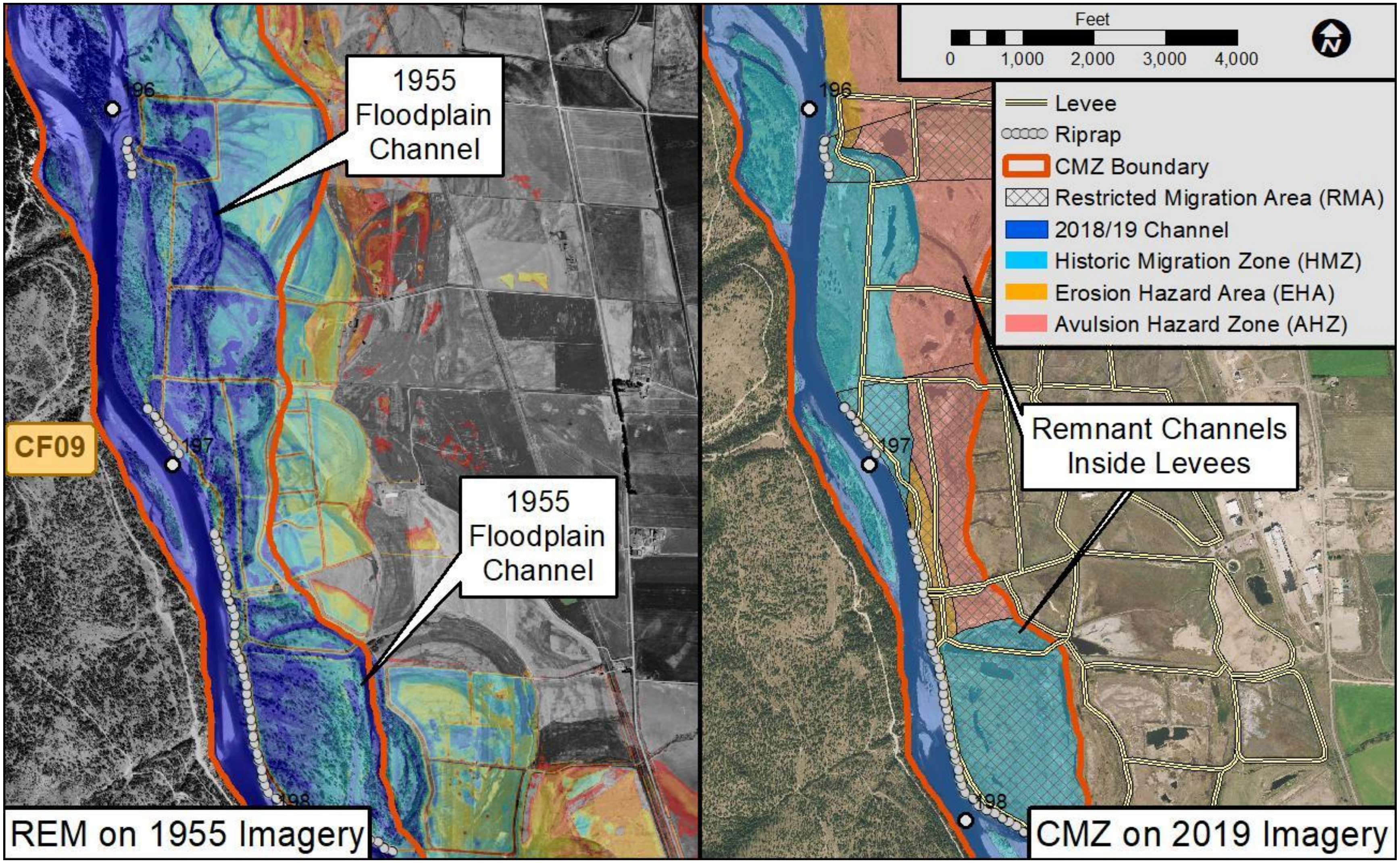

Figure 109. REM (left) and CMZ (right) maps for Smurfit Stone.

Figure 110. View downstream of Clark Fork River at Smurfit Stone during May 2018 flood.

6.2.2 Risk of Channel Migration into Ponds

According to a draft Clark Fork River Berm Surveillance and Contingency Plan (Newfields, 2019), there are two berms at the site forming continuous physical barriers to flooding events. These two berms are referred to as the "CFR Berm" and "Inner Berm" (Figure 111). The CFR berm is about 4.4 miles long and separates the site from the Clark Fork River, constructed as a man-made barrier between treated wastewater and the active river corridor (Newfields, 2019). It ranges in height from 8 to 15 feet above surrounding ground with an average top width of 15 to 25 feet. Two segments of the CFR berm were identified by EPA as "Special Concern Areas" after the 2018 flood (Newfields, 2019, Figure 111). The berms were constructed with native materials and underlain primarily by alluvial sands and gravels. The Inner Berm shown in Figure 111 was not addressed in the plan since flood evaluations indicated that the CFR berm would not be overtopped during a 100-year flood (Newfields, 2019).

The CFR berm is the primary infrastructure on site that separates the Clark Fork River from its historic and natural Channel Migration Zone, which is now occupied by wastewater storage ponds. As such, any risk of channel migration through the CFR berm is a primary concern on site.

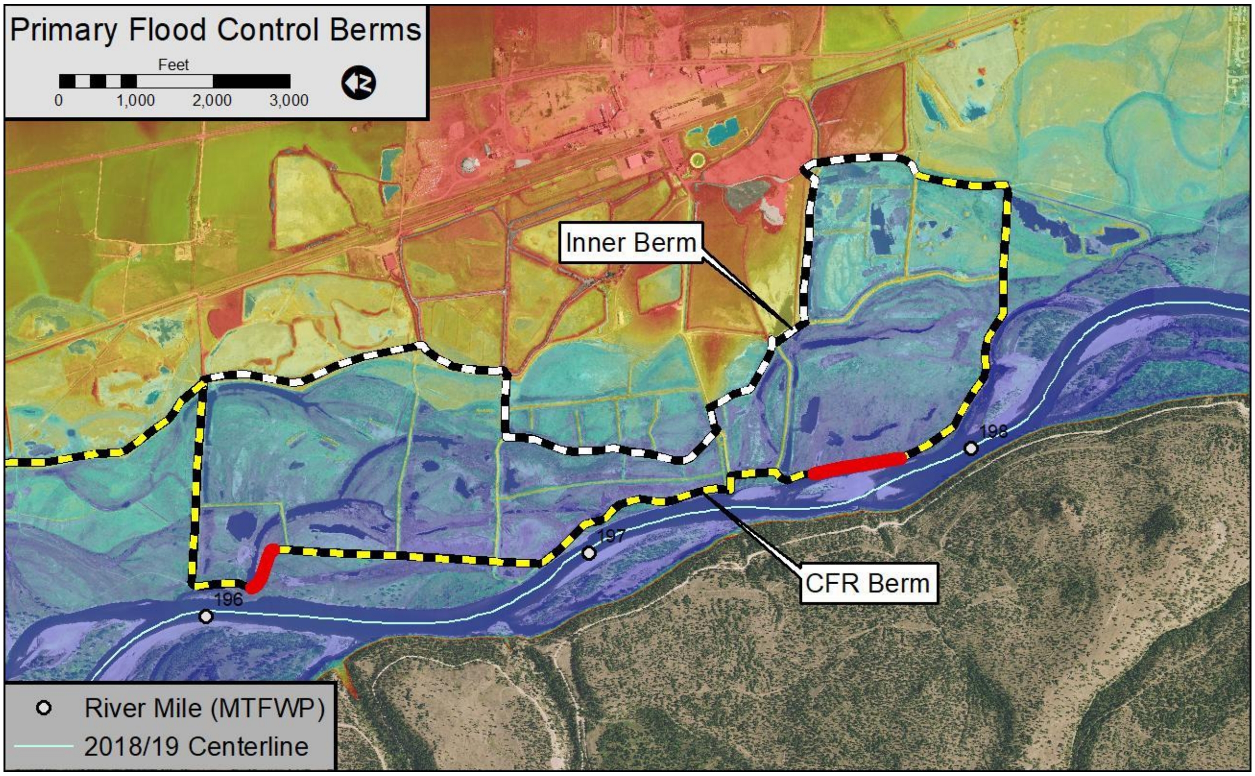

Figure 111. Primary flood controls berms at Smurfit Stone; red lines denote EPA "Special Attention Areas" following 2018 flood review (Newfields, 2019).

Since the primary means of protecting the CFR berm from channel migration is bank armor, the following discussion describes aspects of armor construction, maintenance, and current conditions with respect to river process. Figure 109 shows that most of berm is currently armored. In most areas the armor is on the CFR berm itself where it forms the stream bank, and in other areas there is a floodplain buffer between the armored streambank and berm.

The construction and maintenance history of the bank armor on the CFR berm provides some context as to the risk of berm erosion. In many places the main current of the river flows directly against the armored berm toe. In addition, the berms locally project into the active channel, which amplifies erosive energy along the riprap toe. Figure 112, which is a 2018 flood image along the berm edge, exemplifies this situation at the upstream end of Pond #11.

Permit records show that armoring the berms at the mill site was an ongoing construction/maintenance endeavor in recent decades. According to River Design Group (RDG, 2016), approximately 10 permits were issued (310) to perform maintenance activities on the berms between 1974 and 2007. These projects have included armor construction/extension, damaged armor rehabilitation, breach repair, and seepage treatments.

One important caveat in this discussion is that the armor mapping used in this evaluation was developed remotely using aerial imagery. There may be additional armor in place that is overgrown or even buried on site that is not accounted for in this discussion. In general, however, using several suites of imagery coupled with Google Earth oblique evaluations provide a good representation of bank armor extents. That said, the issues raised here should be used to incentivize a field assessment of specific areas to determine if the risks described here are already mitigated.

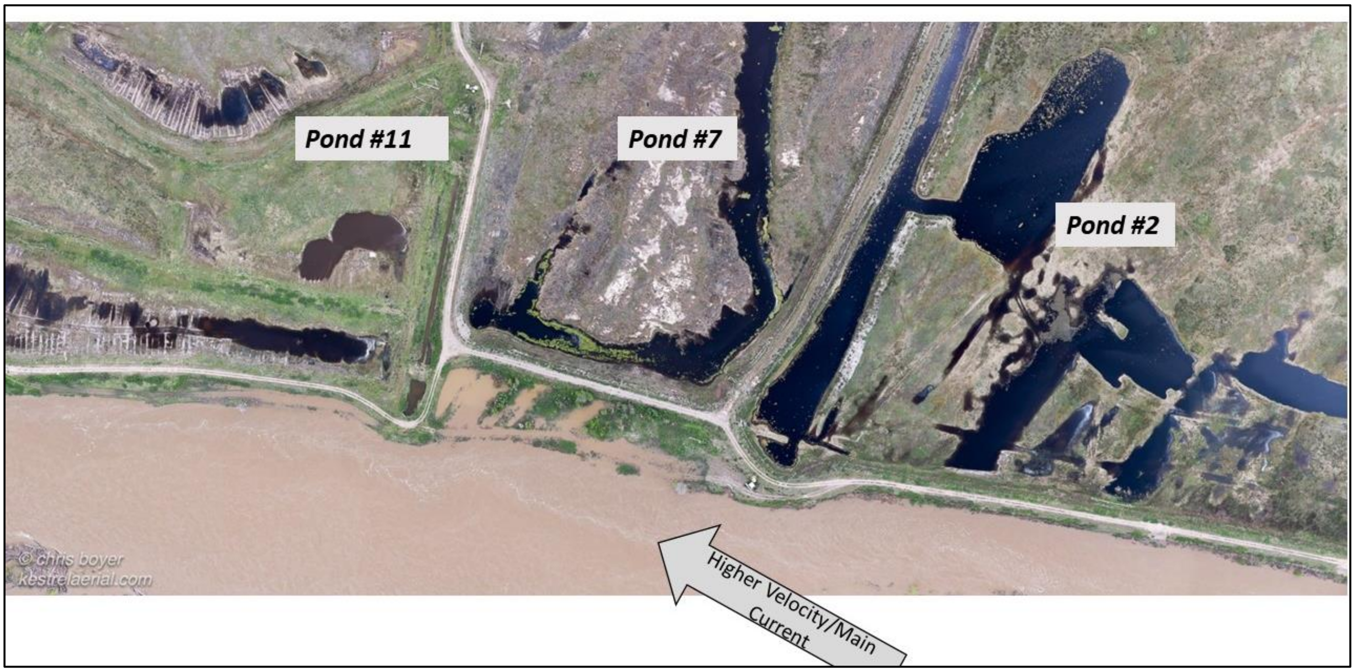

Figure 112. 2018 photo of floodwaters against Smurfit Stone berms (Ponds #2, #7, and #11 from right to left).

6.2.2.1 Pond #2

On the upstream end of the Smurfit Stone Mill Site at RM 198, The river has been migrating to the northeast towards the Pond #2 Berm (Figure 113 and Figure 114). About 1,000 feet upstream of the berm, the river has migrated about 70 feet since 2017 towards a swale that was a primary thread in the 1970s (Figure 113). A growing point bar on the left bank of the river will continue to drive right bank erosion and bend development at this location. As a result, increased activation of this meander should be expected, along with the erosion potential that comes with a higher frequency, duration, and magnitude of flow.

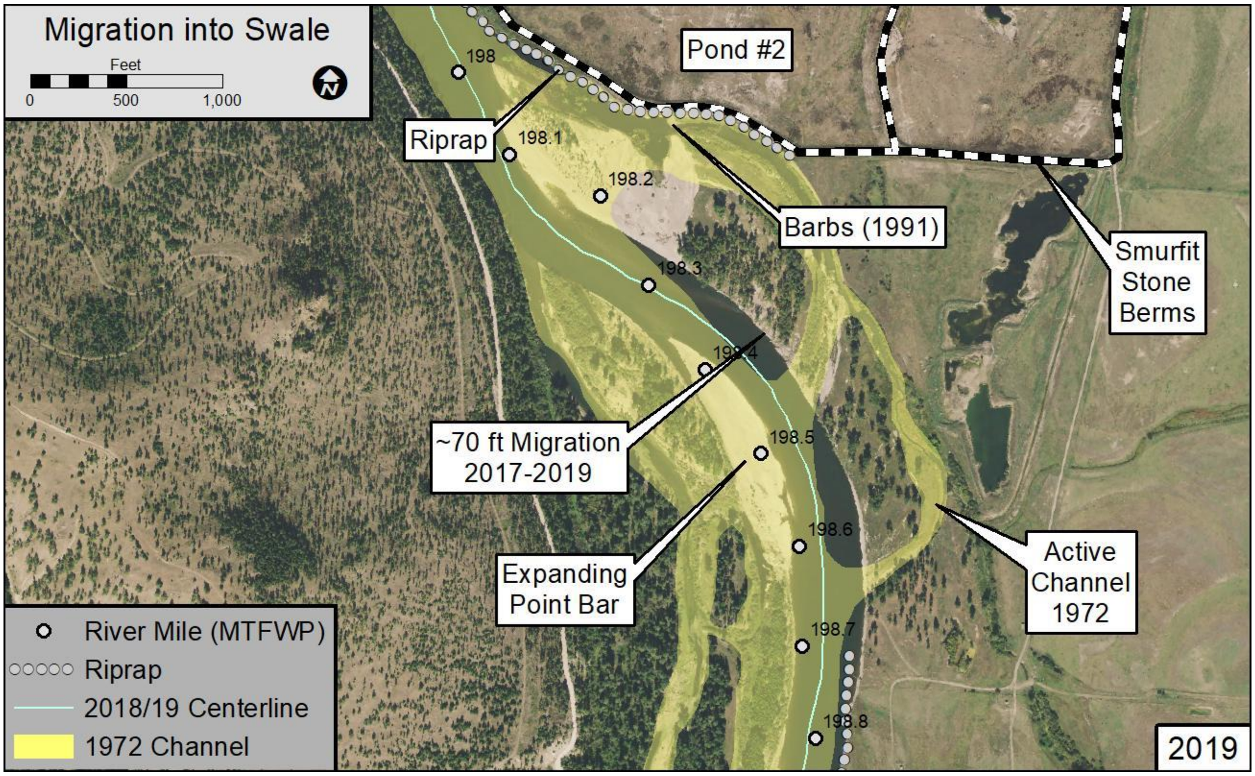

Figure 113. Bank migration just upstream of Smurfit Stone showing 2018 migration towards abandoned meander that flows against Berm along Pond #2.

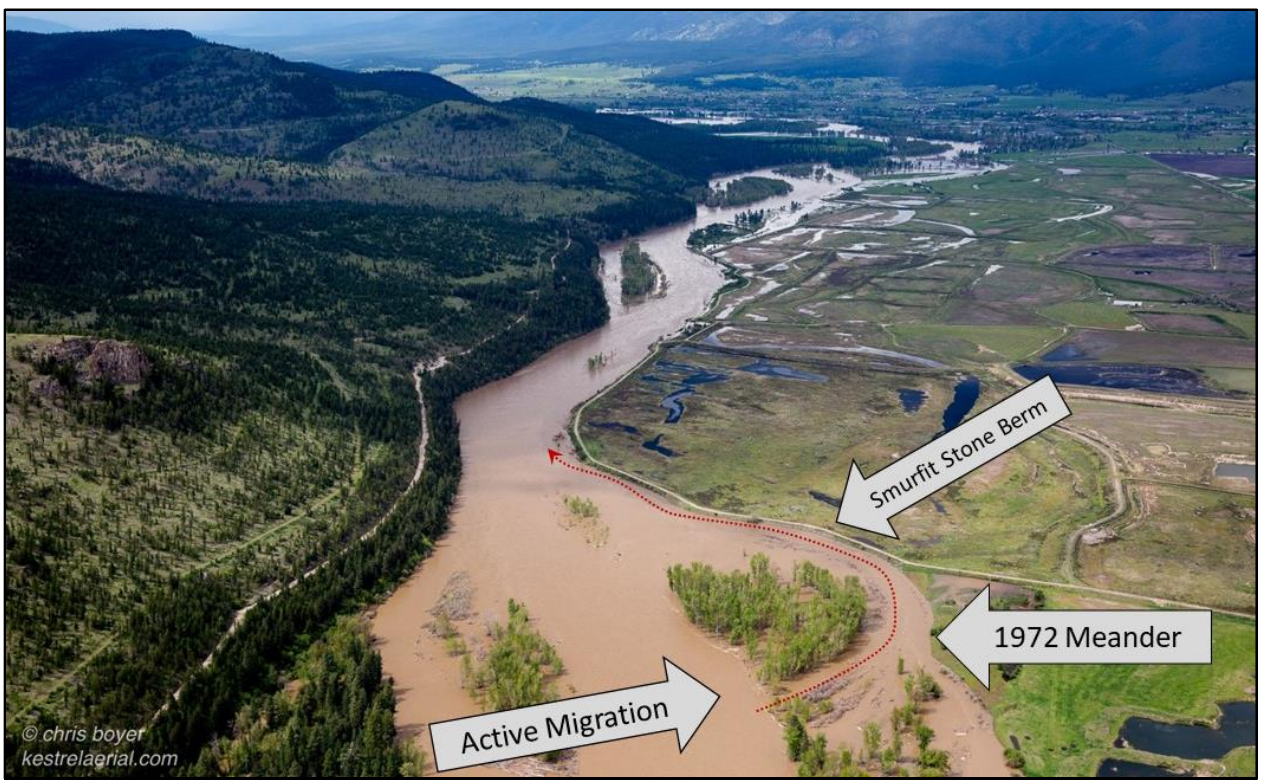

Figure 114. 2018 flood photo showing high flow activation of meander swale that flows against Smurfit Stone berm at upper end of mill site (May 10, 2018).

The history of armor maintenance along the CFR berm at Pond # 2 includes the following (Missoula County Conservation District 310 Permit applications):

May 17, 1976: *300 feet of riprap. The application submitted by the mill owner stated, "Due to a changing course of flow in the Clark Fork River, the west side of the pond 2 berm is being eroded. The placement of 300 lineal feet of rock riprap is needed to prevent further erosion during high river flow and possible loss of the pond 2 berm." The application also requested to riprap 2,200 lineal feet of the south berm of pond 2*.

The 300 feet of riprap was probably deemed necessary when the bendway cutoff and re-oriented the river to the west, which would have increased erosive pressure on the right bank near RM 198 (Figure 113). The 2,200 feet of additional rock appears to have been placed on the right bank of the older channel on the south side of Pond #2.

October 1978: *200 feet of repair on the south berm of pond 2, 1,200 feet of the west berm of pond 2.*

As the river adjusted to the cutoff, the armor protecting the west side of the CFR berm at Pond #2 was evidently extended.

October 1985: *500 feet of riprap "During each spring runoff, the river has cut away the bank in the west side of storage pond 2. ... To prevent the river from eventually cutting into the pond berm, we are proposing to rock riprap 500 feet of riverbank." The area proposed for riprapping is the same as indicated in the 1976 and 1978 permit applications.*

Additional riprap on the west side of Pond #2.

September 1991: *Two rock barbs on the river side of Pond 2. Riprap had failed at this location on many previous occasions. An October 1991 floodplain permit application submitted for same project stated, "The purpose of the bank barbs is to reduce the continued erosion to the riprap along the berm of our wastewater pond 2." The barb location is in same location as 1976, 1978, and 1985 permit applications for riprap placement along the face of pond 2.*

The 1995 imagery shows barbs at the location labeled in Figure 113. At that time, a primary channel was hitting this bank at a right angle.

May 2001: *An Emergency 310 permit application requested for repair of the berm of Pond 2. A leak of 150 gallons per minute was discovered, discharging wastewater into the river. The leak was indicated in the same area as previous repairs made to the pond 2 berm. Clay was applied at the outlet of the leak to stop the leak and the pond level was lowered. A rodent burrow was identified as the cause of the leak.*

We have no records of any maintenance performed since 2001.

Peter Nielsen of Missoula County performed a visual inspection of the rock barbs placed in 1991 to see if the rock barbs remain in place or whether they still retain any functional utility for protection of the berms (date of inspection unknown). The inspection revealed that some rock remnants of the barbs remain below the low water mark, but rock placed above the low water mark has been eroded or dropped into the river channel. Missoula County expressed concerns that those barbs provide "very questionable function to protect the Pond 2 embankment." This is a concern because the ongoing shifts in river location just upstream of the barbs will likely increase erosive pressure against the barbs in coming years.

Figure 114 shows that this area around Pond #2 is marked by a substantial narrowing of the river's Channel Migration Zone as it approaches the Smurfit Mill Site. This can create problems regarding sediment continuity, as abrupt artificial narrowing of stream corridors commonly results in deposition upstream (such as at bridges). Any increased rate of sediment storage in the area shown in Figure 113 will drive additional channel movement and create new stressors on the existing berm/armor system.

Another lesson from the Pond #2 armoring history is that maintenance permits have been repeatedly requested in addition to permits for armor extension. The maintenance requirements do not necessarily originate from a single major flood but can develop from constant pressure on a given segment of armor, even at low to moderate flows or from non-hydrologic processes such as animal burrows. There is currently an EPA designated "area of special concern" against Pond #2, this site should be monitored frequently for both loss of berm integrity as well as protective armor decay.

6.2.2.2 Pond #11

Although the CFR berm continuously forms a physical boundary between the river and the mill site, the armor is discontinuous. This is apparently because the berm is locally set back from the active river channel and thus is not imminently threatened by bank erosion. This creates some risk however in that a primary mode of armor failure is unraveling on its upstream end due to local scour behind the rock. There is a good example of this developing risk against Pond #11 (Figure 115).

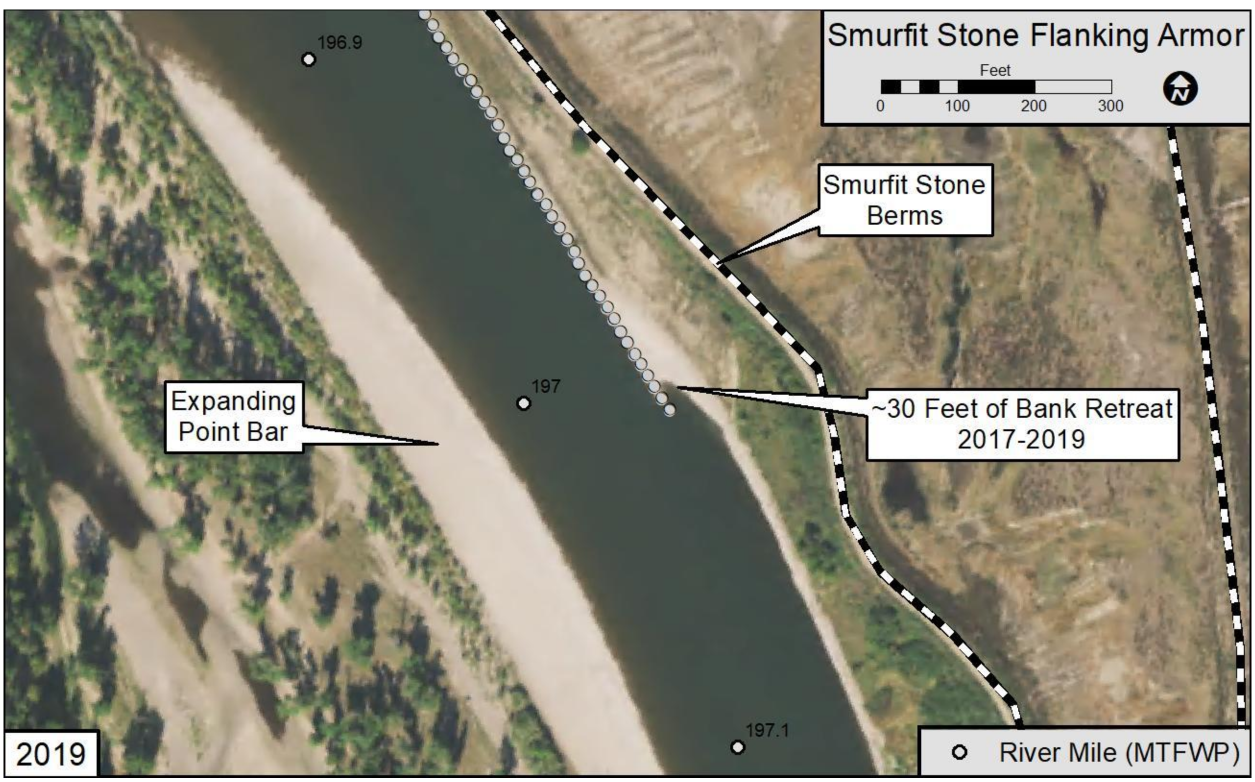

Figure 115. 2019 image showing local scour behind bank armor at RM 197 at Pond #11.

Figure 116 shows water flowing behind the bank armor during the 2018 flood. And Figure 117 shows an oblique Google Earth image of the same site. This flow concentration on the back side of a bank treatment can cause rapid erosion between thee armor and berm, and this should be carefully monitored.

Figure 116. 2018 flood photo of bank armor at RM 197 (Pond #11) showing linear rock treatment largely submerged; note high flow velocities visible on upper end of treatment.

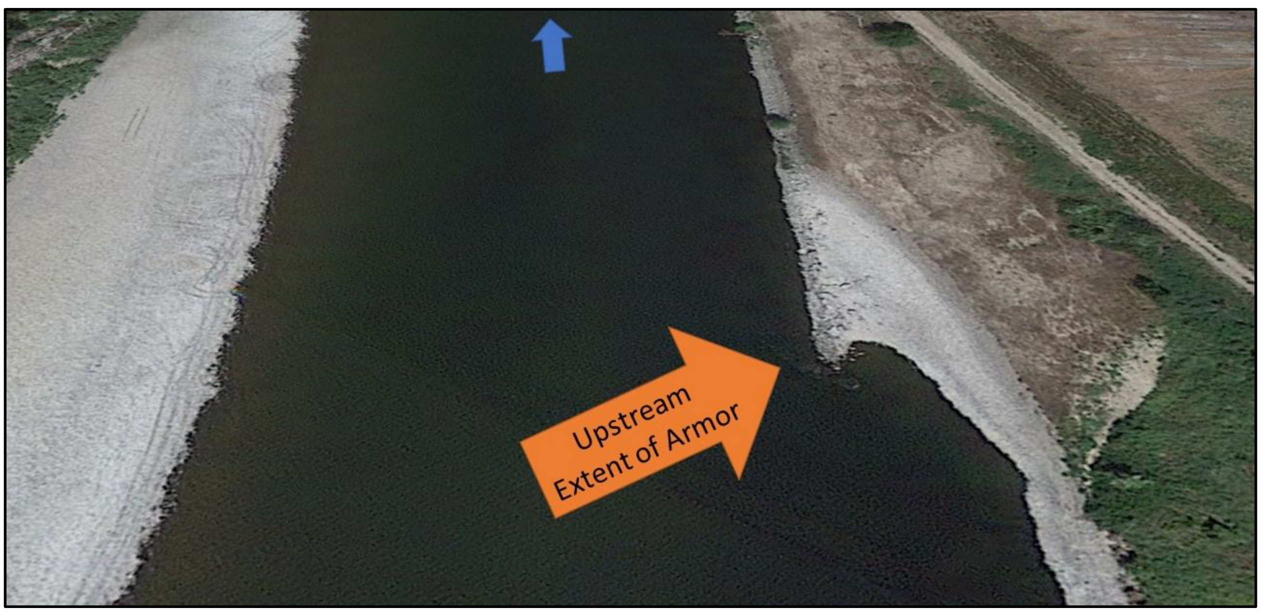

Figure 117. Google Earth image showing scour behind armor at RM 197.

The permit history at Pond #11 includes a request to riprap 300 feet of the CFR berm in 1976 as well as a request to repair 1,600 feet in 1978. The original armor construction in this area is uncertain, but it appears to have been built sometime in the early 1970s.

6.2.2.3 Pond #13a

Another example of potential armor damage is shown in Figure 118. This is located at the downstream (northern) end of the mill site. In 2018, a scour pocket formed at the head of the armor which will increase its risk of failure in coming years. East of the armor, floodwaters have scoured out floodplain area between the armor and the Smurfit Stone Berm. Figure 119 shows that at high flow the water flowing behind the armor hits the berm at a right angle, increasing the potential for local scour at the toe of the berm. This section of berm, which runs at a high angle to the Clark Fork River corridor axis, should be monitored and maintained as necessary. This section of the CFR berm was identified as an "area of special concern" by the EPA following the 2018 flood (Newfields, 2016).

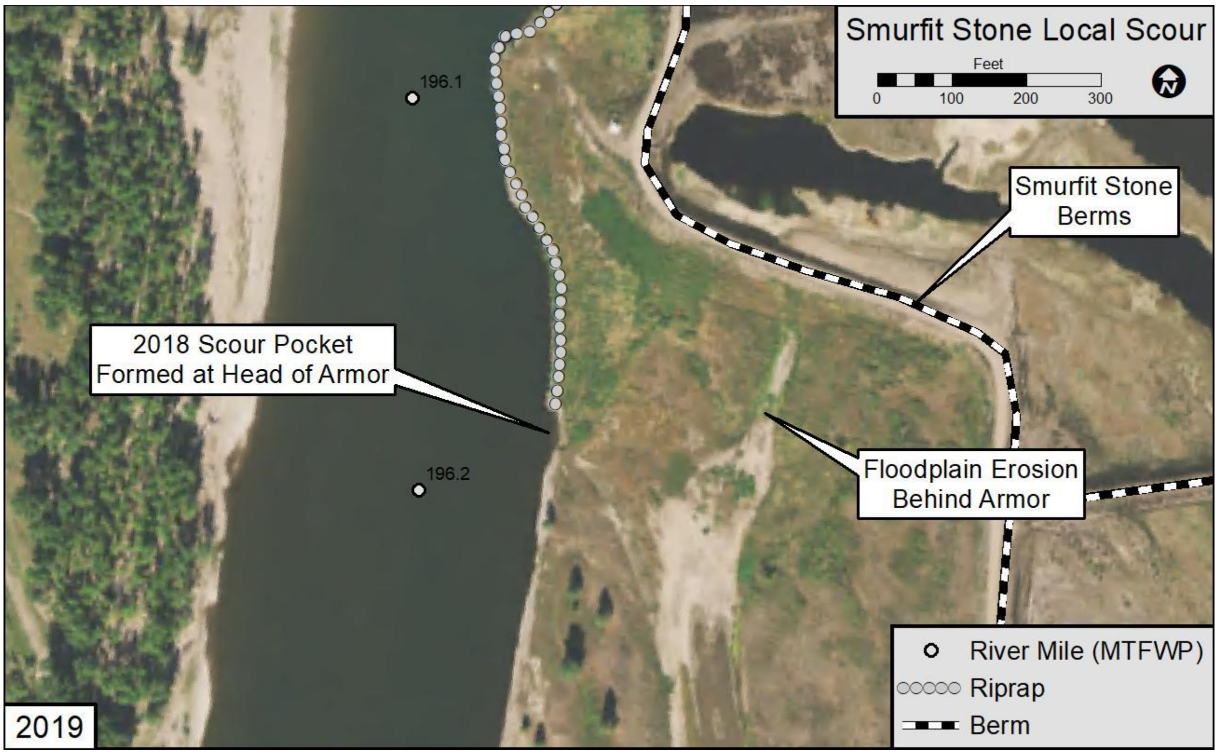

Figure 118. Local scour pocket formed during 2018 flood at head of riprap bank treatment, RM 196.15 (Pond #13a).

Figure 119. View upstream of armor at RM 196.15 showing flow behind treatment hitting Smurfit Stone berm at right angle.

6.2.3 Risk of Avulsion through Ponds

In general, the berms at Smurfit Stone are 8-15 feet higher than the ground surface. Previous overtopping analyses of the berms showed that there is at least 4 feet of freeboard along the CFR berm at a 100-year flood, indicating that it will not overtop (Newfields, 2019). Regardless, Newfields (2019) also identified the potential for under-seepage to occur that has the potential to destabilize the berm via erosion of underlying materials. Available information suggests that it is highly unlikely that overflows will top the berm without some sort of preceding failure due to slumping, piping, or river erosion (although recent hydrologic analysis suggest that the 100-year discharge in this area is 1,000 cfs higher than the previously adopted discharge, which may slightly reduce the previous freeboard presumption (Pioneer Technical Services, 2020)). Avulsions would therefore have to be preceded by some other sort of failure that allows water to flow into the settling ponds. If that were to occur, however, there very well may be risk of channel formation through the ponds.

Internal berms on the mill site have historically breached. EPA documented a breach through the berm at the northwest corner of the emergency spill Pond #8 into wastewater storage Pond #9. Additionally, "a breach through the dike at the western corner of Sludge Pond 5 was also noted…." (Missoula County).

The floodplain berms at Smurfit Stone site have the potential to dramatically alter floodwater flow paths and scour potential in the event of their breaching. The potential impacts of dike breaching have not been incorporated into the CMZ mapping; hence the projected avulsion hazard zones should not be used to indicate the limits of potential impacts of such an event. This would require a hydraulic analysis of breaching scenarios that is beyond the scope of the CMZ mapping effort (River Design Group, 2016).

Ter Horst and Jongejan (2014) studied the importance of evaluating domino effects of flooding in nested levee systems in the Netherlands and concluded that risk assessments that are carried out for individual levees versus groups of levees may strongly underestimate flood risk.

Additionally, the flood mapping in this area apparently does not consider the potential impacts of ice jamming on flood stage. In Glendive, Montana, a levee was constructed to protect the town in 1959. The levee was designed to protect the town against a 100-year flood with three feet of freeboard. Subsequent ice jam floods of 1969, 1986, and 1994 all came within 0.5-1.5 feet of overtopping the West Glendive Levee (USACOE, 2014). A hydraulic modeling study performed in 2002 showed that, under ice jam conditions, the West Glendive Levee provided approximately 30-yr flood protection with no freeboard and 10-year protection with four feet of freeboard. As described in Section 1.8.2, ice jams do occur on the Clark Fork River.

6.2.4 Special Attention Areas Based on High Water Observations in 2018

The 2018 flooding revealed areas of concern associated with two Smurfit Stone outflows. Narrow surface cracks adjacent to former holding pond HP2 south of Outfall 1 and a repaired boil area in former holding pond HP13 near Outfall 3.

6.2.4.1 Outfalls #1 and #3

The EPA identified two areas at or adjacent to outfalls as Special Attention Areas (Newfields, 2019). One is where narrow surface cracks were observed on the CFR berm adjacent to Pond #2 just south of Outfall #1 and the other is at a repaired boil area near Outfall #3. Peter Nielsen of Missoula Public Health (2017) reported that there is documentation of an embankment failure “causing an uncontrolled headcut and threatening the discharge outfall number 3 during the 1997 flood.” Additionally, photos were submitted by the Potentially Responsible Parties (PRPs) to assert that the berms were not overtopped, even though the flood caused the embankment to fail. The primary point made by Nielsen (2017) was that:

> *…the record contains ample evidence of occurrences of erosion compromising the stability of the berms without overtopping.*

One thing to consider in monitoring these areas is their location in the Clark Fork River Channel Migration Zone. Figure 120 shows the locations of these outfalls on a 1955 image, with the active 1955 channels mapped. Both outfalls are located on recent channels mapped as active in 1955. This could have strong implications for berm stability, as there have been other situations where levees have breached in such settings.

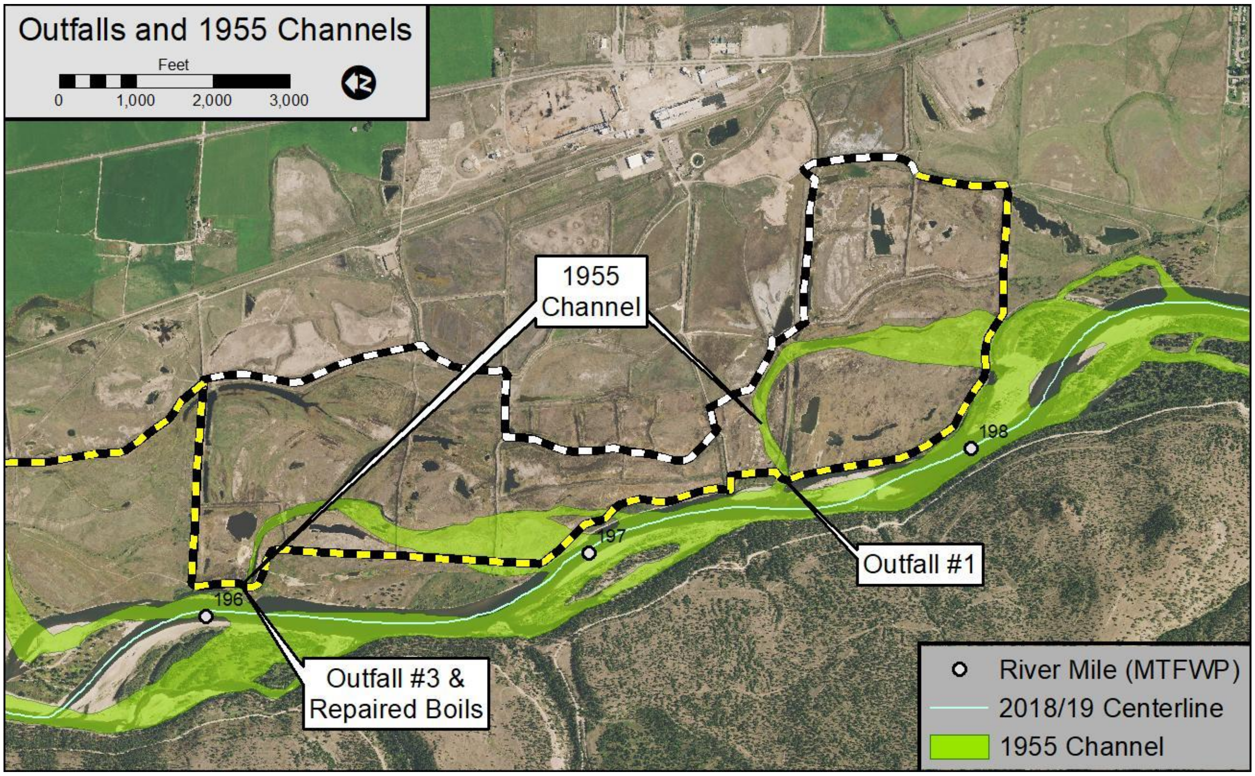

Figure 120. 1955 image of Smurfit Stone showing Outfall #1 and #3 locations on 1955 channel threads.

The following is a summary of a berm breach assessment performed on the Yuba and Feather Rivers in California, where civil engineers testified in court that the breach was caused by over-pressuring in gravels of an older channel that ran under the levees.

In 1991, a civil engineer named Richard Meehan from Palo Alto testified in a trial in Sacramento that a levee on the Feather River was prone to collapse in a fashion similar to two nearby levees that had failed previous disasters; one in 1955 near Yuba City that killed 38 people and another on the Yuba River in 1986 (https://web.stanford.edu/~meehan/flood/xsfexam.html). In 1996 the levee failed, about 1,500 feet from the area he pinpointed as failure prone. First boils developed on the levee, and crews tried to wall off the boils with sandbags. Witnesses then said "a 30-foot high geyser erupted near the base of the levee." A 600-foot-long stretch of levee collapsed within minutes. Meehan had postulated that this levee breach as well as two others was due to floodwater saturation of a subsurface layer of gravel. The water flowed to the landward side of the levee and "erupted, geyser-like, undermining the structures and causing their collapse." He also testified that the area had experienced sand boils on four occasions since 1955.

Meehan, who was at Stanford University, and his colleague J. David Rogers from Missouri University presented their findings regarding the 1986 levee break at a 2008 conference in Berkeley (Rogers and Meehan, 2008). They reported that they were interested in the 1986 levee breach on the Yuba River because it happened well after the flood had crested, when the stage was 8.6 feet below the levee crest. They reported that five eyewitnesses described the same failure sequence, seen from the landward side of the failed levee:

> *The ground at the base of the levee essentially turned to mush; and water began bubbling up, across a very narrow area, just 170 feet wide. This was followed by the sudden "collapse" of the landward side of the levee embankment "into a hole;" after*

which the river side of the levee quickly collapse, and the flood waters began pouring through the breach. It was as if "a bomb had gone off…."

This mass failure of the landward side of the levee was different than typical piping style failures. They pointed out the following in their presentation:

- River meander belts in the Sacramento Valley "conceal a complex understory of pinched and truncated channels of varying permeability."
- Borings into the levee showed fine hydraulic mining debris overlying channel sands and coarse gravels that formed a low permeability cap on the gravels.
- Permeability can vary by four orders of magnitude in floodplain deposits—if you miss the high permeability channels, you fail to characterize the site conditions for any meaningful seepage analyses.

In a 2001 court case, the judge noted that "the levee had been aligned improperly, so as to overlie old river channels."

Stratigraphic conditions on the Clark Fork River floodplain are somewhat different than that of the Yuba, because there is no expansive fine grained mining-derived silt layer on top of old channels. As a result, heightened groundwater pressures that result in ultimate breaching of the cap and creation of geysers may be unlikely at the Smurfit Stone Mill site. It is interesting, however that the outfalls were built on historic channel threads, and that there has been concern regarding their stability, with reports of boils forming on the landward side of Outfall #3.

6.2.5 Berm Monitoring and Maintenance

The risk of bank armor failing and causing a berm breach will be an ongoing issue at the old mill site. As a result, bank protection maintenance is a critical aspect of long-term infrastructure protection. Newfields (2019) reported on a "Visual Berm Surveillance Plan" for high water events at Smurfit Stone. This includes either weekly or daily inspections of the berm during high water, depending on stage. The two EPA-designated "Special Attention Areas" will be "paid particular attention" during monitoring events (Figure 111).

Based on our understanding of the Channel Migration Zone encroachment created by the berms, the permit history of berm protection, and identified berm failure mechanisms, it is clear that preventing river reoccupation of the old mill ponds will require careful monitoring and ongoing maintenance of existing infrastructure. To that end, the adoption of a berm surveillance plan that is triggered by *flood-events alone* creates some concerns, including the following:

1. **Planform Issues:** Larger scale planform dynamics on the river can dramatically change hydraulic conditions anywhere along the berm, which can threaten armor or berm integrity independent of flooding.
2. **Ongoing Erosion:** Armor decay can occur at moderate flows, especially where local scour potential is amplified where the river's thalweg intersects the upstream end of any riprap project.
3. **Ice Dynamics:** Ice has been shown to cause drive erosion on site, as indicated in a 1998 floodplain permit for a riprap repair project: "We [Smurfit Stone] proposed to repair a section of streambank that was severely damaged by ice during the winter of 1996-1997 and by flood flows that followed in June and July of 1997" (Missoula County). The applicant also noted that "the proposed work is required prior

to high water this year, since the lack of bank protection may cause the entire discharge facility to be washed out during this spring's runoff."

4. **Non-flood Related Issues:** An emergency 310 permit application was requested to repair the berm at Pond #2 when a leak of 150 gallons per minute of wastewater discharge was discovered in an area where the Pond 2 berm had been previously repaired. The cause of the leak was determined to be a rodent burrow. This is clearly a non-flood related issue.
5. **Deferred Maintenance:** According to Missoula County Conservation District, the last permitted maintenance/repair work performance at the mill site was in 2001. For the last 19 year, evidently no maintenance has been performed.
6. **Relic Channels:** Approximately 480 acres of the Clark Fork River Channel Migration Zone is currently restricted by the CFR berm. The restricted area includes relic channels that were active in the 1950s as well as older swales that are at risk of reactivation/avulsion in the event of berm breaches. Some of the relic channels that cross under the berm have been used as outfalls, one of which (Outfall #3) has a recorded history of boil formation and breaching without overtopping. Other levee failures in California have been attributed to such conditions, where under-seepage occurs along older channel threads, creating enhanced risk of failure.

From a river function standpoint, an optimal solution at the Smurfit Stone Mill Site would be to remediate all ground within the Historic Migration Zone and remove berms to reconnect the river to its floodplain. Removal of both the berms and bank protection would allow the river to migrate freely through the site, allowing for sediment recruitment, sediment storage, riparian recovery, and re-establishment of a natural stream corridor that is ecologically productive and resilient to future floods, ice, or sediment delivery events.

7 CMZ Management Concepts

7.1 CMZ Management and Stream Corridor Resiliency

The management of the river as a "corridor" is an important first application of CMZ mapping. Minimizing economic losses due to land loss, infrastructure failure, or bank amor 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 perpendicular 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 Clark Fork River has 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 on the river that show largely unimpeded channel movement and resulting complex channel forms, both spatially and temporally. The Clark Fork and Bitterroot River CMZ corridors are locally thousands of 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. Wood recruitment in more dynamic reaches such as the Kelly Island area is common, and entrainment of both wood and sediment through bank erosion supports aquatic habitat development and sustenance. These conditions clearly contribute to the long-term viability of our willow/cottonwood corridors and provide geomorphically deformable river channels that can adjust to changing inputs in the future.

7.2 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 and define anticipated future alignment issues so support cost-effective risk mitigation.

Upstream of Bonner, there has been extensive encroachment into the Clark Fork CMZ by transportation infrastructure that runs parallel to the river along a relatively narrow valley. In many cases old swales are completely cut off from the active channel, and much of the river has been relocated and channelized. Restoring a wider CMZ in some of these areas would be beneficial to overall river function and would reduce ongoing costs associated with bank armor construction and maintenance. As some of the restrictions are created by the abandoned rail line, specific opportunities may exist in these areas either to allow the grade to erode out or to strategically breach/remove the rail line embankment to restore natural stream function.

7.3 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 siting 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 121. Residential development within EHA of Clark Fork River during the 2018 flood near Frenchtown (May 10, 2018).

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Appendix A: 11X17 CMZ Maps (Separate Document)